An overview of the biological aspects, nature of damage, and strategies for managing the Gram pod borer (*Helicoverpa armigera*: Hubner) in chickpea: A review

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; *Helicoverpa armigera*, Chickpea, Pod damage, Management, Insecticide, biological control

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 its play 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 gram pod borer, *Helicoverpa armigera* 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 [7,8,9,10]. 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 % in India [12], 90 % in Pakistan [13] and 5-15 % in Bangladesh [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 [15] reported 182 host species of crop plants for *H. armigera.* 47 species of host plants were reported by [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.

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. *H. armigera* 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. 10–85% yield losses in chickpea have been documented in India [12,19,20,21,22]. In Bangladesh and Nepal, pod borer damage in unprotected chickpea fields has been in the range of 5–15% [23]. In northern Pakistan, up to 90% 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*[24,25,26,27,]. 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.

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 ^{o}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 1,000[29,30] typically on leaves, pods, or flowers. 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^{o}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.

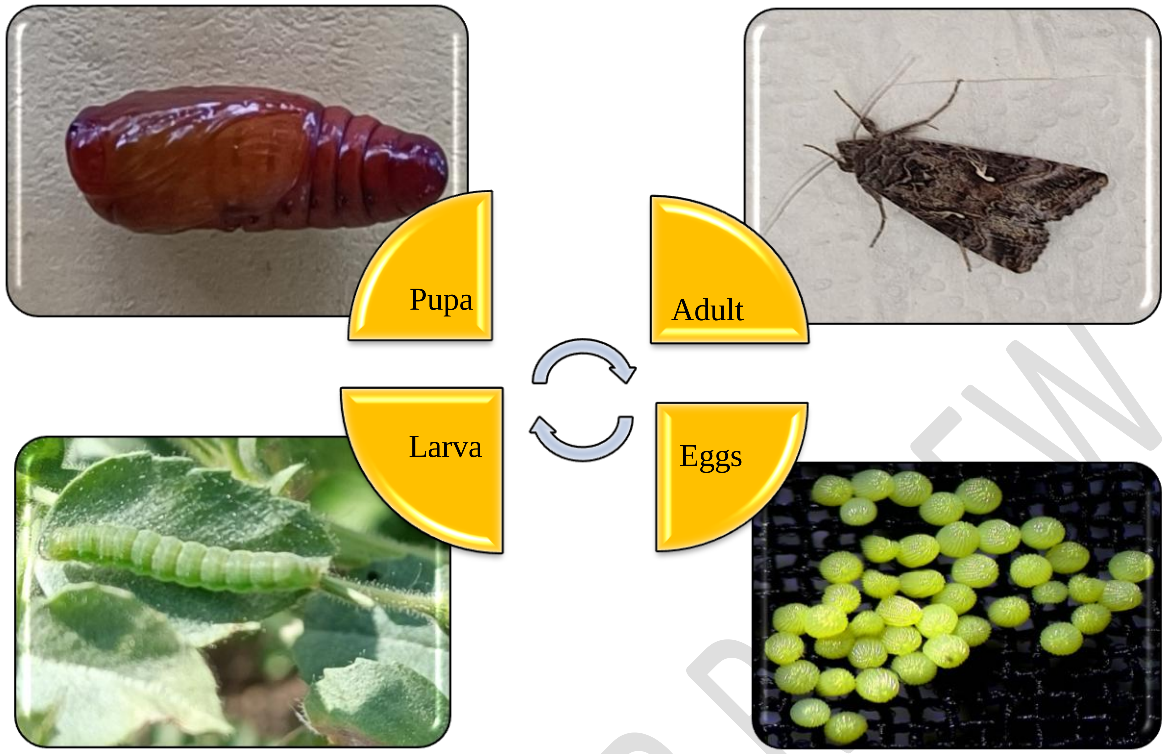

Fig.1:- Life cycle of Gram pod borer, *Helicoverpa armigera*

Host range

Helicoverpa 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. [15, 37,38] reported 182 host species of crop plants for *H. armigera*, 47 species of host plants were reported by[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 [39,40,41,42,43]. 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].

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 1^{st},2^{nd} and 3^{rd} 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.

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.

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.

Agronomic recommended practices

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.

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.

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% in pod damage. This underscores the potential of trap cropping as a practical and effective approach in integrated pest management strategies.

Nutrient management:-Fertilizers are primarily applied to produce high yield of a crop, butthe application of nutrients to crop results direct effect on pest attacks[64]. Increased application of NPK 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 increased 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 (nitrogen, phosphorus, and potassium) to manage and control the pod borer population.

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% 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 69,70,71]. 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 [73, 74, 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 [76,77,78,79,80]. 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.

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% 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 [85,86,87,88]. Consequently, there is an urgent need to prioritize and implement eco-friendly approaches for managing chickpea pod borers to ensure sustainable production.

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] as well as difficult to adulterate when produced or harvested by farmers themselves. 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 [91,92,93]. Applying Neem Seed Kernel Extract (NSKE 5%) treatment reduced the pod borer population in chickpea [94,95,96]. Leaf, bark, and seed extract from *Annona squamosa* have pesticidal and insect antifeedent properties[97,98,99]. Applying a potent plant pesticide with vermiwash is the best alternative to chemical fertilizer and pesticides. In Indiasignificant 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% reduction in pod damage, surpassing the 70% 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 [101,102,103,104,105,106,107,108,109,110,111,112,113].

Additionally Entomopathogenic nematodes (EPNs) have emerged as effective biological control agents against the notorious pest *Helicoverpa 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 programs 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 soil, the environment, 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 [117,118,119,120,121,122,123]. 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. [97] demonstrated that 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.

Chemical control

In response to outbreaks of Gram pod borer, *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]. In summary, 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.

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.

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. In summary, the present review underscores the efficacy of an integrative and ecologically sensitive approach to chickpea cultivation for sustainable gram pod borer management.

References

1) Merga, B., & Haji, J. (2019). Economic importance of chickpea: Production, value, and world trade. Cogent Food & Agriculture. https://doi.org/10.1080/23311932.2019.161571
2) Yegram, L. (2021). Nutritional Composition, Anti nutritional Factors and Utilization Trends of Ethiopian Chickpea (*Cicer arietinum* L.). International Journal of Food Sciences.
3) Veer, R., Chandra, U., Gautam, C. P. N., Yadav, S. K., Sharma, S., Kumar, S., & Kumar, S. (2021). Study on incidence of insect pests in chickpea. Journal of Entomology and Zoology Studies, 9(1), 146-150.
4) Ujjan, R. L., Ahmed, A. M., Alhilfi, A. Z. A., Khoso, F. N., Rahoo, A. M., Rajput, I. A., & Soomro, D. M. (2019). Performance of pheromone traps at different heights for mass trapping of *Helicoverpa armigera* (Noctuidae: Lepidoptera) in chickpea field. Asian Journal of Agricultural Biology, 7(4), 610-616.
5) Jai, B. K., Soni, V. K., & Chandraker, H. K. (2020). Surveillance of pod borer, *Helicoverpa armigera* (Hubner), and its natural enemies on chickpea at Sahaspur Lohara blocks. Journal of Pharm. Phytochem., 9(3), 1995-2000.
6) Sharma, P.K., Kumar, U., Vyas, S., Sharma, S., & Shrivastava, S. (2012). Monitoring of *Helicoverpa armigera* (Hubner) (Lepidoptera: Noctuidae) through pheromone traps in

chickpea Cicer arietinum crop and influence of some abiotic factors on insect Population. Journal of Environmental Science, 1, 44–46.

7) Anwar, M., & Shafique, M. (1993). Integrated control of gram pod borer, *Helicoverpa armigera* (Hubner) in Sindh. In: Proceedings of Pakistan Congress of Zoology, pp. 215–222.
8) EPPO. (2006). Distribution maps of quarantine pests, *Helicoverpa armigera*.
9) Fichetti, P., Avalos, S., Mazzuferi, V., & Carreras, C. (2009). Lepidópteros asociados al cultivo de garbanzo (*Cicer arietinum* L.) en Córdoba, Argentina. Boletín de Sanidad Vegetal Plagas, 35, 49-58.
10) Zohary, D., Hopf, M., & Weiss, E. (2012). Domestication of plants in the old world: The origin and spread of domesticated plants in Southwest Asia, Europe, and the Mediterranean Basin. Oxford University Press.
11) Patil, S.B., Goyal, A., Chitgupekar, S.S., Kumar, S., & El-Bouhssini, M. (2017). Sustainable management of chickpea pod borer: A review. Agronomy for Sustainable Development, 37, 20.
12) Reed, W. (1983b). Estimation of crop losses due to insect-pests in pulses. Indian Journal of Entomology, 2, 263–267.
13) Ahmed, K., Khalique, F., Afzal, M., & Malik, BA. (1986). Pulses entomology report. Food Legumes Improvement Programme, Pakistan Agricultural Research Council, National Agricultural Research Center, 4–10.
14) Pande, S., & Narayana Rao, J. (2000). Integrated management of chickpea in the rice-based cropping systems of Nepal: Progress Report of the ICRISAT and NARC (Nepal Agricultural Research Council, Khumaltar) collaborative work in farmers' participatory on-farm trials on the validation of improved production practices [specifically integrated pest (diseases and insects) management (IPM)] in seven villages of five districts in Nepal, 29th October 1999 to 30th April 2000. International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, Andhra Pradesh, India, p. 33.
15) Pawar, C.S., Bhatnagar, V.S., & Yadhav, D.R. (1986). Heliothis spp. and their natural enemies with their potential for biological control. Proceedings of the Indian Academy of Sciences - Animal Sciences, 95, 697-703.
16) Singh, G., & Balan, J.S. (1986). Host plant and natural enemies of *Heliothis armigera* in Haryana. Indian Journal of Ecology, 13, 175-178.
17) Vyas, H. G., & Lakhohaura, B. D. (1996). Evaluation of Heliothis nuclear polyhedrosis virus for control of *Heliothis armigera* on chickpea at Pantnagar, (U.P.) Gujarat Agric Uni Res J, 21(2), 50–54.
18) Rajesh, K., Chakravarthy, M. K., Mondal, P., & Chakraborty, S. (2017). Evaluation of advanced chickpea genotypes for resistance to pod borer, *Helicoverpa armigera* (Hübner). International Journal of Current Research, 9(1), 44580-4458.
19) Ahmed, K. (1984). Research on pulses entomology at National Agricultural Research Center, Islamabad. In Proceedings of the group discussion: pulse pests management, 05–10 Dec 1983, ICRISAT Center, India (pp. 28–30). Patancheru A.P. 502 324, India.

20) Lal, S. S., Yadava, C. P., & Dias, C. A. R. (1985a). Assessment of crop losses in chickpea caused by *Heliothis armigera*. FAO Plant Protection Bulletin, 33, 27–35.
21) Das, G. P. (1987). Efficacy of neem oil on the eggs and grub mortality of Callosobruchus chinensis Linn. (Bruchidae: Coleoptera). Tropical Grain Legume Bulletin, 34, 14–15.
22) Yadava, C. P., & Lal, S. S. (1997). Studies on host plant resistance against gram pod borer, *Helicoverpa armigera* in chickpea. In: Symposium on integrated pest management for sustainable crop production, 2–4 December 1997, Indian Agricultural Research Institute, New Delhi, India, 37.
23) Musa, A. M. (2000). On-farm chickpea seed priming trials and demonstrations in the High Barind Tract of Bangladesh. Research Report 1999–2000, People's Resource Oriented Voluntary Association, Rajshahi, Bangladesh, p. 29.
24) Rivnay E (1962). Field crop pests in the Near East. Netherlands Junk Publisher, The Hague, 450.
25) Elmosa, H. (1981). FAO/UNEP Near Eastern inter-country program for the development and application of integrated pest control in cotton growing, 1980 report, p 44.
26) Hariri, G. (1981). The problems and prospects of Heliothis management in Southwest Asia. In: Proceedings of International Workshop on Heliothis Management, 15–20 November 1981, ICRISAT, India, pp 369–373.
27) White, G. F. (1987). Environmental effects of arid land irrigation in developing countries. MAB Technical Series, 8, UNEP/SCOPE/UNESCO, France, 1–67.
28) Zalucki, M. P., Daglish, G., Firemponeng, S., & Twine, P. H. (1986). The biology and ecology of *Heliothis armigera* (Hübner) and H. punctigera (Wallengren) (Lepidoptera: Noctuidae) in Australia: what do we know? Australian Journal of Zoology, 42, 329–346.
29) Mironidis, G., & Savopoulou-Soultani, M. (2012). Effects of constant and changing temperature conditions on diapause induction in *Helicoverpa armigera* (Lepidoptera: Noctuidae). Bulletin of Entomological Research, 102(2), 139.
30) Shanower, T.G., Yoshida, M., & Peter, J.A. (1997). Survival, growth, fecundity, and behavior of *Helicoverpa armigera* (Lepidoptera: Noctuidae) on pigeonpea and two wild Cajanus species. Journal of Economic Entomology, 90(3), 837-841.
31) Ali, A., Choudhury, R.A., Ahmad, Z., Rahman, F., Khan, F.R., & Ahmad, S.K. (2009). Some biological characteristics of *Helicoverpa armigera* on chickpea. Tunn Journal of Plant Protection, 4, 99–106.
32) Singh, B.K., & Singh, R.P. (2007). Effect of host plant nutrition and pesticidal management on larval population of *Helicoverpa armigera* (Hubner) in chickpea *Cicer arietinum*. Indian Journal of Entomology, 69(4), 345–349.
33) Hackett, D. S., & Gatehouse, A. G. (1982). Diapause in *Heliothis armigera* (Hubner) and H. jletcheri (Hardwick) (Lepidoptera: Noctuidae) in Sudan Gezira. Bulletin of Entomological Research, 72, 409–422.
34) CABI. (2007). Crop Protection Compendium, 2007 Edition. © CAB International Publishing, Wallingford.

35) Pearson, E.O. (1958). Insect pests of cotton in tropical Africa. Commonwealth Institute of Entomology, London, pp. 355.
36) Pimbert, M.P. (1990). Some future research directions for Integrated Pest Management in chickpea: A viewpoint. Chickpea in the Nineties: Proceedings of the Second International Workshop on Chickpea Improvement, 4–8 December 1989, ICRISAT, Patancheru, India, pp. 151–163.
37) Cunningham, J. P., & Zalucki, M. P. (2014). Understanding heliothine (Lepidoptera: Heliothinae) pests: What is a host plant? Journal of Economic Entomology, 107(3), 881-896.
38) Fitt, G. P. (1989). The ecology of Heliothis species in relation to agro-ecosystems. Annual Review of Entomology, 34, 17-52.
39) Chandra, B. K. N., & Rai, P. S. (1974). Two new ornamental host plants of *Heliothis armigera* Hubner in India. Indian Journal of Horticulture, 31(2), 198.
40) Gahukar, R. T. (2002). Population dynamics of *Helicoverpa armigera* (Hubner) (Lepidoptera: Noctuidae) on rose flowers in central India. Journal of Entomological Research, 26(4), 265–276.
41) Multani, J. S., & Sohi, A. S. (2002). *Helicoverpa armigera* (Hubner) on carnation, Dianthus *caryophyllus* Linn. in Punjab. Insect Environment, 8(2), 82.
42) Kakimoto, T., Fujisaki, K., & Miyatake, T. (2003). Egg laying preference, larval dispersion, and cannibalism in *Helicoverpa armigera* (Lepidoptera: Noctuidae). Annals of the Entomological Society of America, 96(6), 793–798.
43) CABI. (2006). Crop Protection Compendium, 2006 Edition. CAB International Publishing, Wallingford.
44) Naresh, J. S., Malik, V. S., & Kaushik, S. K. (1989). Larval population and damage of *Heliothis armigera* (Hubn.) estimated on different plant densities of chickpea during five weeks. Bulletin of Entomology, 27, 70–73.
45) Bhatnagar, V. S. (1987). Conservation and encouragement of natural enemies of insect pests in dryland subsistence farming: Problems, progress and prospects in the Sahelian Zone. Insect Science and Its Application, 8, 791-795.
46) Hou, M., & Sheng, C. (2000). Effects of different foods on the growth, development, and reproduction of cotton bollworm, *Helicoverpa armigera* (Hubner) (Lepidoptera: Noctuidae). Acta Entomologica Sinica, 43(2), 168-175.
47) Bantewad, S. D., & Sarode, S. V. (2000). Influence of different hosts on the biology of *Helicoverpa armigera* (Hübner). Shashpa, 7(2), 133-136.
48) Firempong, S., & Zalucki, M. P. (1990). Host plant preferences of populations of *Helicoverpa armigera* (Hübner) (Lepidoptera, Noctuidae) from different geographic locations. Australian Journal of Zoology, 37(6), 665-673.
49) Reed, W., & Pawar, C. S. (1982). Heliothis: A global problem. In Reed, W., & Kumble, V. (Eds.), Proceedings of the International Workshop on Heliothis Management, 15–20 November 1981 (pp. 9–14). ICRISAT, Patancheru.

50) Navi, S., Kumar, S. C., Naresh, N. T., Yogesh, G. S., & Hanagi, C. (2018). Evaluation of IPM Package against pod borer, *Helicoverpa armigera* (Hubner) in chickpea through front line demonstration in Chamarajanagar district of Karnataka. International Journal of Chemical Studies, 6, 843–845.
51) Schulten, G.G.M. (1987). Challenges facing agricultural entomology in the tropics. Insect. Sci. Appl., 8, 397-405.
52) Ujagir, R., & Khere, B. P. (1987). Preliminary screening of chickpea genotypes for susceptibility to *Heliothis armigera* (Hub.) at Pantnagar, India. International Chickpea Newsletter, 17, 14.
53) Jeffree, E. (1986). The cuticle, epicuticular waxes and trichomes of plants, with reference to their structure, functions and evolution. In: B.E. Juniper and T.R.E. South surface. Edward Arnold Publication Ltd., London, pp. 23–64.
54) Peter, A.J., Shanower, T.G., & Romeis, J. (1995). The role of plant trichomes in insect resistance: A selective review. Phytophaga, 7, 41–64.
55) Singh, O., Gowda, C.L.L., Sethi, S.C., & Lateef, S.S. (1991). Inheritance of and breeding for resistance to *Helicoverpa armigera* pod borer in chickpea. In: Golden Jubilee Symposium of Indian Society of Genetics and Plant Breeding, 4–8 February 1991, New Delhi, India.
56) Sharma HC (2005). Heliothis/Helicoverpa management: emerging trends and strategies for future research. Oxford and IBH Publishers, New Delhi.
57) Kumar, L., & Bisht, R. S. (2013). Population dynamics of *Helicoverpa armigera* (Hubner) on chickpea crop. Pantnagar Journal of Research, 11, 35–38.
58) Akhtar, MF., Ahmed, I., Nadeem, I., Abbas, Q., Raza, A., Yousaf, MJ., Ahmed, R., & Niaz, T. (2014). Impact of different dates of sowing on gram pod borer (*Helicoverpa armigera*) infestation in chickpea crop. World Journal of Zoology, 9(4), 270–275.
59) Singh, H., Singh, I., & Mahajan, G. (2002). Effect of different dates of sowing on the incidence of gram pod borer (*Helicoverpa armigera)* on different cultivars of chickpea (Cicer arientinum). Agricultural Science Digest, 22(4), 295–296.
60) Parmar, S. K., Thakur, A. S., & Marabi, R. S. (2015). Effect of sowing dates and weather parameters on the incidence of *Helicoverpa armigera* (Hubner) in chickpea. The Bioscan, 10(1), 93–96.
61) Qadeer, G. A., & Singh, Y. P. (1989). Some observations on the outbreak of gram pod borer on grain during rabi 1987-88 in Haryana. Plant Protection Bulletin, 41(1–2), 24–25.
62) Anilkumar, R., Nandan, B., Sharma, J.P., & Kumar, J. (2011). Effect of phosphorus and seed rate on growth and productivity of bold-seeded Kabuli chickpea in subtropical Kandi areas of Jammu and Kashmir. Plant Archives, 10(1), 125–129.
63) Sarwar M, Ahmad N, Toufiq M (2009). Host plant resistance relationships in chickpea (*Cicer arietinum* L.) against gram pod borer (*Helicoverpa armigera* Hubner). Pakistan J Bot, 41(6), 3047–3052.
64) Coaker, T. H. (1987). Cultural methods. In: Burn, A. J., Coaker, T. H., & Jepson, P. C. (Eds.), The Crop in Integrated Pest Management. Academic Press, London, pp. 69–88.

65) Hossain, M. A., Prodhan, M. Z. H., & Haque, M. A. (2009). Response of NPK fertilizer on the incidence of pod borer, *Helicoverpa armigera* (Hubner), and grain yield of chickpea. Bangladesh Journal of Scientific and Industrial Research, 44(1), 117–124.
66) Ramakrishnan, C., Radhakrishnan, T., & Rama Doss, G. (1983). Effect of nitrogen, rhizobium inoculation and phosphorus level on damage of pigeon pea by *H. armigera*. International Pigeon Pea Newsletter, 2, 62.
67) Yadava, C. P. (1987). Ecological studies on gram pod borer, *Heliothis armigera* in chickpea in relation to its biotic and abiotic factors. Ph.D. Thesis, Kanpur University, Kanpur, India.
68) Ahmad, R. (2003). Insect-pests of chickpea and their management. In M. Ali, Shiv Kumar, & Singh NB (Eds.), Chickpea research in India (pp. 69–72). Indian Institute of Pulses Research, Kanpur.
69) Mehta, D. N., Singh, K. M., & Singh, R. N. (1988). Influence of intercropping on succession and population buildup of insect-pests in chickpea. Indian Journal of Entomology, 50(3), 257–275.
70) Prasad, D., & Kumar, B. (2002). Impact of intercropping and Endosulfan on the incidence of gram pod borer infesting chickpea. Indian Journal of Entomology, 64, 405–410.
71) Borah, B. K., Debnath, M. C., Sharma, K. K., & Das, B. (2010). Effect of intercropping on incidence of gram pod borer, Helicoverpa armigera Hubner in chickpea. Insect Environment, 15(4), 8–9.
72) Tripathi, A., Sharma, R.C., Dwivedi, P.K., & Pandey, M. (2008). Effect of intercropping and insecticide on pod borer incidence in chickpea. Journal of Food Legumes, 21(3), 187–188.
73) Prasad, D., & Chand, P. (1989). Effect of intercropping on the incidence of *Helicoverpa armigera* (Hub.) and grain yields of chickpea. Journal of Research, Birsa Agricultural University, 1(1), 15–18.
74) Hossain, M. A. (2003). Management of chickpea pod borer, *Helicoverpa armigera* (Hubner) through intercropping and insecticide spraying. Thai Journal of Agricultural Science, 36(1), 51–56.
75) Reena, Singh SK, Sinha BK, Jamwal BS (2009). Management of gram pod borer, *Helicoverpa armigera* (Hubner) by intercropping and monitoring through pheromone traps in chickpea. Karnataka J Agric Sci, 22(3-special issue), 524–526.
76) Sekar PR, Venkataaiah M, Rao NV, Rao VR, Rao VSP (1996). Monitoring of insect resistance in *Helicoverpa armigera* (Hub.) from areas receiving heavy insecticide application in Andhra Pradesh. J Ent Res, 20(2), 93–102.
77) Nath, P., & Chakravorty, S. (2005). Effect of intercropping on the infestation of chickpea pod borer [*Helicoverpa armigera* (Hubner)]. Journal of Plant Protection and Environment, 29(1), 86–91.
78) Pandey, R., & Ujagir, R. (2008). Effect of intercropping on Helicoverpa armigera (Hub.) infesting chickpea. Annals of Plant Protection Sciences, 16(2), 320–324.
79) Singh, K., & Pandey, J. (2014). Evaluation of intercropping for the management of pod borer, *Helicoverpa armigera* Hub. in chickpea. Bioinfolet, 11(2c), 688–691.

80) Chandra, S., Rachappa, V., Yelshetty, S., Sreenivas, A. G., & Biradar, S. A. (2014). Performance of intercrops in reduction of gram pod borer, Helicoverpa armigera (Hubner) incidence on chickpea. Journal of Experimental Zoology, 17(2), 627–630.
81) Sidde Gowda, D.K., Halle, D., & Sharanabasappa. (2004). Evaluation of different IPM modules and intercropping systems for the management of pod borer in chickpea. Karnataka Journal of Agricultural Science, 17(3), 586–589.
82) Pattar, P.S., Mansur, C.P., Alagundagi, S.C., & Karbantanal, S.S. (2012). Effect of intercropping systems on gram pod borer Helicoverpa armigera Hubner and its natural enemies in chickpea. Indian Journal of Entomology, 74(2), 136–141.
83) Chakravarthy, A. K. (1988). Bird predators of pod borers of field bean (Lablab niger). Tropical Pest Management, 34, 395–398.
84) Gokhale, V. G., & Ameta, O. P. (1991). Predatory behavior of house sparrow, Passer domesticus L. in the population regulation of Heliothis sp. infesting chickpea, *Cicer arietinum*. Indian Journal of Entomology, 53, 631–634.
85) Ali, S., & Dillon, R.S. (1983). A pictorial guide to the birds of the Indian Subcontinent. Bombay Natural History, Oxford, pp. 176–188.
86) Gopali, J. B. (1998). Studies on integrated pest management of pigeon pea pod borer, *Helicoverpa armigera* (Hubner) with special reference to HaNPV and insectivorous birds. (PhD Thesis, University of Agricultural Sciences, Dharwad, India).
87) Gopali, J. B., Yelshetty, S., Teggelli, R., & Mannur, D. M. (2007). Eco-friendly management of pod borer, Helicoverpa armigera (Hubner) by encouraging predatory birds in chickpea ecosystem. In: National Symposium on Legumes for Ecological Sustainability: Emerging Challenges and Opportunities, 3–5 November 2007, Indian Institute of Pulses Research, Kanpur, p 168.
88) Gopali, J. B., Siddalingesh, Teggelli, R., & Yelshetty, S. (2008). Live bird perches—a non-insecticidal approach for the management of chickpea pod borer, *Helicoverpa armigera*. Paper presented at the First International Conference on Agrochemicals Protecting Crop, Health and Natural Environment, 8–11 January 2008, IARI, New Delhi, India, p 214
89) Kamanula, J., Sileshi, G. W., Belmain, S. R., Sola, P., Mvumi, B. M., Nyirenda, G. K. C., Nyirenda, S. P. N., & Stevenson, P. C. (2011). Farmers' insect-pest management practices and pesticidal plant use for protection of stored maize and beans in Southern Africa. International Journal of Pest Management, 57(1), 41–49.
90) Roy, N.K., & Dureja, P. (1998). New eco-friendly pesticides for integrated pest management. Pesticides World, New Delhi, 16–22.
91) Cavallito, C. J., & Bailey, J. H. (1944). Allicin, the antibacterial principle of *Allium sativum* L. Isolation, physical properties and antibacterial action. Journal of the American Chemical Society, 66, 1950–1951.
92) Amonkar, S.V., & Banerji, A. (1971). Isolation and characterization of the larvicidal principle of garlic. Science, 174, 1343–1344.

93) Zhu, B. C., Henderson, G., Chen, F., Fei, H., & Laine, R. A. (2001). Evaluation of vetiver oil and seven insect-active essential oils against Formosan subterranean termite. Journal of Chemical Ecology, 27(8), 1617–1625.

94) Gupta, M. P. (2007). Management of gram pod borer, *Helicoverpa armigera* (Hubner) in chickpea with biorationals. Natural Product Radiance, 16(5), 391–397.

95) Pachundkar, N., Kamble, P., Patil, P., & Gagare, P. (2013). Management of gram pod borer *H. armigera* in chickpea with neem seed kernel extract as a natural pest management practice in Bhojdari village. International Journal of Current Research, 5(10), 2934–2935.

96) Hussain, M., Ahmad, K. S., Majeed, M., Mehmood, A., Hamid, A., Yousaf, M. M., & Khan, A. Q. (2016). Integrated management of *Helicoverpa armigera* on different genotypes of Kabuli chickpea in Punjab, Pakistan. International Journal of Biosciences, 9(2), 110–119.

97) McLaughlin, J. L., Zeng, L., Oberlies, N. H., Alfonso, D., Johnson, H. A., & Cummings, B. (1997). Annonaceous acetogenins as new natural pesticides: recent progress. In: Hedin PA, Hollingworth RM, Masler EP, Miyamoto J, Thompson DG (eds) Phytochemicals for pest control. ACS Symposium Series, 658, 117–133.

98) Alali, FQ., Liu, XX., & McLaughlin, JL. (1999). Annonaceous acetogenins: Recent progress. Journal of Natural Products (Lloydia), 62, 504–540Ali, M., Agarwal, S.C., Rathore, Y.S., & Mishra, J.P. (1998). Agronomic options in the management of biotic stresses in pulse crops. In Proceedings of National Symposium on "Management of Biotic and Abiotic Stresses in Pulse Crops", Kanpur, June 26–28, 1998.

99) Bisen, S. K., & Bansal, S. K. (2014). Feeding deterrent activity of certain plant extracts against *Helicoverpa armigera* pest of Cicer arietinum. Journal of Chemical, Biological, and Physical Sciences, 4(4), 3296–3300.

100) Mishra, K., Singh, K., & Tripathi, C. P. M. (2013). Management of pod borer (*Helicoverpa armigera*) infestation and productivity enhancement of gram crop (*Cicer aritenium*) through vermiwash with biopesticides. World Journal of Agricultural Sciences, 9(5), 401–408.

101) Narayana, K. (1980). Field evaluation of NPV of *Heliothis armigera* on chickpea. In Proceedings of the Workshop on Biological Control of Heliothis spp., 23–25 September 1980. Department of Primary Industries, Toowoomba, Queensland, Australia.

102) Anonymous. (1982). Investigation on new strains of Bacillus thuringiensis (Bt) affecting lepidopterous crop pests. Final Technical Report, PL480 program of USDA (PG-Pa-317, PK-ARS-146). Department of Microbiology, University of Karachi, pp. 67–78.

103) Anonymous. (1983). Insect-pests. Annual report. International Crops Research Institute for the Semi-Arid Tropics, Patancheru, pp. 126–129.

104) Chandra, S. (1987). Production technology from All India pulse improvement project in Nepal. Coordination of grain legume research in Asia. Summary proceedings of the Review and Planning Meeting for Asian Regional Research on Grain Legumes (groundnut, chickpea, and pigeon pea), 16–18 December 1985, ICRISAT, Patancheru, India, pp 45–49.

105) Jayaraj, S., Rabindra, R. J., & Santharam, G. (1987). Control of Heliothis armigera (Hubner) on chickpea and lablab bean by nuclear polyhedrosis virus. Indian Journal of Agricultural Science, 57, 738–741.

106) Pawar, V.M., Aleemuddin, M., & Bhole, B.B. (1987). Bioefficacy of HNPV in comparison with Endosulfan against pod borer on chickpea. International Chickpea Newsletter, 16, 4–6.

107) Rabindra, R. J., & Jayaraj, S. (1988). Evaluation of certain adjuvants for nuclear polyhedrosis virus (NPV) of *Heliothis armigera* on chickpea. Indian Journal of Experimental Biology, 26, 60–62.

108) Balasubramaniam, S., Arora, R.S., & Pawar, A.D. (1989). Biological control of *Heliothis armigera* (Huber.) using Trichogramma pretiosum Riley and nuclear polyhedrosis virus in Sriganganagar district of Rajasthan. Plant Protection Bulletin, 41, 1–3.

109) Vyas, H. G., & Lakhohaura, B. D. (1996). Evaluation of Heliothis nuclear polyhedrosis virus for control of *Heliothis armigera* on chickpea at Pantnagar, (U.P.) Gujarat Agric Uni Res J, 21(2), 50–54.

110) Satish K, Malik VS, Kumar S, Dhawan AK (1998). Management of gram pod borer, *Helicoverpa armigera* (Hubner), by nuclear polyhedrosis virus in chickpea. In: Proceedings of International Conference on Ecological Agriculture: Towards Sustainable Development, Chandigarh, India, 15–17 November 1997, pp 329–333.

111) Pokharkar, D.S., Chaudhary, S.D., & Verma, S.K. (1999). Utilization of nuclear polyhedrosis virus in the integrated control of fruit borer (*Helicoverpa armigera*) on tomato (*Lycopersicon esculentum*). Indian Journal of Agricultural Sciences, 69(3), 185–188.

112) Hossain, M. A., Rahman, M. A., Khan, A. S. M. R., & Rahman, M. M. (2001). Effectiveness of Heliothis nuclear polyhedrosis viruses (HNPV) in chickpea pod borer management. Bangladesh Journal of Agricultural Research, 26(4), 625–627.

113) Hossain, M. A. (2007). Efficacy of some synthetic and biopesticides against pod borer, *Helicoverpa armigera* (Hubner) in chickpea. Tropical Agriculture Research and Extension, 10, 74–78.

114) Glazer, I., & Navon, A. (1990). Activity and persistence of entomoparasitic nematodes tested against *Heliothis armigera* (Lepidoptera: Noctuidae). Journal of Economic Entomology, 83, 1795-1800.

115) Askary, T.H. (2010). Nematodes as biocontrol agents. In: Sociology, organic farming, climate change, and soil science (Ed. E. Lichtfouse). Springer, Heidelberg, Germany, 347-378.

116) Askary, T.H., & Abd-Elgawad, M.M.M. (2021). Opportunities and challenges of entomopathogenic nematodes as biocontrol agents in their tripartite interactions. Egyptian Journal of Biological Pest Control, 31, 42.

117) Salama HS (1984). *Bacillus thuringiensis* Berliner and its role as a biological control agent in Egypt. Z Angew Entomol, 98(1–5), 206–220.

118) Salama HS, Foda MS, Sharaby A (1986). Possible extension of the activity spectrum of *Bacillus thuringiensis* strains through chemical additives. J Applied Ent, 101(1–5), 304–313.
119) Karel, A. K., & Schoonhoven, A. V. (1986). Use of chemical and microbial insecticides against pests of common beans. Journal of Economic Entomology, 79, 1692–1696.
120) Ahmed, K., Khalique, F., Malik, BA. (1989). Studies on *Helicoverpa armigera* management in Pakistan. Proceedings of the 1st International Conference on Economic Entomology, 11, 153–161.
121) Ahmed, K., Lal, SS., Morris, H., Khalique, F., Malik, BA. (1990). Insect-pest problems and recent approaches to solving them on chickpea in South Asia. In Proceedings of the Second International Workshop on Chickpea Improvement, 4–8 December 1989, ICRISAT, Patancheru, India (pp. 165–168).
122) Khalique, F., & Ahmed, K. (2001). Synergistic interaction between *Bacillus thuringiensis* (Berliner) and lambda-cyhalothrin (Pyrethroids) against chickpea pod borer, *Helicoverpa armigera* (Hubner). Pakistan Journal of Biological Sciences, 4, 1120–1123.
123) Khalique, F., & Ahmed, K. (2003). Impact of *Bacillus thuringiensis* subsp. Kurstaki on biology of *Helicoverpa armigera*. Pakistan Journal of Biological Sciences, 6, 615–621.
124) Ahmed, K., Khalique, F., Malik, B, A., Riley, D. (1994). Use of microbial insecticides in Pakistan: Special reference to control of chickpea pod borer *Helicoverpa armigera* (Hubner). Agronomy for Sustainable Development, 37(20), 38–44.
125) Ahmed, K., Khalique, F. (2012). Oviposition and larval development of *Helicoverpa armigera* (Hubner) (Lepidoptera: Noctuidae) in relation to chickpea, Cicer arietinum L. (Fabaceae) crop phenology. Pakistan Journal of Zoology, 44, 1081–1089.
126) Anonymous. (1997). Entomology annual report, All India coordinated research project on improvement of chickpea, Kanpur, India, pp. 204–216.
127) Rashid, A. A., Habib, S., Lal, H. A., Siddiqi, S. Z., & Arshad, M. (2003). Comparative efficacy of various insecticides to control gram pod borer (*Helicoverpa armigera* Hubner) on chickpea: Regional Agriculture Research Institute, Bahawalpur, Punjab, Pakistan. Asian Journal of Plant Science, 2(4), 403-405.
128) Ahmed, S., Zia, K., & Shah, N. (2004). Validation of chemical control of gram pod borer, *Helicoverpa armigera* (Hubner) with new insecticides. International Journal of Agriculture and Biology Pakistan, 6(6), 978-980.
129) Gowda, D. K. S., Patil, B. V., & Yelshetty, S. (2007). Performance of different sprayers against gram pod borer, *Helicoverpa armigera* (Hubner) on chickpea. Karnataka Journal of Agricultural Sciences, 20(2), 261-264.
130) Mahmudunnabi, M., Dutta, N. K., Rahman, A. K. M. Z., & Alam, S. N. (2014). Development of biorational-based integrated pest management package against pod borer, *Helicoverpa armigera* Hubner infesting chickpea. Journal of Biopesticides, 6(2), 108–111.