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Helicoverpa armigera (Hubner) on chickpea: Biology, damage, ecology, resistance and integrated management: A review

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ABSTRACT

Chickpea (*Cicer arietinum* L.) is one of the most important grain legumes for food, nutritional and livelihood security, particularly in South Asia and other semi-arid production regions. Among its insect constraints, the gram pod borer, *Helicoverpa armigera* (Hübner) (Lepidoptera: Noctuidae), remains a major and highly adaptable pest because larvae feed on foliage, flowers and, most importantly, developing pods and seeds. Its wide host range, high reproductive capacity, mobility, concealed feeding on reproductive structures and ability to develop resistance to insecticides make management difficult. Latest literature published from 2010 to 2026 shows a clear shift from dependence on conventional insecticides towards integrated pest management based on monitoring, economic thresholds, host-plant resistance, biological control, botanicals, selective insecticides, molecular breeding and precision application. Yield-loss studies demonstrate that damage can become economically serious even at relatively low larval densities, and recent threshold work has quantified economic injury at about 2.08 larvae m⁻¹ row and an action threshold near 1.56 larvae m⁻¹ row under the tested conditions. Host resistance research has identified antixenosis and antibiosis traits associated with trichomes, pod characteristics, phenolics, flavonoids, organic acids, proteinase inhibitors and induced defence pathways. Genomic studies have further identified QTLs and marker-trait associations for larval population, pod damage and resistance, opening opportunities for marker-assisted breeding. Biological control using *Helicoverpa armigera* nucleopolyhedrovirus (HaNPV), *Bacillus thuringiensis* (Bt), *Beauveria bassiana* and parasitoids such as *Habrobracon hebetor* and *Campoletis chlorideae* has shown useful potential, particularly when incorporated into IPM rather than used as isolated tactics. Chemical management remains important during outbreaks, but recent evidence of resistance, including reduced susceptibility to indoxacarb in chickpea-associated populations, emphasizes rotation of effective modes of action and threshold-based application. Recent advances include transgenic chickpea expressing Cry1Ab/Ac or Vip3Aa proteins, genome-wide association studies, metabolomics and jasmonate-mediated defence research, as well as drone-based spray technology. The review synthesizes these developments and identifies research priorities for durable, economical and environmentally responsible management of *H. armigera* in chickpea.

Keywords: Chickpea, *Helicoverpa armigera*, Gram pod borer, Host plant resistance, HaNPV, Bt, Biological control, Insecticide resistance, Economic threshold, Integrated pest management

1. Introduction

Chickpea is a major pulse crop cultivated across Asia, Africa, the Mediterranean region and other semi-arid environments. Its importance extends beyond grain production because it provides dietary protein, minerals and dietary fibre and contributes biologically fixed nitrogen to cropping systems. However, chickpea productivity is constrained by a range of abiotic and biotic stresses. Insect pests are particularly important because they can directly reduce the number and weight of harvested seeds. Among these pests, *H. armigera* is one of the most destructive because larvae attack multiple plant parts and are especially damaging during flowering and pod formation. The pest is commonly known as gram pod borer, chickpea pod borer or cotton bollworm depending on the crop and region.

The biology of *H. armigera* contributes strongly to its pest status. It is highly polyphagous and has been recorded from a very large number of host plants. Its larvae pass through several instars, and older larvae are particularly damaging because they consume large amounts of plant tissue and bore into pods. The reproductive structures provide protected feeding sites and make direct contact with insecticides less reliable. EFSA's pest categorisation notes that the species has more than 180 recorded host species from over 45 families and that larvae feeding inside reproductive structures can be difficult to detect and control. Resistance to insecticides is also widely documented at the species level.

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In chickpea, the management challenge is intensified by the crop's relatively narrow genetic base for high levels of pod-borer resistance and by the variable expression of resistance across environments. Research during 2010–2026 has therefore concentrated on understanding plant–insect interactions, screening germplasm, identifying biochemical and molecular mechanisms of resistance, establishing economic thresholds, improving biological control, and integrating selective insecticides with non-chemical tactics. Patil *et al.* (2017) [1] emphasized that sustainable management requires resistant cultivars, agronomic practices, monitoring and biological control rather than reliance on repeated insecticide use.

The present review summarizes research published during 2010–2026 on *H. armigera* associated with chickpea. The discussion covers taxonomy and identification, distribution, biology and seasonal ecology, crop damage and yield loss, monitoring and economic thresholds, host plant resistance, transgenic and molecular approaches, cultural management, biological control, botanicals, chemical management, insecticide resistance, integrated pest management, recent precision-application technologies and future research priorities.

2. Taxonomy, distribution and pest status

Helicoverpa armigera belongs to Order Lepidoptera, Family Noctuidae, and is closely related to other *Helicoverpa* species. Accurate identification is important because the genus contains morphologically similar species. Molecular tools can complement morphological identification where species discrimination is difficult. The species is distributed across Asia, Africa, Europe, Australia and other regions and is capable of long-distance movement. Evidence from India has demonstrated facultative migratory flight behaviour, indicating that populations may move between landscapes and crops and thereby complicate local forecasting and resistance management.

The pest is important in chickpea because its occurrence overlaps the reproductive phase of the crop. Larvae feed initially on leaves and tender tissues, but the most economically important injury generally occurs on flowers and pods. A single larva may damage multiple pods, and the presence of feeding holes, frass and partially consumed seeds can reduce both quantity and quality of grain. Patil *et al.* (2017) [1] reviewed the pest as capable of causing very high damage under favourable conditions and emphasized that indiscriminate pesticide use can create residues, resistance, pest resurgence and adverse effects on beneficial organisms.

The literature also shows strong geographical variation in pest pressure. Temperature, relative humidity, crop phenology, host availability and landscape composition influence seasonal abundance. Consequently, recommendations developed in one agro-ecological zone should not automatically be transferred to another without local validation.

3. Biology and life cycle

Adult moths are generally nocturnal and females lay eggs singly or in small numbers on young leaves, flowers and other suitable plant parts. Egg laying is influenced by host preference, plant surface characteristics and crop phenology. After hatching, larvae begin feeding on tender tissues. Young larvae may remain on foliage, whereas older larvae move to flowers and pods. Mature larvae are robust and may vary in colour, with longitudinal stripes and characteristic markings; however, field identification should be supported by standard entomological keys when necessary.

The larval stage is the principal damaging stage. As larvae grow, their consumption increases markedly and they become capable of boring into pods. Pupation occurs in soil, and adults emerge to continue the cycle. The number of generations and duration of each stage depend on temperature, host quality and environmental conditions. Because the insect can survive on numerous cultivated and wild hosts, off-season reservoirs can contribute to early infestation of chickpea.

Host plant quality affects larval growth and nutritional performance. Comparative studies of *H. armigera* on different host plants demonstrate that host chemistry can alter consumption, growth, development and nutritional indices. In chickpea, biochemical compounds on leaves and pods can therefore contribute to resistance by reducing feeding or impairing larval development. These effects form the biological basis for antixenosis and antibiosis.

Aspect	Key observation from literature
Scientific name	<i>Helicoverpa armigera</i> (Hübner)
Order / family	Lepidoptera / Noctuidae
Common name on chickpea	Gram pod borer / chickpea pod borer
Host range	Highly polyphagous; >180 hosts from > 45 families reported
Major damaging stage	Larva, especially later instars
Critical crop stage	Flowering to pod formation and grain filling
Major injury	Defoliation, flower feeding, pod boring and seed consumption
Management concern	High adaptability and insecticide resistance
Recent direction	IPM, resistance breeding, biocontrol and precision application

Recent work comparing *H. armigera* growth on chickpea and artificial diet has further emphasized the value of standardized laboratory rearing for resistance screening and toxicological studies. Artificial diet permits controlled evaluation of larval development, but field validation remains essential because plant architecture, climate and natural enemies modify pest performance under agricultural conditions.

4. Nature and symptoms of damage in chickpea

Damage by *H. armigera* changes with crop stage. During early vegetative growth, larvae feed on leaves and tender shoots, producing irregular holes. During flowering, larvae feed on flowers and reproductive tissues. At pod development, the pest becomes much more damaging because larvae bore holes into pods and consume developing seeds. A typical pod may show a circular feeding hole with frass around the opening. Seeds may be partially or completely consumed, and damaged pods may dry prematurely or fail to contribute marketable grain.

The relationship between larval density and yield loss is not linear under all conditions. Plant stage, pod load, genotype, weather and duration of infestation influence the final loss. Akanksha and Singh quantified yield reductions ranging from 8.80 to 51.20% in threshold experiments on chickpea, with the greatest reduction observed at three larvae m⁻¹ row. Their regression-based estimates gave an economic injury level of 2.08 larvae m⁻¹ row and an economic threshold level of 1.56 larvae m⁻¹ row under the experimental conditions.

Earlier field protection experiments also demonstrated the magnitude of potential loss. Deshmukh *et al.* reported that effective protection increased chickpea grain yield by 683 kg ha⁻¹, equivalent to a 69.98% increase over the untreated comparison in their experiment; the calculated avoidable yield loss was 41.17%. Such results should be interpreted as site- and season-specific estimates rather than universal loss coefficients.

In a Moroccan study, *H. armigera* was also confirmed as a major chickpea pest, and the authors emphasized the need to quantify local yield loss before defining control thresholds. This reinforces the importance of regional economic injury studies rather than using a single threshold across all chickpea production systems.

Study / period	Key quantitative observation	Management implication
Akanksha & Singh; 2016–17 and 2017–18	Yield loss 8.80–51.20%; EIL 2.08 larvae m ⁻¹ row; ETL 1.56 larvae m ⁻¹ row	Threshold-based intervention
Deshmukh <i>et al.</i> ; chickpea field study	Protected plots yielded 683 kg ha ⁻¹ more; 69.98% increase; 41.17% avoidable loss	Economic importance of protection
Singh <i>et al.</i> , 2022	Average annual losses described as 40–50% in the transgenic chickpea study	Need for durable resistance
Meerut study, 2021–23	Peak larval population 4.20 and 3.80 larvae plant ⁻¹ in two seasons	Seasonal monitoring is essential

5. Seasonal incidence and abiotic factors

Seasonal abundance of *H. armigera* is governed by crop phenology and weather. In chickpea, larval populations generally increase when the crop enters flowering and pod formation. Temperature affects egg development, larval growth, pupation and adult activity, while humidity and rainfall influence survival and natural mortality. Kaneria *et al.* reported significant negative correlations of larval population with maximum and minimum temperature ($r = -0.739$ and -0.725 , respectively) and positive correlations with morning and evening relative humidity ($r = 0.695$ and 0.743) under Saurashtra conditions. A two-season study at Meerut recorded first appearance around the 50th–51st standard meteorological week and observed peak populations of 4.20 and 3.80 larvae plant⁻¹ during the 12th and 11th standard meteorological weeks in successive seasons. Such results demonstrate why pest surveillance should begin before peak flowering rather than after visible pod damage has become widespread. Weather-based forecasting has therefore received increasing attention. Sagar *et al.* validated a weather-based forewarning model for *H. armigera* in chickpea. Forecasting is valuable because it can help synchronize scouting, pheromone trapping and intervention with likely pest build-up, reducing unnecessary insecticide applications. Migration adds another dimension to seasonal dynamics. Patil *et al.* documented evidence of facultative migratory flight in *H. armigera* in India. Migrating adults can introduce new populations into chickpea-growing areas, and the origin and movement of these populations may influence local pest pressure and resistance characteristics.

6. Monitoring and surveillance

Monitoring is the foundation of IPM because the decision to control *H. armigera* should depend on pest density, crop stage and expected economic loss. Field scouting should include direct counts of eggs and larvae, assessment of flower and pod damage, and observation of natural enemies. Sampling should be systematic across the field because larval populations are often aggregated rather than uniformly distributed.

Pheromone traps are useful for detecting adult activity and identifying periods of population increase. Patil *et al.* (2017) [1] emphasized pheromone monitoring as an important component of sustainable management. Trap catches do not directly equal larval density, however, and should be combined with field scouting. A practical programme therefore uses pheromone traps for early warning and plant sampling for action decisions.

Economic thresholds provide a bridge between monitoring and intervention. The threshold of approximately 1.56 larvae m⁻¹ row reported by Akanksha and Singh provides a useful example, but thresholds must be validated for cultivar, region, crop value and control

cost. Thresholds may also differ between vegetative and reproductive stages because the economic value of flowers and pods changes as the crop develops.

Parameter	Reported relationship / observation	Source
Maximum temperature	Negative correlation, $r = -0.739$	Kaneria <i>et al.</i> , 2018
Minimum temperature	Negative correlation, $r = -0.725$	Kaneria <i>et al.</i> , 2018
Morning RH	Positive correlation, $r = 0.695$	Kaneria <i>et al.</i> , 2018
Evening RH	Positive correlation, $r = 0.743$	Kaneria <i>et al.</i> , 2018
Peak population	4.20 and 3.80 larvae plant ⁻¹	Singh <i>et al.</i> , 2023
Migration	Facultative migratory flight documented in India	Patil <i>et al.</i> , 2021

Digital agriculture can strengthen surveillance. Smartphone-based image recognition, automated pheromone trap counting, geographic information systems, weather-linked forecasting and drone-based scouting are promising areas. Their practical value will depend on affordable hardware, reliable algorithms and validation across diverse chickpea environments.

7. Host plant resistance

Host plant resistance is one of the most sustainable components of *H. armigera* management because it reduces pest establishment and damage without requiring repeated external inputs. Resistance in chickpea is generally quantitative rather than controlled by a single major gene. Antixenosis reduces host preference or oviposition, while antibiosis adversely affects larval survival, growth, development or reproduction. Tolerance, in which plants maintain yield despite injury, may also contribute to field performance.

Screening studies have identified chickpea genotypes with reduced larval population, leaf consumption and pod damage. Sree Latha and Sharma reported that several desi genotypes were less preferred for oviposition than tested kabuli genotypes, indicating an antixenosis component. Earlier screening by Srivastava and Srivastava also linked susceptibility with higher egg and larval numbers and differences in leaf-extract acidity.

Biochemical resistance is associated with secondary metabolites and plant defence compounds. Research summarized in the 2025 review by El Bouhssini and colleagues indicates that trichomes, phenolics, flavonoids, organic acids, defence enzymes and proteinase inhibitors can contribute to resistance. Pod thickness and surface traits may reduce larval establishment or feeding efficiency, while biochemical compounds can impair digestion and growth.

The 2026 metabolomics work on chickpea crop wild relatives has strengthened this understanding by showing multi-layered chemical resistance associated with secondary metabolites. Such work can help identify donor parents and candidate compounds for breeding. However, biochemical resistance should be evaluated together with agronomic performance because strong resistance in an exotic donor may be linked with undesirable plant traits.

8. Molecular genetics, QTLs and genomic selection

Molecular breeding has become an important research direction since phenotypic resistance is quantitative and environmentally variable. Barmukh *et al.* developed a dense linkage map using an interspecific recombinant inbred population involving a susceptible *Cicer arietinum* accession and resistant *Cicer reticulatum* accession. The map contained 3,873 loci spanning 949.27 cM. Nine main-effect QTLs and 955 epistatic QTLs were detected, with main-effect QTLs explaining up to 42.49% of phenotypic variation for resistance component traits. A QTL cluster on CaLG03 was particularly promising.

Rehman *et al.* (2024) [2] extended the genomic approach using 173 chickpea genotypes evaluated over two years and genotyped with a 50K Axiom CicerSNP array. They detected 53 marker–trait associations for mean larval population, seven for percentage pod damage and two common associations for pest resistance. A common marker, Affx_123255526 on chromosome Ca2, was associated with larval population, pod damage and pest resistance. Candidate genes included SCAMPs, quinone oxidoreductase and NB-LRR proteins, indicating possible links with secretion of defence compounds, oxidative responses and immune-related signalling.

These findings create opportunities for marker-assisted selection, genomic prediction and gene pyramiding. Nevertheless, QTL validation across environments is essential. Resistance alleles may have modest

effects individually, and genotype × environment interactions can alter phenotypic expression. Future breeding programmes should therefore combine field screening, molecular markers, biochemical profiling and agronomic selection.

The 2026 proteomic and metabolomic studies further indicate that chickpea resistance is regulated through interconnected defence pathways. Comparative proteomics has implicated early jasmonic-acid signalling and linoleic-acid-derived compounds in resistance, while crop wild relatives contain diverse secondary metabolites with potential *anti*-herbivore activity. Integrating these datasets may reveal candidate genes and metabolites that can be used in pre-breeding and precision breeding.

Resistance mechanism	Representative traits	Likely effect on <i>H. armigera</i>
Antixenosis	Trichomes, surface chemistry, plant architecture	Reduced oviposition/feeding preference
Antibiosis	Phenolics, flavonoids, organic acids, protease inhibitors	Reduced larval growth and survival
Tolerance	Yield maintenance despite injury	Reduced economic impact
Pod-based resistance	Pod thickness and biochemical traits	Reduced penetration/feeding
Induced defence	Jasmonate signalling, defence enzymes	Rapid response after herbivory

9. Transgenic and gene-based approaches

Because conventional resistance in cultivated chickpea is often moderate, transgenic approaches have been investigated to introduce stronger protection. Ganguly *et al.* developed transgenic chickpea lines expressing fused Cry1Ab/Ac genes using constitutive and pod-specific promoters. The rationale was to increase toxin expression in the tissues most important for protection against pod borer.

Research on chickpea-mediated effects of Bt showed that resistant genotypes can act together with Bt to reduce larval survival and development. Dhillon and Sharma also examined tritrophic interactions involving Bt-treated chickpea, *H. armigera* and the parasitoid *Campoletis chlorideae*. Their findings showed that adverse effects on the parasitoid were largely indirect, through early mortality or reduced quality of the insect host. This highlights the need to evaluate transgenic or microbial technologies within a broader ecological framework.

Singh *et al.* (2022) [3] evaluated transgenic chickpea carrying a codon-modified Vip3Aa gene. Vip3Aa is of interest because its receptor interactions differ from those of classical Cry proteins, offering a possible route for resistance management and broader protection against lepidopteran pests. The study supports continued evaluation of Vip proteins as an alternative or complementary technology, although biosafety, resistance management, regulatory requirements and farmer acceptance must be considered.

Transgenic approaches should not be treated as a replacement for IPM. High-dose expression, refuge strategies, toxin rotation or pyramiding, monitoring for resistance and integration with natural enemies are important principles for maintaining durability. Further research is required before any technology is considered suitable for widespread deployment.

10. Cultural and agronomic management

Agronomic practices influence pest abundance by changing crop phenology, canopy structure and host availability. Early or timely sowing can sometimes help the crop escape periods of peak *H. armigera* pressure. Optimum plant density can alter canopy microclimate and make larvae easier to detect. Excessive nitrogen may increase plant attractiveness or nutritional quality for herbivores, so balanced nutrient management is preferable to excessive nitrogen application.

Patil *et al.* (2017) [1] summarized several agronomic tactics, including early sowing, optimum plant density and balanced fertilizer management. Trap or intercrops such as coriander, mustard, linseed, sun-

flower, sorghum and marigold have also been reported as components of pest management programmes. Their effectiveness depends on spatial arrangement, timing and local pest ecology, and they should be considered complementary rather than universally effective.

Bird perches can increase predation by insectivorous birds, while conservation of flowering resources can support parasitoids and predators. Removal of alternate host weeds around the field may reduce pest reservoirs in some situations, although indiscriminate weed removal can also eliminate natural enemies and therefore requires ecological consideration.

The practical value of cultural methods is greatest when they are combined with monitoring and biological control. Because no single agronomic tactic can consistently prevent infestation, combinations should be locally evaluated for cost, labour demand and compatibility with mechanized chickpea production.

11. Biological control

Biological control is central to sustainable management of *H. armigera*. Important microbial agents include HaNPV, *Bacillus thuringiensis* and entomopathogenic fungi such as *Beauveria bassiana*. Parasitoids such as *Habrobracon hebetor* and *Campoletis chlorideae* can also contribute to natural mortality. Conservation of indigenous predators and parasitoids is particularly important because repeated broad-spectrum insecticide use can disrupt these populations.

HaNPV is highly specific to *H. armigera* and is therefore attractive for IPM. Field studies have shown that HaNPV-based schedules can suppress larvae effectively, especially when applications are timed against young larvae. Yadav *et al.* compared management schedules in chickpea and found that three HaNPV sprays were statistically comparable with a flubendiamide schedule in their experiments. Combination schedules involving HaNPV and selective insecticides also performed well.

Bacillus thuringiensis produces insecticidal proteins that act primarily through the larval midgut. Its efficacy can depend on formulation, exposure, larval age and plant chemistry. Research by Paramasiva *et al.* showed that chickpea leaf-surface compounds can influence the biological activity of Bt, although organic-acid concentrations naturally present on chickpea did not eliminate Cry1Ac activity. This indicates that plant–microbe–insect interactions must be considered when optimizing Bt use.

Beauveria bassiana is another useful biological option. Bajya *et al.* evaluated *B. bassiana* against chickpea pod borer and considered its

safety to natural enemies. Entomopathogenic fungi can be particularly useful in resistance-management programmes because their modes of infection differ from conventional neurotoxic insecticides.

Allahyari *et al.* evaluated combinations of HaNPV and Btk with *Habrobracon hebetor* and demonstrated the potential for pathogen–parasitoid synergy. Such approaches are consistent with the IPM principle of combining mortality factors that act through different mecha-

nisms. However, compatibility, timing and environmental conditions must be considered before field-scale adoption.

Recent work in 2026 reported a native *B. thuringiensis* strain, NIBSM Bt-18, formulated as a 1% talc-based biopesticide. The study reported suppression of larvae and pod damage by up to 70% and chickpea yield increases of 7–49% across regions. These findings illustrate the continuing development of locally adapted microbial products.

Biological agent	Mode / role	Key evidence
HaNPV	Specific viral pathogen of <i>H. armigera</i>	Effective in field management schedules
Btk	Bt toxin-mediated larval mortality	Useful against young larvae; plant interactions matter
<i>Beauveria bassiana</i>	Fungal infection of larvae	Potential resistance-management partner
<i>Habrobracon hebetor</i>	Larval parasitoid	Can act synergistically with pathogens
<i>Campoletis chloridae</i>	Larval parasitoid	Important natural enemy; tritrophic interactions studied
NIBSM Bt-18	Indigenous Bt biopesticide	2026 field study reported up to 70% larval/pod-damage suppression

12. Botanicals and plant-derived products

Botanical insecticides offer a potential low-residue component of chickpea IPM. Neem-based products are especially relevant because azadirachtin has antifeedant, growth-regulating and oviposition-related effects. Other plant extracts have also been evaluated, but efficacy can vary with plant material, extraction method, concentration, weather and larval age.

Fite *et al.* evaluated *Azadirachta indica* and *Milletia ferruginea* extracts against *H. armigera* on chickpea and demonstrated their potential for infestation management. Botanical products can be particularly useful when applied against young larvae and integrated with biological control. However, they should not be assumed to be harmless to all beneficial insects; selectivity should be tested under local conditions.

Akanksha and Singh reported successful insecticidal modules combining neem-based products, microbial agents and newer insecticides. Their work supports the concept of sequential or rotational use rather than repeated application of a single product. The economic benefit of botanicals should be assessed using total management cost and yield protection rather than larval mortality alone.

Future research should standardize botanical formulations, characterize active compounds, evaluate shelf life and establish compatibility with parasitoids and microbial biopesticides. Locally available plants may offer low-cost options, but farmer preparation must be standardized to reduce variability.

13. Chemical control and newer insecticides

Chemical insecticides remain important when *H. armigera* populations exceed economic thresholds. However, the objective of modern chemical management is not maximum insecticide use; it is timely, selective and economical intervention. Older broad-spectrum compounds have progressively been supplemented or replaced by newer chemistries such as diamides, oxadiazines, spinosyns and insect growth regulators.

Wadaskar *et al.* reported strong suppression of *H. armigera* on chickpea with flubendiamide, rynaxypyr, emamectin benzoate and spinosad, with reported reductions of 94.3–99.9% over control at 7 and 14 days after application in their experiment. Such results show the value of selective chemistry, but repeated use of one active ingredient can accelerate resistance.

Akanksha and Singh evaluated insecticidal modules under Punjab conditions. Three applications of indoxacarb produced 0.00 larvae m⁻¹ row, 1.41% pod damage and 1950 kg ha⁻¹ grain yield compared with 29.22% pod damage and 1140 kg ha⁻¹ grain yield in the un-

treated control; the reported benefit:cost ratio was 6.9. These results demonstrate that well-timed chemical control can protect yield, but the study should not be interpreted as a recommendation for repeated indoxacarb use because resistance has since been documented in chickpea-associated populations.

The selection of an insecticide should therefore consider mode of action, local resistance status, crop stage, pre-harvest interval, effects on natural enemies and label recommendations. Tank mixtures and repeated use of compounds with similar target sites should be avoided unless specifically justified by resistance-management guidelines.

Recent precision-application studies are also relevant. Kambrekar *et al.* (2026) [4] compared drone and knapsack application of insecticides against *H. armigera* in chickpea, reflecting a move towards precision delivery. Drone spraying may improve timeliness and reduce labour requirements, but spray coverage, droplet size, weather conditions, operator training, regulatory compliance and cost must be evaluated before adoption.

14. Insecticide resistance

Resistance is one of the most important threats to long-term *H. armigera* management. The species has a history of resistance to multiple insecticide classes because of strong selection pressure, high reproductive capacity and gene flow. Resistance can involve target-site mutations, metabolic detoxification, reduced penetration and behavioural mechanisms. Chickpea production is affected because populations may move among chickpea, cotton, pigeonpea, tomato and other host crops.

Kaur *et al.* investigated inheritance of Cry1Ac resistance in *H. armigera* from India, demonstrating the genetic basis of resistance to Bt toxin exposure. Although that study was not restricted to chickpea, it illustrates the capacity of *H. armigera* populations to evolve resistance to novel toxins.

Bade *et al.* (2024) [5] specifically examined *H. armigera* infesting chickpea in western Maharashtra. Solapur populations showed a 7.00-fold resistance ratio to indoxacarb 15.8% EC, while chlorantraniliprole, cyantraniliprole, emamectin benzoate and spinosad remained toxic to the tested populations. The findings demonstrate spatial variation in susceptibility and reinforce the need for local resistance monitoring.

Resistance management should include rotation among effective modes of action, avoidance of unnecessary applications, use of economic thresholds, preservation of natural enemies and integration of microbial or host-resistance tactics. Where transgenic technologies are used, toxin pyramiding and appropriate resistance-management plans become essential.

Resistance-management principle	Practical implication
Threshold-based spraying	Avoid unnecessary selection pressure
Mode-of-action rotation	Do not repeatedly use the same target site
Use of biological control	Adds mortality through different mechanisms
Host resistance	Reduces pest survival before insecticide exposure
Resistance monitoring	Detects changes before field failure becomes widespread
Selective chemistry	Preserves parasitoids and predators
Transgenic toxin diversity	Reduces probability of rapid single-toxin resistance

15. Economic threshold and decision-based management

Economic thresholds translate entomological measurements into farm decisions. The ETL is the pest density at which control should begin to prevent the population from reaching the economic injury level. In chickpea, threshold studies are particularly valuable because insecticide applications can be costly and repeated spraying may damage natural enemies and select resistance.

The reported EIL of 2.08 larvae m⁻¹ row and ETL of 1.56 larvae m⁻¹ row provide a quantitative basis for decision making under the tested Punjab conditions. However, thresholds depend on insecticide cost, chickpea price, yield potential, natural control, cultivar susceptibility and crop stage. Therefore, these values should be regarded as reference points rather than universal values.

A practical decision system can combine pheromone-trap catches, field larval counts, weather forecasts, flowering stage and pod dam-

age. If larval density remains below threshold, conservation of natural enemies is preferable. If density approaches the threshold, biological or botanical tactics can be considered. When the threshold is exceeded, a selective insecticide with a suitable mode of action may be used. Follow-up scouting is essential to determine whether the intervention worked and whether additional treatment is justified.

16. Integrated pest management framework for chickpea

The literature from 2010–2026 strongly supports an integrated rather than single-tactic approach. The first layer is prevention through timely sowing, balanced crop nutrition, optimum plant density and management of alternate hosts. The second layer is monitoring through field scouting and pheromone traps. The third layer is biological regulation through predators, parasitoids, HaNPV, Bt and entomopathogenic fungi. The fourth layer is host resistance through resistant germplasm and molecular breeding. Chemical intervention is reserved for situations where pest density reaches economically damaging levels.

An effective IPM programme should also consider compatibility. For example, broad-spectrum insecticides can reduce parasitoid abundance and thereby weaken biological control. Conversely, selective insecticides may be compatible with parasitoids and microbial agents when properly timed. Similarly, Bt and HaNPV should be targeted against susceptible larval stages rather than large, concealed larvae. The sequence and timing of tactics can therefore be as important as the individual efficacy of each tactic.

Farmer adoption is another major component. Technologies that require complicated equipment, expensive inputs or multiple labour-intensive operations may have limited uptake. The most practical programmes are those that provide measurable yield protection at an acceptable cost and can be implemented with existing farm resources. Demonstration plots, farmer field schools and mobile advisory systems can improve adoption of threshold-based management.

IPM component	Examples	Main objective
Prevention	Timely sowing, balanced nutrition, field sanitation	Reduce initial pest build-up
Monitoring	Pheromone traps, plant sampling, weather models	Detect and forecast population increase
Host resistance	Resistant lines, molecular markers	Reduce establishment and damage
Biological control	HaNPV, Bt, <i>B. bassiana</i> , parasitoids	Increase natural mortality
Botanicals	Neem and plant extracts	Reduce feeding and development
Selective insecticides	Diamides, spinosyns, emamectin etc.	Rapid suppression above threshold
Resistance management	Mode-of-action rotation and monitoring	Delay resistance evolution
Precision application	Drone and targeted spraying	Improve timing and coverage

17. Recent advances during 2020–2026

The recent literature shows a transition from conventional efficacy trials to systems-level pest management. Genomics has enabled identification of QTLs and marker–trait associations. Proteomics and metabolomics are revealing defence pathways and compounds. Transgenic technologies have expanded from Cry proteins to Vip3Aa. Microbial control has progressed towards indigenous strains and improved formulations. Precision agriculture is introducing drone-based application, and forecasting studies are linking weather to pest dynamics.

The 2020 QTL study provided a dense genetic framework for resistance, while the 2024 Western Himalayan study used a 50K SNP array and identified markers associated with larval population, pod damage and resistance. These developments make marker-assisted breeding more feasible, particularly when combined with wild chickpea resources.

The 2022 Vip3Aa study is important because Vip3Aa has a different mode of receptor interaction from classical Cry proteins, offering a potential option for insect resistance management. The technology remains a research and regulatory subject rather than a routine field recommendation.

The 2025 review literature has emphasized integrated management and seasonal dynamics, while the 2025 defence review highlighted antixenosis and antibiosis mechanisms and multiple QTLs. In 2026, field evaluation of indigenous Bt and drone-based spraying demonstrated how biological and precision technologies are moving from laboratory concepts towards field-scale evaluation. The 2026 metabolomics study further strengthens the molecular understanding of resistance in crop wild relatives.

Together, these developments indicate that future management will increasingly rely on data integration: pest counts, weather, host genotype, resistance status, natural-enemy activity and economic information should be considered simultaneously rather than independently.

18. Research gaps and future prospects

Despite substantial progress, several gaps remain. First, durable high-level resistance in elite chickpea cultivars is still limited. Wild relatives offer useful resistance but may carry linkage drag. Pre-breeding, genomic selection and gene editing may help transfer resistance-associated loci while retaining yield and quality traits.

Second, resistance to insecticides is not monitored uniformly across chickpea-growing regions. Regular susceptibility surveillance should be established for major active ingredients, with standardized bioassays and molecular diagnostics. Resistance maps could be combined with crop and migration data to support regional management decisions.

Third, biological control requires better formulation, storage and field-delivery technologies. HaNPV and fungal biopesticides can be sensitive to ultraviolet radiation, temperature and application timing. Adjuvants, improved formulations and evening application may increase persistence, but each modification should be evaluated for compatibility with natural enemies.

Fourth, economic thresholds need updating under changing climates and input prices. A threshold derived under one price structure may become inappropriate when insecticide cost, chickpea price or yield potential changes. Dynamic thresholds linked to weather, crop stage and economic parameters would be more useful than static values.

Fifth, climate change may alter pest phenology, migration and geographic distribution. Warmer winters could affect survival, while changes in rainfall and cropping patterns may alter host availability. Long-term datasets combining weather, pheromone catches and field damage are required to model future risk.

Finally, digital tools need farmer-centred validation. Automated trap counting, smartphone diagnostics and drone application can improve timeliness, but their success depends on affordability, connectivity, training and local calibration. Technology should reduce management complexity rather than add another layer of cost.

19. Conclusion

Helicoverpa armigera remains a major insect constraint to chickpea because of its polyphagy, high reproductive potential, concealed pod feeding, mobility and capacity to develop resistance. Research published from 2010 to 2026 demonstrates that sustainable management is best achieved through integration of monitoring, economic thresholds, resistant cultivars, biological control, botanicals, selective insecticides and resistance-management practices.

Host plant resistance has progressed from phenotypic screening towards biochemical, genomic, proteomic and metabolomic approaches. QTLs, SNP markers and candidate defence genes provide valuable resources for developing resistant cultivars. Transgenic Cry and Vip technologies demonstrate additional possibilities, although regulatory and resistance-management considerations remain important.

Biological control with HaNPV, Bt, *Beauveria* and parasitoids provides useful non-chemical mortality and can reduce selection pressure on synthetic insecticides. Chemical control remains valuable when economic thresholds are exceeded, but recent evidence of resistance, including reduced susceptibility to indoxacarb in chickpea-associated populations, demonstrates why repeated use of a single chemistry is unsustainable.

The future of chickpea pod-borer management lies in precision IPM: resistant cultivars, reliable forecasting, pheromone-based monitoring, conservation of natural enemies, locally adapted microbial agents, selective insecticides and precision application should be combined according to local pest pressure and economics. Continued research linking entomology, plant breeding, molecular biology, climate science and farm economics will be essential for durable management of *H. armigera* in chickpea.

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