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A Review on the Biology, Ecology, and Management Tactics of *Helicoverpa armigera* (Lepidoptera: Noctuidae)

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A R T I C L E I N F O

Review Article

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A B S T R A C T

In the agronomical field, different internal and external factors are responsible for substantially diminished crop harvest. A hindrance that can be listed in those factors is insect pests. African bollworm (*Helicoverpa armigera*) is a significant polyphagous, rapacious feeder, and the serious pest of agricultural cosmos. This pest can infest a wide array of species (almost 180 plant species) and a diverse range of families regarding it to be the most versatile and economically important nuisances for crops. *H. armigera* is widely far-reaching throughout the globe mostly in the Asian domain. Likewise, the subsequent number of instars makes it more detrimental and positively influences its existence pattern. The biological parameters like high fecundity, reproducibility, and comparatively long-life period support in the incitement of damage threshold (DT). Thusly, this article depicts the presentation and control tactics against *H. armigera*, and further incorporates science and damage to acquaint this pest and access raise in production.

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Introduction

In crop cultivation, many variables can decrease crop yield. One significant reason is arthropod creepy crawlies. Insects that cause damage to the ovary are oftentimes more dangerous than those that harm leaves, stems, and roots (Mapuranga et al., 2015). Plants having a place with a wide range of families Asteraceae, Fabaceae, Malvaceae, Poaceae, and Solanaceae are exposed to yield and quality loss due to different lepidopterous pests (Czepak & Albernaz, 2013; Murúa et al., 2014; Mapuranga et al., 2015). *Helicoverpa armigera* (Lepidoptera: Noctuidae) is a profoundly polyphagous, multivoltine, and cosmopolitan vermin that is viewed as the most ruinous nuisances of field crops around the world (Stark & Banks, 2003; Sharma et al., 2011; Saraf et al., 2015). It is perhaps the most significant and decimating insect nuisances of a wide scope of rural crops around the world, plaguing around 300 plant species. It is a rapacious feeder that causes critical decreases in yield of financially significant harvests like tobacco (*Nicotiana tabacum*), cotton (*Gossypium hirsutum L.*), (*Sorghum bicolor L.*), canola, corn (*Zea mays L.*), soybean (*Glycine max L.*), pearl millet (*Pennisetum glaucum*), tomato (*Solanum lycopersicum L.*), okra (*Abelmoschus esculentus*), chickpea (*Cicer arietinum L.*), pigeon pea (*Cajanus cajan*), sunflower (*Helianthus annuus L.*), groundnut (*Arachis hypogeal*), and is relied upon to turn into a lethal nuisance in a few fruit trees (Sarate et al., 2012; Vinutha et al., 2013; Murúa et al., 2014; Safuraie-parizi et al., 2014; Salman Ahmad et al., 2015; Saraf et al., 2015). The overall monetary related loss because of this vermin in the country alongside yield losses is assessed to be US$ 5 billion (Sharma et al., 2011; Tay et al., 2013). In India and China, half of the pesticides in agribusiness are utilized for controlling this vermin (Pogue, 2004). Generalist feeders like *H. armigera* oviposit on a wide range of hosts and thus cause significant yield losses in crop plants and huge monetary erosion each year (Sarate et al., 2012; Saraf et al., 2015). Even though *H. armigera* causes huge monetary erosion consistently, however, it is critical vermin of those aforesaid crops around the world (Safuraie-parizi et al., 2014). The species *H. armigera* is similar to other caterpillar species like *Helicoverpa zea*, *Heliothis virescens*, and *Helicoverpa gelotopoeon*. Every one of them has a place with the family Noctuidae and subfamily Heliothinae and, along these lines, they share some morphological attributes. However, the caterpillar staining design is variable, as per the food they consume, ecological conditions, and time of hatchlings (Pratissoli et al., 2015).

H. armigera can persevere in exceptionally unfriendly conditions including climatic conditions, especially temperature, dampness, precipitation, agronomic practices, and cropping systems of the areas because of provisions, like, polyphagous, high versatility, high fruitfulness, and facultative diapauses. The capacity of insects to make due on different host plants is a versatile component for their endurance in the biological system. Polyphagous pests requires physiological systems to defy the fluctuating substance intricacies presented by various host plants, which is certainly administered by *H. armigera* (Sharma et al., 2011; Sarate et al., 2012). In due course, this vermin has obstructed the majority of the pioneering classes of engineered pesticides and control methodologies (Abedi et al., 2014). Thus, complete information on the life history of insects and their status as vermin give a significant premise to create effective pest management strategies (Sharma et al., 2011). Accordingly, the motivation behind this review is to make speculations regarding *H. armigera* to assess its frequency on the assortment of farming harvests (Safuraie-parizi et al., 2014).

Distribution

H. armigera is topographically far-reaching, being available in Europe, Asia, Africa, and Oceania (Czepak & Albernaz, 2013; Murúa et al., 2014). This species assaults more than 180 developed crop species around the world (Murúa et al., 2014). In early 2013, its event was affirmed in cotton (*Gossypium hirsutum*), and in soybean (*Glycine max*) plants invading different harvests (seeds staying from past crops) in the territories of Goiás, Mato Grosso, and Bahia, Brazil; after which this nuisance was viewed as isolate (Gary Peter Fitt, 1994). *H. armigera* is one of the most genuine insects of tomato crop whose harm fluctuates from various locales in India particularly in Solan space of Himachal Pradesh and further likewise in Spain (Mehta et al., 2010; Sharma et al., 2011; Czepak & Albernaz, 2013).

Lifecycle

This nuisance has a high regenerative potential since every female can deposit 1,000 to 1,500 eggs, independently, on plant parts above ground like on leaves, stems, blossoms, especially around evening time, as a rule on the adaxial leaf face and bushy surfaces (Czepak & Albernaz, 2013; Mapuranga et al., 2015; Pratissoli et al., 2015). The female moths metamorphosed from caterpillars by feeding on corn, chickpea, and capsicum lays about 1125.4, 1173.3, and 481.5 eggs individually (Mehta et al., 2010). The incubation period lies between 3-4 days in summer (Shah et al., 2011; Mapuranga et al., 2015). Further, the hatching period goes from 5-7, 5-6, and 4-6 days in the primary, second and third generations, separately (Sharma et al., 2011). The larvae develop through five phase, which in summer require around 21 days, however, the period varies accordance to generation (Mapuranga et al., 2015). The normal term of the larval period in the first, second, and third era is about 30.4 days, 38.2 days, and 23-28 days, respectively (Sharma et al., 2011). Before pupal shaping, the fully fed caterpillar spends through 4.2, 4, and 4.76 days as the pre-pupal period during successive generations. The pupal period lasts about 21.2, 24.3, and 13.7 days, respectively. The late spring pupal stage endures around 14-21 days; diapausing pupae (or larvae) take a lot longer to develop (Sharma et al., 2011; Mapuranga et al., 2015). *H. armigera* finishes its life cycle (egg to grown-up) inside 55-61 days in the winter season and 42-50 days in the summer season (Figure 1), contingent upon the food which it relies on (Walker et al., 2000; Murúa et al., 2014; Saraf et al., 2015). Howsoever, it takes at least 44.2 days in the third era and a limit of 65.25 days in the second era (Sharma et al., 2011). In normal climatic situations, various parameteras like temperature, mugginess, precipitation, different cropping systems, and so forth influence the existence pattern of pests (Murúa et al., 2014; Mapuranga et al., 2015; Saraf et al., 2015).

Morphological Features

Eggs

The newly laid eggs are a yellow-white tone and have 28 longitudinal edges with vertical edges of rotating length, which encompass a smooth apical that contains the micropyle, discovered laid on the upper portion of the plant. The eggs are practically circular pomegranate formed with a leveled base and become obscured to grayish-brown prior to incubating (Sharma et al., 2011; Mapuranga et al., 2015; Saraf et al., 2015) (Figure 2).

Larvae

The larvae pass through five instars before becoming pupa and the size of the first, second, third, fourth, and fifth instar hatchling is regarded to be about 1.44 × 0.49 mm, 3.43 × 0.78 mm, 8.30 × 0.07 mm, 17.8 × 0.34 mm, and 32.40 × 5.20 mm long and expansiveness, separately (Sharma et al., 2011) (Figure 2). The hatchlings are forceful and whenever upset, they segregate from the plant and twist upon the ground (Saraf et al., 2015). The first and second instars hatchlings are semi-clear yellowish to rosy brown in shading with a spotted appearance. The head, thoracic, anal-centric shields, prothoracic legs, and even setae are dull brown to dark in shading (Sharma et al., 2011; Mapuranga et al., 2015; Saraf et al., 2015). In the third instar, the shading became yellowish-white with many dark spots from the front to the backside of the body (Sharma et al., 2011). In the fourth instar, the adjustment of body tone is obvious having dorsal side light yellow with grayish longitudinal queues. The larvae have a saddle-like design on their first abdominal section, because of the presence of noticeable dark stomach tubercles with a coriaceous surface (Sharma et al., 2011; Czepak & Albernaz, 2013; Pratissoli et al., 2015). The head becomes dim brown in the fifth instar with a light green body having a broken stripe along each side of the body (Sharma et al., 2011). The completely developed larvae are lined by a trademark pale line along the back and on one or the other side of its body (which runs longitudinally). Its appearance changes from green to light yellow, rosy brown, or dark and are around 30 – 40 mm long (Czepak & Albernaz, 2013; Mapuranga et al., 2015) (Figure 2). The ecological conditions and kind of food devoured enormously impact the improvement and fulfillment of full-size caterpillars (Vinutha et al., 2013; Mapuranga et al., 2015).

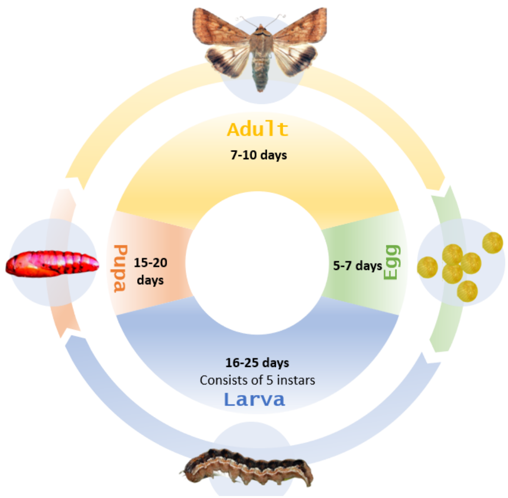

Figure 1. Lifecycle of *Helicoverpa armigera* (Genç and Yücel, 2017)

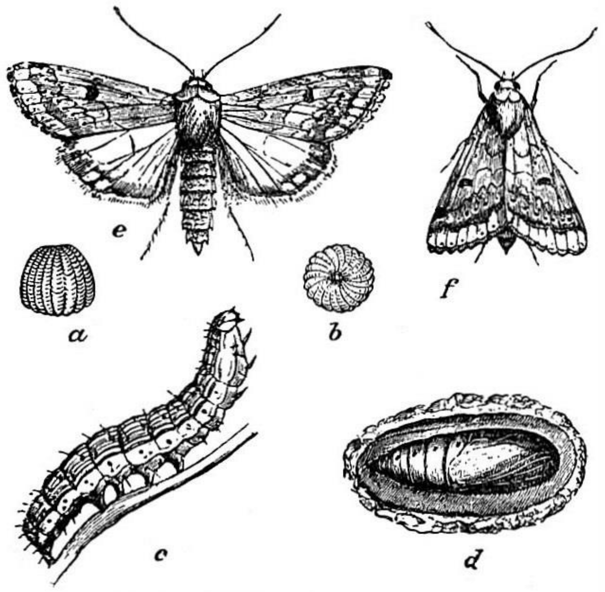

Figure 2. Morphological illustrations of different stages of *Helicoverpa armigera*

(a) Egg; (b) Highly magnified egg; (c) Larva; (d) Pupa in cell; (e) Adult with full wing spread; (f) Adult in resting position [Retrieved from (Mally, 1911)].

Figure 3. Injuries caused by *Helicoverpa armigera* caterpillar

(a, b, c) Damage caused by the caterpillar in tomato fruit; (d, e, f) *H. armigera* larva feeding on cotton bolls; (g) *H. armigera* larva attacking a soybean pod; (h) *H. armigera* larva feeding inside a chickpea pod; (i) Pod Borer from the damaged pod [Retrieved from (Czepak & Albernaz, 2013; Lusana, 2020; Pratissoli et al., 2015; Wubneh, 2016)]

Pupae

The pupation happens in the soil at a profundity of 3-15 cm or the tip of plant leaves or cob (in the occurrence of maize). After feeding ceases, larvae tunnel into the soil and pupate or go into diapause relying upon climatic conditions (Czepak & Albernaz, 2013; Mapuranga et al., 2015). The male pupa is about 23.19 mm long, 6.23 mm in expansiveness. It has comprehensively adjusted front and tightening back. The newly shaped pupa is light green yellowish in shading. Nonetheless, it turns out to be light brown to hazier shading during the emergence time frame (Figure 2). The mid-region is particularly set apart into ten fragments with spiracles situated on the fourth and ninth portions (Sharma et al., 2011; Mapuranga et al., 2015).

Adult

The adult moth arises following 18 days and a half years (winter diapause) (Mapuranga et al., 2015). Adults of *H. armigera* present strong sexual dimorphism, with the primary pair of wings introducing a greenish-dim shading, for males, and an orange-earthy colored tone, for females; further, the females are more obscure than males and include a tuft of hair at the tip of the midsection (Gary Peter Fitt, 1994; Sharma et al., 2011; Czepak & Albernaz, 2013; Saraf et al., 2015). The body of the male measure around 19 mm long with 38.65 mm wing territory, while the female has a 20.57 mm body length with 42.80 mm wing expanse (Sharma et al., 2011). The adults have a line with seven to eight spots on the forewing's edges, with sporadic and cross-over earthy colored lattice, and furthermore a dark comma imprint or kidney-molded spot on their focal part on each wing. Hindwings are light-hued with a dull earthy colored boundary and a light spot in the focal point of the apical limit (Sharma et al., 2011; Czepak & Albernaz, 2013; Mapuranga et al., 2015; Saraf et al., 2015) (Figure 2). This species is exceptionally mobile and can endure, much under antagonistic conditions. It has a few generations every year since its cycle from egg to adults keeps going from four to about a month and a half. Besides, it can without much of a stretch scatter since adults are regular transients and can arrive at significant distance dispersal up to 1,000 km to 2,000 km (Czepak & Albernaz, 2013; Murúa et al., 2014).

Damage

H. armigera is an exceptionally polyphagous lepidopteran pest. Fundamentally, the larvae phase of *H. armigera* is very adverse. Also, this herbivore can cause erosion to diverse monetarily significant harvests, viz. vegetables, legumes, blossoms, cereals, decorative plants, and natural product trees (Sarate et al., 2012; Czepak & Albernaz, 2013; Mapuranga et al., 2015; Pratissoli et al., 2015). *H. armigera* larvae insatiably feed on the nitrogen-rich plant parts including leaves and stems, even though they incline toward buds, inflorescences, products of the soil, causing harm in the vegetative and regenerative plant stages prompting generous monetary misfortune (Czepak & Albernaz, 2013; Murúa et al., 2014; Mapuranga et al., 2015; Pratissoli et al., 2015; Salman Ahmad et al., 2015). The immediate harm to the structure of blossoming and fruiting of host plants by *H. armigera* caterpillars bring about low efficiency and the broad utilization of sprays hoists significant expenses of control, individually (Figure 3) (Pratissoli et al., 2015).

The early instar larvae of *H. armigera* are ravenous foliar feeders which later shift to the seeds, natural products, or bolls, prompting enormous decreases in yield. It is an amazingly perilous pest since its reproduction rate is very high; it can relocate over a significant distance. In nature, early instars of *H. armigera*, as a rule, feed on leaves low in supplements, and during additional development, they experience conceptive constructions that are supplementally rich (Sarate et al., 2012; Saraf et al., 2015). In the occurrence of cotton, direct harm to cotton is brought about by larvae feeding on buds and bolls (Figure 3). A damaged cotton boll may have a distinct circular opening and be just partially eaten. The larvae cause considerable bloom and boll losses because of their exercise. A few larvae on a plant can annihilate every one of the bolls within 15 days altogether, causing 1175 kg/ha yield erosion (Mapurangaa et al., 2015). In the Indian subcontinent, chickpea fills in as the significant original host after winters for *H. armigera*. On the off chance that the pervasion is high in chickpea, the populace level of ensuing generations is seen to be impressively higher bringing about crop loss in the later occasional yields like cotton and tomato. The yield loss in chickpea might be pretty much as high as 95% under rancher's field conditions (Gary Peter Fitt, 1994).

Control and Management:

Cultural Method

Adjusting the planting dates

One of the most crucial elements determining agricultural productivity is sowing crops at the best time. The pod borer population is influenced by weather variables like maximum and minimum temperatures, daylight hours, and wind speed. In Asian regions, early crop planting reduces the number of pod borer larvae and the proportion of damaged pods (Mapuranga et al., 2015; Patil et al., 2017). Planting dates are picked to such an extent that the significant blossoming and conceptive stages don't correspond with the period when *H. armigera* is at high occurrences (Mapuranga et al., 2015; Genç & Yücel, 2017).

Crop rotation

Another cultural control strategy that most farmers have used is this. To disrupt the life cycle of pests and diseases, the main crop, such as cotton, may be rotated with other crops (maize, wheat, and soybeans). For red and pink bollworms, which have limited host ranges, crop rotation is useful. Because cotton squares and bolls are the sole food sources for the pink bollworm, a large-scale switch to other crops has a significant influence on this pest (Mapuranga et al., 2015).

Field disinfection

The leftover mass in the cultivated field should be annihilated to forestall the development of vermin and end the auxiliary age. All types of vermin can be constrained by this technique (Mapuranga et al., 2015; Genç & Yücel, 2017). By cutting the stems below the first branch, it is necessary to remove the plant's aerial portions (Mapuranga et al., 2015).

Plant geometry

The severity of pod damage is also influenced by plant geometry. Crops that are more densely populated often have greater larval populations, which reduces output. Because farmers may have limited choices to lower the seed rate because of unfavorable physical soil conditions and poor seed germination, thinning may be advised to reduce plant density (Mahmood, 2021). A microclimate that is favorable to the dark-loving Helicoverpa larvae of pests is probably created by higher plant density. Helicoverpa population dynamics on crops show that greater densities of crops and populations of larvae and pupae are more abundant than low densities (Patil et al., 2017).

Trap cropping

Trap cropping is a strategy for concentrating a pest populace into a sensible region by furnishing with a space of a host crop or a space of a favored host crop as a diversionary host (Vinutha et al., 2013; Mapuranga et al., 2015). Intercropping of primary crops and trap crops, in a characterized way, is apparent in most smallholder cultivating networks. Harvests typically utilized are cowpeas, sorghum, maize, soya beans, watermelons, and pumpkin are acceptable snare crops for *H. armigera*. They are by and large the most favored hosts for oviposition and larval turn of events. This guides most harm to these yields and saves the primary harvests (Mapuranga et al., 2015; Genç & Yücel, 2017). On account of cotton, the diversionary hosts, maize and sorghum show incredible potential to outperform the *H. armigera* harm. Further, the *H. armigera* populace on cotton, okra, and pigeon pea can be enormously diminished by developing neem as a snare crop and marigold in the case of tomato fields (Vinutha et al., 2013; Mapuranga et al., 2015).

Intercropping or mixed cropping

In the conventional agricultural method, intercropping has many benefits over solitary cropping, including protection against pests and unusual weather. It has been shown that combining some crops with primary crops will lessen pod borer damage. This may be due to the companion crop having more natural enemies or the pod borer not preferring to lay eggs in a field with the intercrop (Patil et al., 2017). Intercropping modifies the crop geometry and the cropping system and prevents insect larvae from migrating from one crop place to another (Mahmood, 2021).

Profound plowing

The upsides of profound furrowing go about as a supporting way to deal with controlling pupae of *H. armigera*. Plowing opens pupae to birds and over the top sun heat. The plowing of stubble decreases overwintering populaces of *H. armigera* and postharvest cultivation annihilates them (Mapuranga et al., 2015).

Synchronous planting

Synchronous planting ian the neighborhood avoids the development of vermin from more seasoned to more youthful plants (Mapuranga et al., 2015; Genç & Yücel, 2017).

Nutrient Management

Fertilizers are generally used to increase agricultural productivity, but they may also indirectly affect insect infestations. The bushier the plants get as a consequence of the greater degree of NPK treatment, the more vulnerable they become to pod borer and vice versa. Because the plant is bushy, the dark-loving pod borer has a better place to hide, which results in more pod damage (Patil et al., 2017). Additionally, higher phosphorus concentrations greatly reduce pest occurrence and enhance yield. Applications of fertilizers alter plant physiology and make it a host plant for the pod borer (Mahmood, 2021).

Other cultural strategies

One circuitous social technique which could be incorporated under this heading is the guideline of crop agronomy, assortment, dispersing, and compost systems to deliver the yield and hence target larvae, more available to insect poisons or microbial plans applied by regular means (Mapuranga et al., 2015).

Chemical Method

Prior to chemical use, productive exploring of harvests ought to be done that gives a gauge of nuisance levels in the field. Synthetic is applied when the pest populace comes to or surpasses the economic injury level (Mapuranga et al., 2015). The normal economic injury level for H. armigera is 12 eggs/24 explored plants. Exploring grants synthetic control to be viable with the organic control technique. It maintains a strategic distance from the utilization of pesticides when pest populaces are beneath the financial edge; this permits the development of normal foes (Mapuranga et al., 2015; Patil et al., 2017). The chemical insecticides can be sprayed in different stages of the crops (Figure 4).

<table>
<tr><td rowspan="4">Conventional
(Soybeans, Chickpea, Pigeonpea, Groundnut)</td><td rowspan="4">Helicoverpa armigera
(Lepidoptera: Noctuidae)</td><td>Stage</td><td>Seedling</td><td>Early Flowering</td></tr>
<tr><td>Recommended Treatment</td><td>Insecticide Seed Treatment or Foliar</td><td>Foliar Insecticide</td></tr>
<tr><td>Stage</td><td>Early Flowering-Early Pod Filling</td><td>Mid-Late Pod Filling</td></tr>
<tr><td>Recommended Treatment</td><td>Foliar Insecticide</td><td>Foliar Insecticide</td></tr>
</table>

Figure 4. Treatment recommendations across four treatment windows based on pest complex occurrence and conventional crop's growth stages for *H. armigera* [Modified from (Haile et al., 2021)]

Table 1. List of chemical pesticides with their application rate

S.N.	Chemical Compounds	Application rate	References
1.	Endosulfan (Thionex 35 EC)	500 a.i./ha	(Mahmood, 2021; Mapuranga et al., 2015)
2.	Indoxacarb 14.5% SC	0.5 ml/L	(Yogeeswarudu & Venkata Krishna, 2014)
3.	Diazinon 60% EC	-	(Wubneh, 2016)
4.	Cypermethrin	1.0 ml/L	(Rahman et al., 2014)
5.	Emamectin benzoate	200 ml/acre	(Chohan et al., 2020)
6.	Spinosad 45% SC	73g a.i./ha	(Gupta et al., 2020; Mahmood, 2021)
7.	Thiodicarb	410 a.i./ha	(Mapuranga et al., 2015)
8.	Profenofos 50% EC	2.0 ml/L	(Yogeeswarudu & Venkata Krishna, 2014)
9.	Novaluron 10% EC	75g a.i./ha	(Rai, 2015)
10.	Alphamethrin 10% EC	2 ml/L	(Gupta et al., 2020)
11.	Fenvalerate	40 a.i./ha	(Mapuranga et al., 2015)
12.	Profenofos + cypermethrin	600 ml/acre	(Gupta et al., 2020)

Table 2. List of biological organisms with their application rate

S.N.	Entomopathogenic organisms & Parasitoids	Application rate	References
1.	*Verticillium lecanii*	5%	(Gupta et al., 2020)
2.	*Campoletis chloridae*	-	(Wubneh, 2016)
3.	*Beauveria bassiana*	10^11 conidia/ha	(Haile et al., 2021; Toffa et al., 2021)
4.	*Metarhizium anisopliae*	10^9 conidia/ml	(Souza et al., 2020)
5.	Ichneumonid	-	(Wubneh, 2016)
6.	*Trichogramma Sps.*	-	(Haile et al., 2021; Sarate et al., 2012)
7.	*Steinernema feltiae*	-	(Ebrahimi et al., 2018)
8.	*Bacillus thuringiensis ssp. kurstaki*	32,000 IU/mg	(Mantzoukas, 2019)
9.	Nuclear polyhedrosis viruses (NPVs)	300 LE/ha	(Patil et al., 2017)

The pesticides like indoxacarb 14.5 SC @ 0.5 ml/l show best in controlling *H. armigera* larval populace, to lessen the invasion and furthermore produce the most extreme grain yield, trailed by profenofos 50 EC @ 2.0 ml/l, imidacloprid 17.8 SL @ 1 m/l, novaluron 10 EC @ 1.5 ml/l, fipronil 5 SC @ 2.0 ml/l and lambda cyhalothrin 5 EC @ 1 ml/l, respectively. Further, Insecticides like endosulfan, fenvalerate 20EC, cypermethrin, fluvalinate 2E, deltamethrin 2.5 EC, and carbaryl are likewise broadly used to control this infamous vermin (Table 1) (Mehta et al., 2010; Yogeeswarudu & Venkata Krishna, 2014; Mapuranga et al., 2015). In addition, the use of engineered and customary insect sprays in rotational premises gives the best outcome (Mapuranga et al., 2015).

Since the use of synthetic insect, poisons cause unfavorable impacts like harmfulness to non-target living beings (predators, parasitoids, and pollinators), advancement of pest spray obstruction, pest resurgence, natural contamination, and health perils. Accentuation ought to be given to the IPM approach which lays weight on negligible utilization of the insecticides and their mix with other control strategies (Mehta et al., 2010).

Biological method

Vertebrates' predators

Many birds have a high pace of insect admission and the acknowledgment of this reality leads to primer investigations concerned either with a relationship of birds to the concealment of harmful insects or their insurance and consolation in regions with a high danger for insects' pervasion. The birds like Common myna (*Acridotheres tristis*), Redbilled blue jaybird (*Cissa erythrorhyncha*), Magpie robin (*Copsychus saularis*), Jungle crow (*Corvus macrorhynchos*), Black drongo (*Dicrurus adsimilis*), Gray tit (*Parus major*), House sparrow (*Passer domesticus*), Redvented bulbul (*Pycnonotus cafer*), White-cheeked bulbul (*Pycnonotus leucogenys*), Pied bramble talk (*Saxicola caprata*), and Jungle motor-mouth (*Turdoides striatus*), feeds on lepidopteron larvae encompassing *H. armigera* larvae in tomato, cotton, and a lot more harvest fields. The action of insectivorous or depredatory birds is high during the morning and evening hours of the day and by and large, gets peaked in the plowing phase (Mehta et al., 2010).

Invertebrates' predators

The classical organic control technique includes usage of regular foes of pests which help to manage populaces of damaging and different life forms. The arachnids (*Cheirancanthium lawrencei*, *Prucetia kunensis*) impact the larvae phase of *H. armigera* and Ladybird bugs and its larvae (*Exochomus flavipes*, *Cheilomenes linata*, *C. deisha*, *Hippodamia variegate*) is impeding to the eggs and hatchlings stages. Further, Assassin bug (*Phonoctonus spp.*, *Aphidius spp.*, *Encarsia sublutea*, *Eretrocerus spp.*) impacts the eggs phase of *H. armigera* (Mapuranga et al., 2015).

Parasitoids

The release of entomophages, for example, *Trichogramma spp.* and, *Habrobracon hebetor* wasps go about as egg parasitoids and demonstrate potential to be utilized in the administration of *H. armigera*, considering the effect that this species can foster protection from specific insecticides and are base strategical part of organic control (Table 2) (Pratissoli et al., 2015; Saraf et al., 2015).

Entomopathogens

The *Bacillus thuringiensis Berliner*, a bacterium that produces δ-endotoxins harmful protein hinders larvae of various types of Lepidoptera including *H. armigera*. *Bacillus thuringiensis* can be utilized by splashing its spores and precious stones on the crops that potentiated and synergized the insecticidal action. The poisonousness of *Bt* subspecies kurstaki and aizawai changes fundamentally among Lepidopteran species and life stages (Table 2) (Abedi et al., 2014).

Mechanical Method

Trapping

Generally, pheromones traps are fundamentally more powerful than light snares in the case of *H. armigera*. Every insect species has its exceptional mark fragrance that is pheromone. The controlling of *H. armigera* utilizing pheromones traps is extremely effective and ecologically protected. The pheromones in the snares fundamentally target creating calling female's situation for males and in this manner pulled in males get caught and further mating diminishes (Vinutha et al., 2013).

Botanical method

Neem (*Azadirachta indica A.*) fill in as characteristic biopesticides and is portrayed as naturally nonpersistent and consequently, are probably not going to bring about ecological tainting (Mehta et al., 2010; Vinutha et al., 2013; Salman Ahmad et al., 2015). Among the various plant botanicals, compounds got from different parts of the neem tree (leaves, seeds bit, and so forth) i.e., Azadirachtin (tetranortriterpenoids) show insecticidal properties and is perceived as quite possibly the most encouraging plant items for IPM (Mehta et al., 2010; Mamoon-ur-rashid et al., 2012; Salman Ahmad et al., 2015). Azadirachtin shows various poisonous consequences for H. armigera by going about as an antifeedant, oviposition obstacle, repellent, and sterilant (Salman Ahmad et al., 2015; Kumar & Kler, 2021). It further restrains the amalgamation and arrival of shedding chemicals from the prothoracic organ, prompting defective ecdysis and disturb transformation in the youthful phase of this vermin (Abedi et al., 2014; Salman Ahmad et al., 2015). Nonetheless, a few different mixtures like deacetylazadirachtinol, meliantriol, vepol, salannin, sulfur compounds, and so on additionally show shifting levels of pest impediment that altogether diminishes the pupal endurance, pupal weight, and grown-up rise (Atawodi & Atawodi, 2009; Salman Ahmad et al., 2015).

Neem-based formulations like Nimikrin, Nimbidin, Achook, NeemAzal, Nimbecidine, and Neem Jeevan Triguard have been utilized against the *Helicoverpa armigera* larval populace in tomato and different harvests (Table 3) (Prakash & Srivastava, 2008; Mehta et al., 2010; Vinutha et al., 2013). Neem items can be likewise blended in with other biopesticides, microbial, or synergists. Their positive eco-toxicological profile and a brief time of industriousness in the climate settle on them a decent decision IPM program in *H. armigera* plagued crops (Abedi et al., 2014).

Biotechnological Method

RNA interference (RNAI) technology

The *H. armigera*, is an ordinary Lepidopteron pest and is especially famous for its protection from different sorts of normal insect poisons. Thus, a biotechnical strategy i.e., RNA interference (RNAi) trigged by dsRNA is started for controlling this pest by hushing its particular lethal genes. The dsRNA is conveyed either by infusion, ingestion, or through ingestion of designed microbial forms expressing dsRNA (Jing & Zhao-jun, 2014). Additionally, nanotechnology is another biotechnical approach for pest control. This includes pest management through the formulations of nanomaterials-based pesticides, insecticides, bio-forms, anti-agents, and pheromone that upgrades viability and explicitness of those aforesaid compounds. It is additionally used to convey DNA and other desired synthetic substances into plant tissues for assurance of host plants against lepidopterans pests (Vinutha et al., 2013).

Transgenic varieties

An integrated control strategy against any insect pest may be developed based on resistant cultivars. The adoption of pest-resistant plants results in a consistent, cumulative decrease in insect populations that costs farmers essentially nothing extra (Mapuranga et al., 2015; Mahmood, 2021). Therefore, finding, analyzing, and using a genetic mechanism that provides long-lasting resistance to pod borers should be the breeding objective. As long as a reliable source of resistance is available, developing genetically enhanced cultivars with better pod borer resistance is possible (Patil et al., 2017; Mahmood, 2021).

There are various transgenic assortments of cotton, soybean, maize, tomato, developed all through the world. For instance, now a day's Bt cotton i.e., a transgenic assortment of cotton, conveying Cry1Ac gene confined from *Bacillus thuringiensis* is explicitly utilized that shows protection from *H. armigera*. Moreover, Bt cotton is viable with most IPM strategies. The toxins, for example, Cry1Ac, Cry2Ab, and Vip 3A created by Bt cotton assortments are just ingested by the phytophagous insects and, accordingly, they have little impact on useful insects and further definitely works on the yields by stifling *H. armigera* (Stark & Banks, 2003; Mamoon-ur-rashid et al., 2012; Vinutha et al., 2013; Mapuranga et al., 2015; Saraf et al., 2015).

Table 3. List of botanical pesticides with their application rate

S.N.	Botanical Compounds	Application rate	References
1.	Neemarin 0.15% EC	15 mg azadirachtin/liter	(Salman Ahmad et al., 2015)
2.	Neem seed water	3% EC	(Mamoon-ur-rashid et al., 2012)
3.	Jatropa Extract	-	(Gopalakrishnan et al., 2011)
4.	Bioneem	0.09% EC	(Abedi et al., 2014)
5.	*Andira paniculata* extract	0.05%	(Neto et al., 2018)
6.	Neem Oil 1% EC	100 mg azadirachtin/liter	(Salman Ahmad et al., 2015)
7.	Mahogany oil	4 ml/L	(Rahman et al., 2014)
8.	NeemAzal	20 ppm	(Mehta et al., 2010)
9.	Tobacco leaf extract	12.5 g/L	(Rahman et al., 2014)

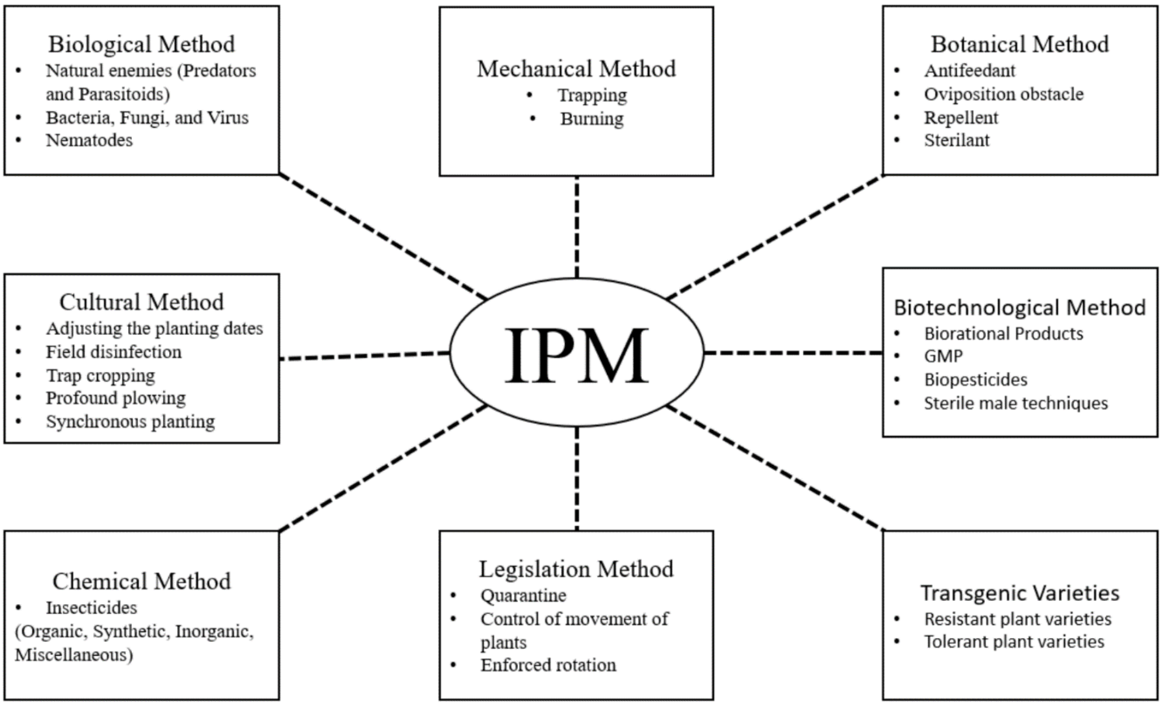

Figure 5. Components of integrated *Helicoverpa armigera* management

Sterile insect technology

Techniques for inherited sterility are often used to reduce the pest population. It is a highly effective method of invasive pest management and has no negative environmental effects. This method involves releasing radiation-sterilized male pests into the natural population to restrict reproduction while mating with female pests. A normal mating between an untreated female and an irradiated male insect produces progeny with aberrant characteristics. As a result, this sterility technique may be effectively used since it won't interfere with any pest control plans (Yadav, Bhattarai, et al., 2022; Yadav, Sharma, et al., 2022).

Integrated pest management (IPM) Strategies

A variety of control approaches are incorporated to manage *H. armigera* in a manner that minimizes environmental contamination and maintains long-lasting pest issue suppression. These strategies fit under the broad categories of cultural control, host plant resistance, chemical control, and biological control (Figure 5) (Mapuranga et al., 2015). It may be possible to effectively manage any pest without harming the environment by combining various pest control methods and making appropriate use of insect sprays that are less harmful to the environment (Yadav, Bhattarai, et al., 2022). The most successful IPM modules for controlling pod borer include pheromone trapping, the sequential release of the bio-control agent (Trichogramma chilonis + Bracon hebetor), and spraying neem seed kernel extract. Pheromone trapping, the sequential release of the bio-control agent (T. chilonis + B. hebetor), and spraying are the next two most successful IPM modules (Patil et al., 2017). The majority of these different IPM strategies have been used against pod borers; among the most significant ones are those listed below (Mapuranga et al., 2015);

- Chemical control procedures and strategies Scouting and economic threshold (ET)
- Use of less toxic and safer chemicals
- Rotation of pesticides

Conclusions

H. armigera has shown a great impact in the agricultural fields with the heavy amount of economic losses and generating food instability in various countries. This pest can infest uncountable fundamental crop species, causing devastating damage. So, legitimate control of this pest is required as soon as possible when it is initially observed. Since the uncontrolled and unmanaged application of pesticides has a great impact on the ecological boundaries. So, alternative management strategies like cultural, biological, botanical, mechanical, and biotechnical approaches ought to be taken into consideration. Rather, integrated pest management (IPM) modules after integration of those aforesaid practices should be formed and adopted for complete control of this nuisance. Besides, the implication of advanced technologies like nanotechnology and tissue culture should be espoused to fabricate efficient and effective pest control tactics. In like manner, the proper survey and surveillance ought to be conducted to forecast the incidence of *H. armigera.*

List of Abbreviations

IPM	Integrated Pest Management
DT	Damage Thresholds
Bt	*Bacillus thuringensisis*
RNAI	RNA interference
SIT	Sterile Insect technique
GMP	Genetically Modified Plants

Author Declaration

The authors declare no irreconcilable circumstances. All authors contributed equally in all phases of preparation of this manuscript. Likewise, the final version of the manuscript was approved by all authors.

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