

International Journal of Advanced Biochemistry Research



ISSN Print: 2617-4693
ISSN Online: 2617-4707
IJABR 2024; SP-8(10): 1265-1271
www.biochemjournal.com
Received: 05-09-2024
Accepted: 11-10-2024

Govindan K

Regional Research Station,
Tamil Nadu Agricultural
University, Paiyur 632112,
Tamil Nadu, India

Sasikumar K

Regional Research Station,
Tamil Nadu Agricultural
University, Paiyur 632112,
Tamil Nadu, India

Senthilumar P

Regional Research Station,
Tamil Nadu Agricultural
University, Paiyur 632112,
Tamil Nadu, India

Mangammal P

²Horticultural College and
Research Institute, Paiyur,
Krishnagiri, Tamil Nadu, India

Senthilkumar M

Horticultural Research
Station, Yercaud, Tamil Nadu,
India

S Thangewari

Department of Plant
Pathology, TNAU, Coimbatore
– 3, Tamil Nadu, India

Sivakumar B

Forest College and Research
Institute, Mettupalayam,
Tamil Nadu, India

Usharani KS

Kumaraguru Institute of
Agriculture, Erode, Tamil
Nadu, India

Corresponding Author:**Sasikumar K**

Regional Research Station,
Tamil Nadu Agricultural
University, Paiyur 632112,
Tamil Nadu, India

Efficacy of new molecule of insecticide, Emamectin benzoate against polyphagous pest, *Helicoverpa armigera* (Hubner): A review

Govindan K, Sasikumar K, Senthilumar P, Mangammal P, Senthilkumar M, S Thangewari, Sivakumar B and Usharani KS

DOI: <https://doi.org/10.33545/26174693.2024.v8.i10So.2706>

Abstract

The presents review article has been reviewed to know the importance of different new molecules insecticides against *Helicoverpa armigera* (Hubner) (Noctuidae: Lepidoptera). It is a is the most prominent insect species that causes major economic damage to various agricultural and horticultural crops. It is highly polyphagous pest attacks over 182 plants species and worldwide occurrence inflicting annual crop damage worth US \$1 billion in India. The caterpillar cause major damage to the crops as it attacks reproductive parts and growing tips. The management of *H. armigera* is very difficult in many crops including both widely grown and economically important crops as cotton, maize, sorghum, tobacco, pigeon pea, green gram, chickpea, black gram, red gram, tomato, chilli, okra and onion etc. However, the indiscriminate use of organophosphates, carbamates and synthetic pyrethroids has created a number of problems such as pests developing resistance to insecticides, pest resurgence and bio concentrations of pesticide residues in consumable produce at harvest. Among the harmful effects of insecticides, persistence of toxic pesticide residues in plants, soil and water are of great concern for consumer's health and safety to animals. It is estimated that more than 50 per cent of applied insecticides reach the soil and water bodies during application At the same time, to overcome the above said problems, attempts have been made for identification of new molecules with higher insecticidal property, selective action and lower mammalian toxicity that fits well in the integrated pest management concept. Despite all the drawbacks that come with chemical control of pests, there are still many reasons that can persuade farmers to still choose to use them. Regardless of several control strategies that were found effective in managing this pest the chemical control plays a vital role because of quick action, readily available and very easy to use unlike alternative methods, such as biological control and other similar methods which can take a long while to plan and often don't have an immediate effect on pests. In case of controlling pests over larger areas chemical management proves to be very cost effective besides economic benefits. If the practice of suggested insecticide at recommended dose is adapted against *H. armigera*. Hence, insecticides with a new mode of action have been desired. One such new molecule, emamectin benzoate is a semi synthetic derivative of avermectin produced as fermentation metabolites of soil actinomycete *Streptomyces avermitilis* Burg (Lasota and Dybas, 1990) ^[60]. This was discovered in 1984 and has both stomach and contact action effective against various lepidopteran pests.

Keywords: New molecule, emamectin benzoate, management, *Helicoverpa armigera*

1. Introduction
2. Losses caused by *Helicoverpa armigera* various field crops
3. Losses caused by *Helicoverpa armigera* various horticultural crops
4. Biology of pod borer *Helicoverpa armigera*
5. Nature of damage caused by *Helicoverpa armigera*
6. Host ranges for *Helicoverpa armigera*
7. Chemical structure and properties of emamectin benzoate
8. Bioefficacy of emamectin benzoate against *H armigera* in field crops
9. Bioefficacy of emamectin benzoate against *H armigera* in horticultural crops

Introduction

Popularly known as Gram pod borer, *Helicoverpa armigera* (Hübner) (Lepidoptera: Noctuidae) is polyphagous pest and it attacks a number of economically important crops both agricultural (cotton, maize, sorghum, tobacco, pigeon pea, green gram, chickpea, black gram,

red gram) and horticultural crops (tomato, chilli, okra and onion) and ornamental crops (Islam *et al.* 2020) ^[1]. The countries affected by the devastating attack of *H. armigera* on various crops include India, Pakistan, Turkey, Mexico, Iran, Australia and Ethiopia (Dinesh *et al.*, 2018) ^[2]. It attacks 182 plants species from 68 different families (Reigada *et al.* 2016) ^[3]. Because of its polyphagy, mobility as adults, and high fecundity (Sudha Rani, *et al.*, 2018) ^[4]. Now days, *H. armigera* management facing considerable challenges in many crops of the world (Li *et al.* 2018; Patil *et al.*, 2017). It is cosmopolitan pest infesting many host plants (Fite *et al.*, 2020) ^[7]. The incidence of this insect begins from early vegetative to maturity stage of the crop. At early stage, the young larvae starts feeding on leaflets, buds, flowers and finally green pods various pulses (Kassi *et al.* 2018) ^[8]. Under favorable environmental conditions it may cause average of 80-90 % damage (Javed *et al.* 2018) ^[9]. The *H. armigera* responsible for causing economic damage and capable of migrating over large distances Junhirun *et al.*, 2018 ^[10] and its preference for flowering and fruiting parts results in heavy loss up to 60 per cent or more under subsistence agriculture in the tropics Japur *et al.*, 2016 ^[11]. *Helicoverpa armigera* is a charismatic insect pest in agriculture accounting for the consumption of over 55 per cent of total insecticides used in India Puri *et al.*, 1995 ^[12]. The problem of this pest is magnified due to its direct attack on fruiting structures, voracious feeding habits, high mobility, fecundity and multivoltine overlapping generations Sarode, 1999. *H. armigera* caterpillars infest flowering and fruiting structures of host plants. The extensive use of insecticides and the nature of damage of *H. armigera* on attacked crops result in high costs of control and low productivity Thameur *et al.* 2020 ^[14].

Farmers largely follow the chemical method as it gives quick results. High frequency application is the common scenario Patil *et al.* 2020 ^[17] Chemical control the pests easy adaptability, effectiveness and immediate control. The indiscriminate and irrational use of chemical insecticide resulted in pest resurgence, resistance and residues. The cotton and pulses growers in India depend heavily on synthetic pesticides to combat pests and the crop consumes about 54 per cent of the total insecticides used in the country. However, the indiscriminate use of organophosphates, carbamates and synthetic pyrethroids has created a number of problems such as pests developing resistance to insecticides, pest resurgence and residues in soil Ahmad *et al.* 2019 ^[16]. The existing chemicals are becoming absolute in the management of pest. *Helicoverpa armigera* management (IPM) approach but its management is largely based on synthetic insecticides. The adaptability of insect pests to most of conventional insecticides is leading to economic yield losses with increased negative side-effects to environment is a big challenge to the modern agriculture Bird, 2017 ^[17].

So newer molecules are to be evaluated for their efficacy. The indiscriminate usages increase cost of cultivation, has also led to destruction of natural enemies. For avoiding this, extra care is required in introducing newer molecules. One such new molecule, emamectin benzoate is a semi synthetic derivative of avermectin produced as fermentation metabolites of soil actinomycetes *Streptomyces avermitilis* Burg., Lasota and Dybas. 1990 ^[60]. This was discovered in 1984 and has both stomach and contact action effective against lepidopteran pests. It has been reported to possess

excellent action against pests cotton and vegetables. It acts on the nerve cells to suppress muscle contraction thus inhibiting the larvae from feeding Govindan *et al.*, 2010 and Lammers, 2018 ^[21]. Emamectin benzoate 5 SG with novel mode of action that is effective even at lower doses and safer to the natural enemies.

Losses caused by *Helicoverpa armigera* various field crops

The average crop losses in India due to this polyphagous pest are estimated to be US \$350 million annually Hayden and Brambila, 2015. According to Vinoth, 2017 the global losses from this pest can be in excess of \$2 billion annually. The gram pod borer, *Helicoverpa armigera* (Hubner) (Lepidoptera: Noctuidae) is highly polyphagous pest and yield loss caused by various agricultural crops reported by several scientist and presented. The *Helicoverpa armigera* is a polyphagous insect and attacks more than 200 species of almost 45 crops throughout the world Rabindra *et al.*, 2004. The total annual yield loss of different crops by *Helicoverpa armigera* has been reported to be a worth of 2 billion US dollars. On an average, 2.5 to 3.0 million tonnes of pulses are lost annually due to pest problems ^[24]. The annual loss due to this was estimated to be US \$ 400 million in pigeonpea Krishna *et al.*, 2016 ^[25]. A yield loss due to pod borers in pigeonpea was estimated to a tune of 40.6 per cent. Several insects have been reported to infest pigeonpea crop at different stages during its growth period in different parts of the country Priyadarshini *et al.* 2013 ^[26].

Chickpea due to *H. armigera* was reported as 10-60 per cent in normal weather conditions Dinesh *et al.*, 2018 ^[2]. Its preference for flowering and fruiting parts results in heavy loss up to 60 per cent or more under subsistence agriculture in the tropics. The pest feeds voraciously from seedling stage to maturity and causes about 50 to 60 per cent damage to the chickpea pods Babar *et al.* 2012. Saxena Saxena *et al.* 2012 stated that pod borer complex infesting redgram heavy yield loss (60 %) is due to *H. armigera* alone.

The extent of losses in Chickpea caused by *H. armigera* varies from region to region and depends upon climate and crop intensity. Its preference for flowering and fruiting parts results in heavy monetary loss of 203 crore rupees annually Suneel Kumar and Sarada, 2015 ^[29]. Gram pod borer, *Helicoverpa armigera* caused yield losses ranging from 40-50 per cent has been reported and may cause even total loss of the crop Rai *et al.*, 2003 ^[30]. Biradarpatil *et al.*, 2018 ^[31] reported that capsule borer, *H. armigera* infested in safflower at harvesting stage, 93.8 to 100 per cent of capsules will be bored, and 57.69 to 80.11 per cent capsule will not have any grains. In cotton crop decline in 15 per cent cotton yield resulting in loss of more than Rs 2000 crore annually due to *H. armigera* has been estimated in India Duraimurugan and Regupathy. 2005 ^[32]. Cotton highly affected by *H. armigera* with 80 per cent loss Fakrudin *et al.*, 2004 ^[33]. *Helicoverpa armigera* cause 25 per cent yield losses generally and in rigorous infestation 40-70 per cent yield loss in sunflower Muhammad *et al.*, 2004 ^[42].

Losses caused by *Helicoverpa armigera* various horticultural crops

Helicoverpa armigera is a polyphagous pest and it can infest a large number of crops and lower the market value of the vegetable crops Prasanna *et al.*, 2013 ^[35]. *H. armigera* to cause economic harm. Around US \$ 78 billion is the annual

value of the crops that are exposed to this species Yengkhom *et al.*, 2019^[36]. Islam *et al.*, 2020^[1] who reported that responsible for 40-50 percent damage to the tomato crop and a yield loss in the range of 20 to 60 per cent Herald and Tayde. 20189. Heavy damage is inflicted by okra fruit borer inflicts direct losses in yield of marketable fruits and vitality of plant resulting in 54.04 percent net yield loss Lammers, 2018^[21]. In okra yield losses (54.04 %) and fruit damage (35-75 %) Karthikeyan and Ayyasamy, 2018^[38]. Considerable economic losses due to *Helicoverpa armigera* reported by many workers to the extent of about 50-60 per cent in tomato fruits Reddy and Zehrm, 2004. Tomato fruit borer, *Helicoverpa armigera* is highly destructive pest causing serious damage and responsible for significant yield loss up to 55 per cent Talekar *et al.*, 2006^[40]. It also caused 40-50 per cent damage to the tomato crop Pareek and Bhargava, 2003. Tomato crop by causing a yield loss in the range of 20 to 60 per cent Tauseef *et al.*, 2016. *Helicoverpa armigera* damage to fruit which is of up to 3.48% of economic damage level. Fruit damage results into disfiguration of surface, rotting through secondary infection by bacteria Swodesh and Bhishma, 2019^[43]. Okra fruit borer, *H. armigera* is the most serious pest which cause direct damage to tender fruits Thara *et al.*, 2019^[44]. *Helicoverpa armigera* is reported that about 69 per cent losses in marketable yield due to attack of this insect pest Kanwar and Ameta, 2007^[45]. As reported by Baikar and Naik, 2016^[46] due to severe attack of *H. armigera* lead to 90 per cent flower and fruit drop in chilli. Economic yield loss in chilli may be 11-75% quantitatively and 60-80 per cent qualitatively in the event of serious infestation Ghosh *et al.*, 2009^[47].

Biology of pod borer *Helicoverpa armigera*

Life cycles of *Helicoverpa armigera* take about 30–34 days with an average temperature of 28 °C from egg to adult Yengkhom *et al.*, 2019^[36]. The oviposition period lasts for 5 to 24 days, and a female may lay up to 3000 eggs (mainly at night) on leaves and flowers. Major chickpea-producing countries pods. Eggs are laid singly on leaves, flowers and young pods. The egg incubation period depends on temperature and varies between 2 and 5 days (usually 3 days). The duration of larval development depends not only on the temperature but also on the nature and quality of the host plant. It varies between 15.2 days on maize and 23.8 days on tomato. The number of larval instars varies from 5 to 7, with 6 being most common Alit *et al.*, 2009. The larvae pupate in the soil. The pre-pupal period lasts for 1 to 4 days. The larvae spin a loose web of silk before pupation. In non-diapausing pupae, the pupal period ranges from about 6 days at 35 °C to over 30 days at 15 °C Alit *et al.*, 2009. The diapausing period for pupae can last several months. Pale colored adults are produced from pupae exposed to temperatures exceeding 30 °C. Female moths generally live longer than males. In the laboratory, longevity varies from 1 to 23 days for males and 5 to 28 days for females. The pod borer exhibits a facultative diapause, which allows it to survive adverse weather conditions in both winter and summer seasons. Crop Protection Compendium, 2007 Edition. © CAB International Publishing, Wallingford. The winter diapause is induced by exposure of the larvae to short photoperiods and low temperatures. In China and India, pod borer populations are composed of tropical, sub-tropical, and temperate ecotypes. In subtropical Australia, the pod

borer undergoes diapauses during the winter, when temperatures are low. High temperatures can also induce diapause. It enters a true summer diapause when the larvae are exposed to very high temperatures (43 °C for 8 h daily), although the proportion of females entering diapause is nearly half compared with that of males. At these temperatures, non-diapausing males are sterile.

Nature of damage caused by *Helicoverpa armigera*

The 1st, 2nd, and 3rd instar larvae initially feed on the foliage (young leaves) of chickpeas and a few other legumes, but mostly on the flowers and flower buds of cotton, pigeon pea, etc. Larvae shift from foliar feeders to developing seeds and fruits as larval instar development progresses Dinesh *et al.*, 2018^[2]. The young chickpea seedlings may be destroyed completely, particularly under tropical climates in southern India. Larger larvae bore into pods/bolls and consume the developing seeds inside the pod Kailash *et al.*, 2009^[49]. The pod borer attacks crop 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, and later, when the pods are formed, the larvae bore into the pods and feed, resulting in low yield. The young pod borer larvae (1st, 2nd, and 3rd instar) occasionally enter the pod and feed upon the developing chickpea grains, but more often they feed from outside the pod with only the anterior part of its body in the pod Kailash *et al.*, 2009^[49].

Host ranges for *Helicoverpa armigera*

H. armigera is a major economic pest of many agricultural and horticultural crops Torres *et al.*, 1996. It feeds on over 300 species belonging to 68 plant families around the world, including major crops such as cotton, soybean, maize and a wide range of horticultural crops Pearce *et al.*, 2017. 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., other Leguminosae, tobacco, potatoes, maize, flax, a number of fruits (Prunus, Citrus), forest trees, and a range of vegetable and flower crops Kanwar and Ameta, 2007^[45].

Chemical structure and properties of emamectin benzoate

1. Avermectins

1.1 Discovery

Avermectins represent a novel class of macrocyclic lactones that have nematicidal, acaricidal and insecticidal activity. They are a mixture of natural products produced by a soil actinomycete, *Streptomyces avermitilis* Burg., MA - 4680 (NRRL 8165), which was isolated in culture at the Kitasato Institute from a soil sample collected at Kawana Ito City, Stizuoka prefecture, Japan.

In screening procedure, cultures were fermented and whole broth tests were conducted for six days via diet incorporation (0.0002% of the diet) on mice infected with *Nematospiroides dubius* (B.), a gastrointestinal nematode. The *in vivo* tests demonstrated good antihelminthic activity. The isolation, characterisation and structural elucidation of the avermectins have been described by Burg and Stapley, 1989^[52].

1.2 Structure and chemistry

The avermectins primarily consist of four major (A1a, A2a, B1a, B2a) components and four homologous minor (A1b, A2b, B1b, B2b) components (Fig 1). The “A” series has a methoxy group at the C₅ position of cyclohexane moiety, while the “B” series has a hydroxyl group. In the “2” series, the double bond is hydrated, having a hydroxyl group at C₂₃ while in “1” series a double bond exists between C₂₂ and C₂₃. The “a” series has a secondary butyl group at C₂₅, while the “b” series has an isopropyl group. The disaccharide substituent at C₁₃ contains two identical α - L - oleandrose units. The B series has more biological activity than the A series (Albers *et al.*, 1981). Abamectin is a mixture of B1a ($\geq 80\%$) and B1b ($\leq 20\%$), utilized for the control of agricultural and household arthropod pests.

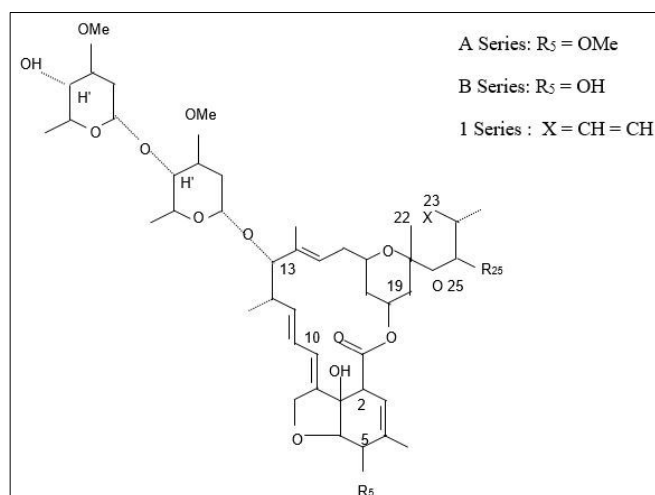


Fig 1: Structure of ivermectin's Lasota and Dybas, 1990 [60]

1.3. Mechanism of action

The experimental findings by Lasota and Dybas, 1990 [60] and Wright, 1985 highlighted the avermectins are likely to act on GABAergic (Gamma - aminobutyric acid) neurons. Turner and Schaeffer, 1989 [55] reported that avermectins increase the muscle permeability to chloride ions, thereby reducing excitatory potentials and input resistance and reduction in membrane permeability. It causes the action of picrotoxin (Chloride ion channel blocker) and bicuculline (GABA receptor antagonist). Thus, avermectins act as a chloride channel agonist (Albrecht and Sherman, 1987). Demonstrated that avermectins are functioning as a GABA agonist in roundworm (Humans) as a model system Kass *et al.*, 1984 [57]. In addition, physiological evidence suggests an increase in membrane permeability to chloride ions Scott and Dwe, 1985 [58]. Sami and Vaid, 1988 [59] proposed that the affinity of avermectins for retinol binding proteins would also have a possible mechanism of action of avermectins.

Abamectin which belongs to the avermectins group, has potent pesticidal activities. It is a broad spectrum pesticide and highly toxic to many arthropods including spidermites, agromyzid leafminers, ants, cockroaches and selected lepidopteran pest species Dybas, 1989 [60] and Pearce *et al.*, 2017. Abamectin is ecologically a selective compound with short residual, low - contact activity rather than physiological selectivity Strong and Brown, 1987. Abamectin is toxic to 84 species of insects in 10 orders, most of which are of economic importance and abamectin is also a promising and effective acaricide Strong and Brown, 1987.

2. Bio efficacy of emamectin benzoate against *Helicoverpa armigera* in field crops

Several scientists evaluated the efficacy of emamectin benzoate against *Helicoverpa armigera* and presented below.

Table 1: Bioefficacy of emamectin benzoate (EB) against field crop pests

S. No.	Crop	Pest	Formulation	Dose	Reference	Remarks
1.	Cotton	Bollworm complex	EB 5 SG	11 ga.i. ha ⁻¹	Udikeri <i>et al.</i> 2004 [62]	Very effective in reducing the boll damage
2	Cotton	American boll worm <i>H. armigera</i>	EB 5 SG	11 g a.i. ha ⁻¹	Lammers, 2018 [21]	Effective in reducing the larval population
3	Cotton	Bollworm complex	EB 5 SG	11 g a.i. ha ⁻¹	Karthik and Thiruvani, 2017 [63]	Effectively reduced the boll damage
4	Sorghum	Ear head worm, <i>H. armigera</i>	EB 5 SG	11 g a.i. ha ⁻¹	Nagare <i>et al.</i> , 2018 [64]	High mortality of 96 to 100 per cent
5	Red gram	Gram pod borer, <i>H. armigera</i>	EB 5 SG	11 g a.i. ha ⁻¹	Sudha Rani <i>et al.</i> , 2018 [4]	Effective in reducing the larval population
6.	Chick pea	Gram pod borer, <i>H. armigera</i>	EB 5 SG	11 g a.i. ha ⁻¹	Taimur <i>et al.</i> , 2018 [65]	Effectively reduced the pod damage
7.	Chick pea	Gram pod borer, <i>H. armigera</i>	EB 5 SG	11 g a.i. ha ⁻¹	Yadav <i>et al.</i> , 2018 [66]	Effectively reduced the pod damage and larval population
8	Sun flower	Capitulum borer, <i>H. armigera</i>	EB 1.9 EC	200 ml / acre	Muhammad <i>et al.</i> , 2020 [34]	Effective in reducing the larval population

3. Bioefficacy of emamectin benzoate against *Helicoverpa armigera* in horticultural crops:

Several scientist

evaluated the efficacy of emamectin benzoate against *Helicoverpa armigera* and presented below.

Table 2: Bioefficacy of emamectin benzoate (EB) against horticultural crop pests

S. No.	Crop	Pest	Formulation	Dose	Reference	Remarks
1.	Chilli	Fruit borer, <i>H. armigera</i>	5SG	3 g/10 Liter	Baikar and Naik, 2016 ^[46]	Effectively reduced the fruit damage
		Fruit borer, <i>H. armigera</i>	5% WDG	3 g/10 Liter	Sarkar and Rai, 2015 ^[70]	Effectively reduced the fruit damage
2	Okra	Fruit borer, <i>H. armigera</i>	5SG	3 g/10 Liter	Thara <i>et al.</i> , 2019 ^[44]	Effectively reduced the fruit damage
		Fruit borer, <i>H. armigera</i>	1.9 EC	3 g/10 Liter	Karthikeyan and Ayyasamy, 2018 ^[38]	Effectively reduced the fruit damage
3.	Tomato	Fruit borer, <i>H. armigera</i>	5SG	4 g/10 Liter	Taimur <i>et al.</i> , 2018 ^[65]	Effectively reduced the fruit damage
		Fruit borer, <i>H. armigera</i>	1.9 EC	4 ml /10 Liter	Khan <i>et al.</i> , 2019 ^[68]	Effectively reduced the fruit damage
		Fruit borer, <i>H. armigera</i>	5SG	4 g/10 Liter	Islam <i>et al.</i> , 2020 ^[1]	Very effective in reducing the fruit damage and larval population
		Fruit borer, <i>H. armigera</i>	5SG	4 g/10 Liter	Patil <i>et al.</i> 2020 ^[15]	Very effective in reducing the fruit damage and larval population
4.	Grapes	Fruit borer, <i>H. armigera</i>	5SG	4 g/10 Liter	Muthukrishnan <i>et al.</i> , 2012 ^[69]	Very effective in reducing the fruit damage and larval population

Conclusion

After reviewing findings of several researchers it can be concluded that gram pod borer, *Helicoverpa armigera* (Hübner) (Lepidoptera: Noctuidae) is polyphagous pest and it attacks a number of economically important crops both agricultural, horticultural crops and ornamental crop. It feeds on over 300 species belonging to 68 plant families around the world, including major crops. Now days, *H. armigera* management facing considerable challenges in many crops of the world. A critical review on various groups of chemical insecticides indicates that for the last five decades conventional insecticides, all neuroactive chemicals have played major role in management of insect pests in pulses, their indiscriminate uses led to several problems like resistance, residue, resurgence and safety to environment. The focus therefore shifted to search for and development of new green chemistries having novel biochemical targets in the context of pest control and resistance management. The novel groups of insecticides like emamectin benzoate is very effective at lower doses and have low risk to non-target organisms and environment, and their versatility in application methods. These important classes of new insecticides will certainly play a greater role in the present context of environmental safety and their consequent uses in integrated pest management and insect resistance management programmes. The main advantages of emamectin benzoate are ecofriendly, easily biodegradable, nontoxic to non target organisms and could be exploited for sustainable insect pest management of *H. armigera* in field and horticultural crops.

References

- Islam K, Tofazzal M, Howlader H, Ahmed KH. Management of *Helicoverpa armigera* (Hubner) infesting tomato using biopesticides under field condition and its effect on tomato yield. J Bangladesh Agricul Univ. 2020;18(1):1–5.
- Dinesh K, Anusha S, Bharu Singh R, Dangi NL. Estimation of avoidable yield losses caused by *Helicoverpa armigera* (Hubner) on chickpea. J Entomol Zool Stud. 2018;5(2):1476–8.
- Reigada C, Guimara KF, Parra JR. Relative fitness of *Helicoverpa armigera* (Lepidoptera: Noctuidae) on seven host plants: A perspective for IPM in Brazil. J Insect Sci. 2016;16(1):3.
- Sudha Rani D, Pradeep Kumar S, Venkatesh MN, Naga Satya CH, Anand Kumar K. Bio efficacy of insecticides against gram pod borer, *Helicoverpa armigera* in redgram. J Entomol Zool Stud. 2018;6(2):3173–6.
- Li C, Qinqin W, Haoliang Q, Qiyuan W, Huizhu Y, Changhui R. Resistance selection of indoxacarb in *Helicoverpa armigera* (Hübner) (Lepidoptera: Noctuidae): Cross-resistance, biochemical mechanisms and associated fitness costs. Pest Manag Sci. 2018;74:2636–44.
- Patil S, Goya B, Satish A, Ch S, Shiv IK, Mustapha B. Sustainable management of chickpea pod borer: A review. Agron Sustain Dev. 2017;37:20.
- Fite T, Tefera T, Negeri M, Damte T. Effect of *Azadirachta indica* and *Milletia ferruginea* extracts against *Helicoverpa armigera* (Hubner) (Lepidoptera: Noctuidae) infestation management in chickpea. Cogent Food Agric. 2020;6:1712145.
- Kassi AK, Javed M. Screening of okra cultivars for resistance against *Helicoverpa armigera*. Pak J Zool. 2018;50:91–5.
- Javed M, Majeed MZ, Sufyan M, Ali S, Afzal M. Field efficacy of selected synthetic and botanical insecticides against *Lepidopterous borers*, *E. vittela* and *H. armigera* on okra. Pak J Zool. 2018;50:2019–28.
- Junhirun P, Wanchai P, Thitaree Y, Torranis R, Opende K, Vasakorn B. The study of isolated alkane compounds and crude extracts from *Sphagneticola trilobata* (Asterales: Asteraceae) as a candidate botanical insecticide for lepidopteran larvae. J Econ Entomol. 2018;111(6):2699–705.
- Japur K, Naveena R, Hosamani AC. Bio-efficacy of emamectin benzoate 5-WG against pigeon pea pod borer, *Helicoverpa armigera* (Hub.) under field condition in steppe climate of HK region. J Environ Biol Sci. 2016;30(1):165–7.
- Puri SN. Present status of IPM in India. In: Proceedings of National Seminar on Integrated Pest Management in Agriculture. Annu Rev Entomol. 1995;51:255–305.
- Sarode SV. Sustainable management of *Helicoverpa armigera* (Hubner). Pestology. 1999;13(2):279–84.
- Thameur B, Ikbal C, Ali R, Asma L. Evaluation of a *Bacillus thuringiensis* isolate-based formulation against the pod borer, *Helicoverpa armigera* Hübner (Lepidoptera: Noctuidae). Egypt J Biol Pest Control. 2020;30(16):2–7.
- Patil PV, Pawar SA, Kadu RV, Pawar DB. Bio-efficacy of newer insecticides, botanicals and microbial against tomato fruit borer *Helicoverpa armigera* (Hubner)

- infesting tomato. J Entomol Zool Stud. 2020;6(5):2006–11.
16. Ahmad M, Bilal R, Munir A, Russell DA. Resistance and synergism of novel insecticides in field populations of cotton bollworm, *Helicoverpa armigera* (Lepidoptera: Noctuidae) in Pakistan. J Econ Entomol. 2019;112(2):859–71.
 17. Bird L. Genetics, cross-resistance and synergism of indoxacarb resistance in *Helicoverpa armigera* (Lepidoptera: Noctuidae). Pest Manag Sci. 2017;73:575–81.
 18. Lasota JA, Dybas RA. Avermectins: A novel class of compounds: Implications for use in arthropod pest control. Annu Rev Entomol. 1991;36:91–117.
 19. Govindan K, Gunasekaran K, Kuttalam S, Aiswariya KK. Bio efficacy of new formulation of emamectin benzoate 5 SG against bollworm complex in cotton. Indian J Plant Protect. 2010;38(2):159–65.
 20. Govindan K, Gunasekaran K, Kuttalam S. Emamectin benzoate 5 SG: A safer insecticide to coccinellid predators in cotton ecosystem. Afr J Agric Res. 2013;8(21):2455–60.
 21. Lammers JW, Macleod A. Report of a pest risk analysis: *Helicoverpa armigera* (Hübner); c2018. [Internet]. Available from: <http://www.fera.defra.gov.uk/plants/plantHealth/pestsDiseases/documents/helicoverpa.pdf>. Accessed [date].
 22. Hayden JE, Brambila J. *Helicoverpa armigera* (Lepidoptera: Noctuidae), the Old-World Bollworm. Pest Alert No. FDACS-02039. Florida Department of Agriculture and Consumer Services, Florida, USA; c2015.
 23. Vinoth KB, Kumaran N, Kubendran D, Kuttalam S. Bio-efficacy of flubendiamide + thiacloprid 480 SC against insect pests of tomato. Pestology. 2010;34(1):44–7.
 24. Rabindra RJ, Ballali CR, Ramanujan B. Biological options for insect pests and nematode management in pulses. In: Pulses in New Perspective. Masood Ali, Singh BB, Shiv Kumar, Vishwa Dhar, editors. Indian Society of Pulses Research and Development; c2004. p. 400–25.
 25. Krishna J, Naveena R, Hosamani AC. Bio-efficacy of emamectin benzoate 5-WG against pigeon pea pod borer, *Helicoverpa armigera* (Hub.) under field condition in steppe climate of HK region. J Environ Biol Sci. 2016;30(1):165–7.
 26. Priyadarshini G, Reddy NC, Reddy JD. Bioefficacy of selective insecticides against lepidopteran pod borers in pigeon pea. Indian J Plant Protect. 2013;41(1):6–10.
 27. Babar KS, Bharpoda TM, Shah KD, Jhala RC. Bio-efficacy of newer molecules of insecticides against chickpea pod borer, *Helicoverpa armigera* (Hubner). AGRES An Int J. 2012;1(2):134–47.
 28. Saxena KB. Genetic improvement of pigeonpea. Trop Plant Biol. 2012;1:159–78.
 29. Suneel Kumar GV, Sarada O. Field efficacy and economics of some new insecticide molecules against lepidopteran caterpillars in chickpea. Curr Biotica. 2015;9(2):153–8.
 30. Rai D, Ujagir R, Singh RK. The larvae parasitization by *Campoletis chlorideae* Wchida (Hymenoptera: Ichneumonidae) of *Helicoverpa armigera* (Hubner) in pure chickpea crop at Pantnagar. J Biocontrol. 2003;17:81–3.
 31. Biradarpatil KA, Jagginavar SB. Crop loss estimation due to capsule borer *Helicoverpa armigera* (Hubner) in safflower. J Pharmacogn Phytochem. 2018;7(4):151–4.
 32. Duraimurugan P, Regupathy A. Synergistic effect of *Bacillus thuringiensis* sub sp. Aizawai with synthetic pyrethroids against insecticides resistance *Helicoverpa armigera* (Hubner). J Biol Sci. 2005;5:678–80.
 33. Fakrudin B, Prakash SH, Krishnareddy KB, Kumar V, Badariprasad PR, Patil BV. Genetic variation of cotton bollworm, *Helicoverpa armigera* (Hubner) of south Indian cotton ecosystem using RAPD markers. Curr Sci. 2004;87:1654–7.
 34. Muhammad A, Muhammad KM, Muhammad Z, Sikander A, Muhammad WH, Kanwal H. Field evaluation of synthetic insecticides against capitulum borer (*Helicoverpa armigera*) infesting sunflower (*Helianthus annuus* L.). Pure Appl Biol. 2020;9(3):1800–6.
 35. Prasanna KN, Chakaravarth A, Kumar LV. Relationship between pheromone trap catches and field damage selected lepidopterous pest on vegetable crops. Pest Manag Horticult Ecosyst. 2013;15:63–7.
 36. Yengkhom SS, Ningthoujam K, Sonali Nakambam NS, Azad TT, Rajesh RKT, Balasubramanian P. Studies on the biology of *Helicoverpa armigera* on different semi-synthetic diet. J Entomol Zool Stud. 2019;7(1):709–12.
 37. Herald KP, Tayde AR. Biology and morphology of tomato fruit borer, *Helicoverpa armigera* (Hubner) under Allahabad conditions. J Entomol Zool Stud. 2018;6(4):1734–7.
 38. Karthikeyan R, Ayysamy R. Field efficacy of emamectin benzoate 1.9 EC against shoot and fruit borer of okra. Int J Entomol Res. 2018;3(2):164–7.
 39. Reddy KVS, Zehrm UB. Novel strategies for overcoming pests and diseases in India. Maharashtra Hybrid Seeds Co. Ltd., India; c2004.
 40. Talekar NS, Open RT, Hanson P. *Helicoverpa armigera* management: A review of AVRDC's research on host plant resistance in tomato. Crop Protect. 2006;5:461–7.
 41. Pareek PL, Bhargava MC. Estimation of avoidable losses in vegetables caused by borers under semi-arid condition of Rajasthan. Insect Environ. 2003;9:59–60.
 42. Tauseef KB, Muhammad H, Asad A, Qurban A, Khawar JA, Abrar A. Comparative bioefficacy of newer insecticides against tomato fruit borer, *Helicoverpa armigera* (Hubner) on tomato crop under field conditions. Pak Entomol. 2016;38(2):115–22.
 43. Swodesh R, Bhishma RD. Integrated management of fruit borer (*Helicoverpa armigera*) of tomato in Nepal. Acta Sci Agric. 2019;3(6):40–6.
 44. Thara KT, Sharanabasappa NRG, Kalleshwara SCM, Sandeep AR. Bio-efficacy of newer insecticide molecules against okra fruit borer, *Helicoverpa armigera*. J Pharmacogn Phytochem. 2019;8(1):2564–7.
 45. Kanwar N, Ameta OP. Assessment of loss caused by insect pests of okra (*Abelmoschus esculentus* (L.) Moench). Pestology. 2007;5:45–7.
 46. Baikaar AA, Naik KV. Efficacy of insecticides against fruit borer, *Helicoverpa armigera* (Hubner) infesting

- chilli under laboratory conditions. *Plant Arch.* 2016;16(2):890–2.
47. Ghosh A, Chatterjee ML, Chakraborti K, Samanta A. Field evaluation of insecticides against chilli thrips (*Scirtothrips dorsalis* Hood). *Ann Plant Protect Sci.* 2009;17:69–71.
 48. Ali A, Choudhury RA, Ahmad Z, Rahman F, Khan FR, Ahmad SK. Some biological characteristics of *Helicoverpa armigera* on chickpea Tunn. *J Plant Protect.* 2009;4:99–106.
 49. Kailash C, Bhowmick AK, Marabi RS, Das SB, Vivek ST, Mastkar A. Evaluation of bioefficacy of emamectin benzoate against gram pod borer (*Helicoverpa armigera* Hubner) and natural enemies on chickpea (*Cicer arietinum*). *Bull Environ Pharmacology Life Sci.* 2017;6(3):402–40.
 50. Torres VLM, Rodrigues M, Lacasa A. An unusual behaviour in *Helicoverpa armigera* Hubner (Lepidoptera: Noctuidae): pupation inside tomato fruits. *J Insect Behav.* 1996;9:981–4.
 51. Pearce SL, Clarke DF, East PD, Elfekih S, Gordon KHJ, Jermin LS. Genomic innovations, transcriptional plasticity and gene loss underlying the evolution and divergence of two highly polyphagous and invasive *Helicoverpa* pest species. *BMC Biol.* 2017;15:63.
 52. Burg RW, Stapley EO. Isolation and characterization of the producing organism. *N Z Vet J.* 1989;29:24–32.
 53. Lasota JA, Dybas RA. Abamectins as a pesticide for agricultural use. In: O-Noco Proceedings Symposium on Onchocerciasis, Leiden, Netherlands. *Acta Leidensia.* 1990;59(1&2):217–25.
 54. Wright DJ. Biological activity and mode of action of avermectins. In: *Proceedings. Neurotox.: Chichester, United Kingdom; c1985 .p. 85.*
 55. Turner MJ, Schaeffer JM. Mode of action of ivermectin. New York: Springer-Verlag; c1989. p. 73–88.
 56. Fritz LC, Waag CC, Gorio A. Avermectin B1a irreversibly blocks postsynaptic potentials at the lobster neuromuscular junction by reducing muscle membrane resistance. *Proc Natl Acad Sci USA.* 1979;76:2062–6.
 57. Kass IS, Stretton AOW, Wang C. The effects of avermectin and drugs related to acetylcholine and 4-aminobutyric acid on neurotransmission in *Ascaris suum*. *Mol Biochem Parasitol.* 1984;13:213–25.
 58. Scott R, Dwe I. Effects of 22, 23-dihydro avermectin B1a on locust *Schistocerca gregaria* muscles that involve several sites of action. *Pestic Sci.* 1985;16:599–604.
 59. Sami BP, Vaid A. Specific interaction of ivermectin with retinol-binding protein from filarial parasites. *J Biochem.* 1988;249:929–32.
 60. Dybas RA. Abamectin use in crop protection. In: *Ivermectin and abamectin.* Campbell WC, editor. New York: Springer-Verlag; c1989. p. 287–310.
 61. Strong L, Brown TA. Avermectin in insect control and biology: A review. *Bull Entomol Res.* 1987;77:357–89.
 62. Udikeri SS, Patil SB, Rachappa V, Khadi BM. Emamectin benzoate 5 SG, a safe and promising bio-rational against cotton bollworms. *Pestology.* 2004;28(6):78–81.
 63. Karthik P, Thiruveni T. Biological compatibility of emamectin benzoate 5 SG with commonly used agrochemicals on cotton. *Trends Biosci.* 2017;10(44):9131–5.
 64. Nagare RD, Mohammad I, Ambilwade PP, Savde VG. Bio-efficacy of different insecticides against ear head worm *Helicoverpa armigera* (Hubner) on sorghum at flowering stage. *Int J Entomol Res.* 2018;3(4):3–5.
 65. Taimur A, Rasool K, Tariq NK, Ayaz K, Ihsan U. Comparative efficacy of bio-pesticide and synthetic agrochemicals on control of *Helicoverpa armigera* larvae on chickpea. *RADS J Biol Res Appl Sci.* 2018;9(2):75–81.
 66. Yadav RKU, Chandra R, Veer A, Raj GCPN, Sachin K, Gajendra S. Relative efficacy of newer insecticides against gram pod borer, *Helicoverpa armigera*. *J Pharmacogn Phytochem.* 2019;8(4):599–601.
 67. Muhammad A, Khan KM, Muhammad Z, Sikander A, Muhammad WH, Kanwal H. Field evaluation of synthetic insecticides against capitulum borer (*Helicoverpa armigera*) infesting sunflower (*Helianthus annuus* L.). *Pure Appl Biol.* 2020;9(3):1800–6.
 68. Khan RR, Shaheen T, Majeed S, Ali A, Arshad M, AlMazidi ISS. Appraisal of biocidal efficacy of some selected biochemical and chemical formulations against *Helicoverpa armigera* (Hubner) in tomato crop. *Int J Zool Animal Biol.* 2019;1–10.
 69. Muthukrishnan N, Govindan K, Visnupriya M. Effect of emamectin benzoate 5 SG against thrips and fruit borer complex on grapevine. *Madras Agric J.* 2012;99(10-12):871–6.
 70. Sarkar PK, Rai P. Effectiveness of pre-mix formulation fipronil 15% + emamectin benzoate 5% WDG against thrips (*Scirtothrips dorsalis* Hood) and fruit borer *Helicoverpa armigera* (Hübner) of chilli. *J Entomol Res.* 2015;39(2):135–9.