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A Review on Synergistic Effect of Insecticides and Plants Extracts against Gram Pod Borer *Helicoverpa armigera* Hubner (Lepidoptera: Noctuidae)

Jagdish M. Mankar[1] and Bhimrao N. Jadhav [2]
Research Std., Department of Zoology, Deogiri College, Chhatrapati Sambhajinagar (MH), India[1]
Guide and Associate Prof., Department of Zoology,
Vinaykrao Patil College Vaijapur, Chhatrapati Sambhajinagar (MH), India[2]
*Corresponding author: mankarjm@gmail.com

Abstract: *Gram pod borer Helicoverpa armigera Hübner (Lepidoptera: Noctuidae) a globally widespread and cosmopolitan insect pest, causing estimated global economic losses of over 3 billion US dollars annually. Crops most affected include cotton, tomato, soybean, grain crops such as corn and sorghum, chickpea and other pulses. Adults of this species possess strong migratory abilities (>2000 km), high fecundity and rapid reproductive rates, completing 4–6 generations per year in most cropping regions. Yield losses of up to 90 percent may occur, contingent upon insect density and cultivar susceptibility. In instances of pod borer outbreaks, Various control measures have been tried or proposed for the treatment of this pest, including synthetic insecticides, Phyto pesticides, microbial pesticides, macro-biocontrol agents and the development of genetically modified crops (e.g. Bt cotton) are considered a last resort for farmers.*

However, Successful control necessitates and the use of an integrated pest management (IPM) approach, wherein biological, chemical and physical control measures are combined for the greatest control efficacy. In addition, multiple studies show that combination of chemicals and plant extracts is effective in the management Helicoverpa armigera and the combination of biological control methods have proven to be more efficacious, sustainable and environmentally friendly of chickpea pod borer.

Keywords: *Helicoverpa armigera*, Plant extract, *Insecticide; Management; Damage*

I. INTRODUCTION

Gram pod borer, Helicoverpa armigera (Hubner) (Lepidoptera: Noctuidae), is a highly polyphagous pest that attacks more than 100 plant species including economically important crops like cotton, tomato, pigeonpea, chickpea, tobacco, etc.
Potential risk: Helicoverpa armigera is considered one of the highest economically important lepidopteran pests globally (Hardwick 1965, Fitt 1989, Tay et al. 2013). Before the introduction and establishment H. armigera in Latin America, It was estimated to cause $2 billion annual yield losses to crops in continents like Africa, Asia, Europe and Australia (Lammers and Macleod 2007, CABI 2019). It is estimated that in India and China 50% of all insecticides used for pest management on crops targeted toward H. armigera. (Lammers and Macleod 2007). Annual economic losses from H. armigera in Brazil is estimated at $2 billion and is expected to increase as it establishes in new areas (Leite et al. 2014). It is estimated that H. armigera could threaten multiple crops collectively valued at approximately $78.3 billion in United States (Kriticos et al. 2015).
Pigeonpea [Cajanus cajan (L.) Millsp.] is a tropical grain legume mainly cultivated in the arid and semi-arid regions of the globe. India produces >78% of pigeonpea and represents about 6% of world's pulses production (FAOSTAT 2023, DAFW 2023). India produced about 4.3 million tonnes of pigeonpea from nearly 4.72 million hectares during 2021 (DAFW 2022). Pigeonpea (Cajanus cajan) is a vital source of dietary protein for more than one billion people across the

developing world. This versatile legume not only addresses nutritional needs but also sustains the livelihoods of millions of resource-poor farmers in Asia, Africa, South and Central America, and the Caribbean. Its resilience to harsh conditions and ability to enrich soil make pigeonpea an indispensable crop for food security and sustainable agriculture (Mir et al. 2014). The crop is reported to be infested by more than 250 insect species (Lateef and Reed 1990, Srivastava and Joshi 2011) and nearly 30 spp. of lepidoptera are found to feed on reproductive structures of the crop (Shanower et al. 1999). However, majority insects [Helicoverpa armigera (Hubner), Maruca vitrata (Fab.) and Melanagromyza obtusa (Malloch)] were described as major yield constraints (Srinivasan et al. 2021). The cultivated host plants, pigeonpea is highly favored by Helicoverpa armigera, which thrives particularly well on this crop (Rajapakse and Walter 2007) causing substantial yield loss in India. Economic crop losses due to H. armigera were estimated at $317 million/annum in pigeonpea (ICRISAT 1992, Ranga Rao and Shanower 1999). On average, 48% pod damage was reported at farmers' fields of Uttar Pradesh (Yogesh et al. 2016).

Economic Threshold Level (ETL) is a critical indicator that defines when pest infestation or crop injury reaches a point where yield losses are likely, signaling the need for control measures such as insecticide sprays. (Pedigo et al. 1986). Economic Threshold Levels (ETLs) for Helicoverpa armigera in pigeonpea have been reported by Goyal et al. (1990) as one larva per plant during flowering and podding stages. For the pod borer complex, Lal et al. (1992) suggested an ETL of 4–7% seed damage, while Sahoo and Senapati (2000) recommended 3.9 larvae per plant or 8.3% pod damage. According to Reddy (2001), infestation at the level of one larva per plant resulted in a reduction of approximately 4.95 green pods, 7.05 dry pods, 18.01 grains, 3.79 g pod weight, and 2.05 g grain weight per plant, with pod damage estimated at 5–7% at harvest. ETLs are dynamic and vary across years, fields, cultivars, crop stages, crop value, geographical locations, and management costs (Fathipour and Sedaratian 2013). Therefore, ETLs must be revalidated for the cultivars currently in use under prevailing agro-ecological and economic conditions. In this context, an experiment was conducted to quantify yield losses and estimate ETLs for H. armigera in the adopted cultivar IPA-203.

Chemical Control: Resistance development in Helicoverpa armigera is much faster and demonstrated strong tendency towards broad-spectrum insecticides, particularly against pyrethroids (Yang et al. 2013). It has developed resistance to 48 active ingredients representing most major insecticide classes and it ranks among the top 10 arthropod species with documented cases of insecticide resistance, (Sparks and Nauen 2015, IRAC 2020). Similarly, carbamate insecticides and organophosphate and also failed to provide complete control. However, newer classes of insecticides, including spinosyns, diamides, and growth regulators, did provide control of H. armigera (Perini et al. 2016, Durigan et al. 2017, Durigan 2018). These insecticides are also not broad spectrum in activity and could preserve beneficial arthropods. Adherence to IRM and IPM guidelines are the best management practices to prevent potential resistance development and extend the durability of these insecticides (Bueno et al. 2017, IRAC 2017). Use of insecticides with different modes of action with rotational use within a cropping season is also important to slow development of resistance of H. armigera (Pomari Fernandes et al. 2015, IRAC 2017, Ahmad et al. 2019).

Life cycle of Helicoverpa armigera:

This pest has a high regenerative potential since every female caterpillar can deposit 1,000 to 1,500 eggs, independently, on parts of plant 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 Chickpea and other host plants and 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 phases, which in summer require around 21 days, however, the period varies according 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).

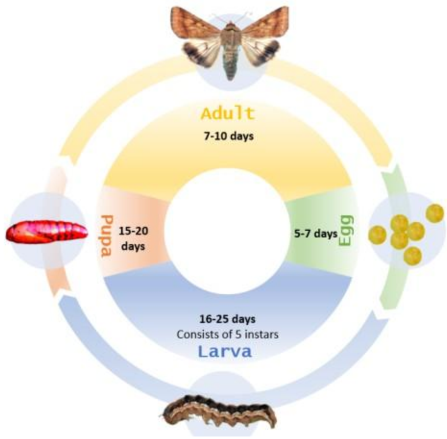

Figure 1. Lifecycle of Helicoverpa armigera (Genç and Yücel, 2017)

Description: The eggs are white to yellowish, brownish at hatching. Young caterpillars are pale green, but later instars are very variable in color (yellowish-green to dark brown) and markings. They become up to 40 mm (1.57 inch) long. The adults vary greatly, too; the forewings are yellowish to orange in females and greenish-gray in males, with a slightly darker transversal band in the distal third. The kidney-shaped marking is slightly distinct and smoky. The hind wings are pale gray with a broad, darker marginal band and a small, brown marking near the base spanning 35-40 mm (1.36 inch).

Damage by larvae: The voracious caterpillars of H. armigera can feed on leaves and stems, but they show a strong preference for reproductive organs such as buds, inflorescences, berries, pods, capsules etc. They bore into these parts, leaving large, round holes. Older larvae often enter the plant tissue with the anterior part of their bodies only. Young instars, however, may disappear completely inside, so they are sometimes not discovered before the produce (e.g. tomatoes) is processed. Secondary infections by fungi and bacteria are very common and they lead to rotting of fruits. Injury to growing tips disturbs normal plant development; maturity may be delayed, and fruits are often dropped.

There is significant potential for enhancing Chickpea yield by lowering production losses owing to major pests in the current situation. Gram pod borer, Helicoverpa armigera (Hubner), cutworm, Agrotis ypsilon (Hufnaga), semi-looper, Autographa nigrisigna (Walker) and aphid, Aphis craoccivora are the most common insect pests found on Chickpea (Koch).

Helicoverpa armigera (Hubner) is one of the most devastating pests of Chickpeas among all insect pests. From seedling through crop maturity, this bug causes damage to Chickpea plants. The primary hurdle to increasing Bengal gram production is the destruction caused by the pod borer, H. armigera (Hubner). H armigera is a polyphagous pest that feeds on over 181 plant species, including gram, Pigeonpea, tomato, okra, cotton and is anticipated to become a major pest on sorghum, pearl millet, maize, tobacco and peanuts (Manjunath et al., 1989). This insect bores into flower buds, blooms, and pods, resulting in a significant loss in production. A single H. armigera caterpillar can harm up to 40 pods in a Chickpea crop. The Chickpea pods are damaged by this insect to the tune of 50 to 60% (Mandal and Mishra, 2003).

The rationale for conducting research on H. armigera arises from its high reproductive potential, wide adaptability, migratory behavior, and ability to develop resistance against multiple classes of insecticides. The indiscriminate use of chemical control has led to serious ecological and economic concerns, including pesticide residues, resistance development, and decline of natural enemies. This situation highlights the urgent need for sustainable, eco-friendly, and cost-effective management approaches. Research on the pest's biology, population dynamics, host preference, and

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interaction with environmental factors will provide essential insights for designing integrated pest management (IPM) strategies tailored to Chickpea and Pigeonpea ecosystems.

II. MATERIAL AND METHODS

In this review article, research paper published from 1986 to 2025 (39 years) were searched using the keywords "Lepidoptera", Helicoverpa armigera life cycle, Insecticides and plant extracts this produced 15,400 articles out of 93 were selected for the analysis based on the current objectives.

III. RESULTS AND DISCUSSION

Pawar et al. (1986) reported the presence of 24 larval parasitoids and 4 egg parasitoids, along with one species of mermithid nematode, associated with Helicoverpa armigera. Additionally, 21 insect species and 5 spider species were recorded as predators of Heliothis. Egg parasitism was found to be negligible (0.30%), whereas larval parasitism reached 16.4%. Among natural enemies, the egg parasitoid. Gupta and Thakur (1990) conducted field experiments demonstrating that monocrotophos (0.05%), fenvalerate (0.01%), and endosulfan (0.08%) effectively controlled Helicoverpa armigera larvae. These treatments resulted in yield increases of 67–70% in November-sown crops and 103–113% in December-sown crops. Dong and Zahoo (1996) opined that azadirachtin has repellent, antifeedant, stomach and contact poison and growth inhibiting effects on many insect pests. It fulfills many of the criteria needed for natural insecticide if it is to replace synthetic compounds. Azadirachtin is safer to environment, and a natural product shows low mammalian toxicity. Puntambekar et al., (1997) reported that Bacillus thuringiensis subsp. kurstaki at 1010 and 108 spores/ml concentration was effective against the major lepidopteran pests comprising the pod borer complex of Pigeonpea (Cajanus cajan), viz. Helicoverpa armigera and Exelastis atomosa under the field trials. Total grain yield from these treatments was at least 1.5 times more than the untreated control. Sadawarte and Sarode (1997) investigated the efficacy of neem seed extract, cow dung, cow urine and combinations with and without insecticides to control H. armigera, E. atomosa and M. obtuse on Pigeonpea. Combinations of neem seed extract, dung and urine were moderately effective in controlling the pest complex but application of neem seed extract with insecticide was most effective. Prabhakara and Srinivasa (1998) reported that the Bt formulations (Biobit, Centari and Dipel) caused 58.72% mortality of third instar larvae of H. armigera after one day of application, while endosulfan and methomyl accounted for 82-90% mortality. The residual activity of Bt formulations decreased more rapidly as compared to that of endosulfan and methomyl. Singh and Singh (1998) reported that, the neem products viz., nimbecidine 0.05%, neemazal, neemgold and achook (WSP) proved safer to predatory coccinellids. Jeyakumar and Gupta (1999) noted that, NSKE 5% reduced oviposition of H. armigera in dose dependent manner during exposure periods of 0-24 and 24-48 hours and also showed oviposition deterrence effect at higher doses (10 and 7.5%). Kulat and Nimbalkar (2000) studied efficacy of HaNPV, Bt. k, NSKE 5% and endosulfan against H. armigera in Pigeonpea. Endosulfan treatment was found more effective in reducing larval population with least pod damage (16.23%) followed by HaNPV altered with endosulfan, Bt. k altered with endosulfan. Das et al., (2000) evaluated five botanicals and two bio-pesticides against H. armigera on Pigeonpea and reported that Endosulfan and Azadirachtin, Annona + Neem treatments were found effective against H. armigera with max yields. Sahoo and Senapati (2000) showed that, the occurrence of both nymphs and adults of mud wasps, spiders and praying mantids were recorded in the Pigeonpea. Giribabu et al., (2002) carried out an experiment during January-March, 1999 to evaluate the efficacy of test insecticides, viz., neem (3 ml and 5 ml), trizophos (700 g a.i./ha), chloropyrifos (400 g a.i./ha), monocrotophos (700 g a.i./ha), abamectin (15 and 20 g a.i./ha) against beneficial spiders on watermelon. Neem at both the concentration and abamectin at 15 g a.i./ha were found to be relatively safe insecticides. Ekesi et al., (2002) studied, ovicidal activity of eight isolates of entomopathogenic Hypomycetes against M. vitrata and Clavigralla tomentesicollis. At 1×108 conidia ml-1, four isolates Beauveria bassiana CPD 3 and 10, M. anisopliae CPD 5 and 12 were found very effective on eggs of M. vitrata and three isolates B. bassiana CPD 9 and M. anisopliae CPD 5 and 12 were found effective on Clavigrallatomen tesicollis with more than 90% egg, larval, nymphal mortality respectively. Borah and Dutta (2003) reported that, predatory spiders of H. armigera in Pigeonpea ecosystem were O. ratnae, O. shewta, Neoscona sp. and P. paykullii which appeared from flowering until maturity and at senescence. Yelshetty et al., (2003) were studied on Pigeonpea pod borer, two modules comprising biointensive and adaptive were compared with recommended package of practices. The adaptive

IPM module consisting of ovicidal application of profenofos 50EC at 1.00 kg a.i. Per ha, NSKE (5.00 percent), HaNPV 250LE per ha followed by alphamethrin 10EC at 0.050 kg a.i/ha and biointensive module consisting of application of HaNPV 250 LE/ha, hand collection, B. thuringiensis 1.00 kg/ha, NSKE 5.00 percent followed by HaNPV 250 LE/ha were found cost effective. Mandal and Mishra (2003) evaluated two insecticides (monocrotophos and endosulfan) and two biopesticides (Heli-cide and Dipel) alone and in combination during kharif 1997– 1998 in Umerkote, Orissa, for managing pigeonpea pests. Endosulfan + Heli-cide was most effective against Helicoverpa armigera but not against Maruca vitrata and Melanagromyza obtusa. The highest cost–benefit ratio was from endosulfan (7.60:1), followed by monocrotophos (5.72:1) and endosulfan + Dipel (5.15:1). Rao et al., (2007) evaluated efficacy of some insecticides and M. anisopliae against M. vitrata in Pigeonpea (cv ICPL 8805) and recorded that spinosad was found more effective with 82% reduction in larval population over control. Sunitha et al., (2008) evaluated certain eco-friendly and new insecticides against 3rd instar larvae of M. vitrata and reported that indoxacarb and spinosad were highly effective, two biopesticides Bt. and M. anisopliae were moderately effective and botanical pesticides were ineffective. C. Kamaraj et al., (2008) evaluated plant extract especially botanical insecticide are currently studied more because of the possibility of their use in plant protection. Biological activity of five solvent plant extracts was studied using fourth instar larvae of gram pod borer Helicoverpa armigera (Lepidoptera: Noctuidae), cotton leaf roller Sylepta derogata (Lepidoptera: Pyralidae) and malaria vector Anopheles stephensi (Diptera: Culicidae). Antifeedant and larvicidal activity of acetone, chloroform, ethyl acetate, hexane and methanol peel, leaf and flower extracts of Citrus sinensis, Ocimum canum, Ocimum sanctum and Rhinacanthus nasutus were used in this study. These results suggest that the chloroform and methanol extract of C. sinensis, ethyl acetate flower extracts of O. canum and acetone extract of O. sanctum have the potential to be used as an ideal ecofriendly approach for the control of the agricultural pests H. armigera, S. derogata and medically important vector A. stephensi. Ramya & Jayakumararaj (2008) found aqueous leaf extracts of 25 medicinal plants caused significant antifeedant activity and up to 78.9% mortality in Helicoverpa armigera larvae, suggesting eco-friendly pest control potential. Jayshri et al., (2008) tested insecticides against H. armigera, indoxacarb 14.5 SC was found most effective (0.58 larvae/plant) fallowed by neem seed oil 5 ml (1larvea/plant) and karang oil 5 ml (1.58 larvae/plant) the present finding are also according with the finding who reported that, the percent pod and grain damage by H. armigera was lowest with use of indoxacarb however these chemical insecticide was notice superior over the biopesticide. Waqas et al., (2008) A laboratory bioassay was conducted using 2nd and 4th instar of Helicoverpa armigera (Hübner) (Lepidopetera: Noctuidae) fed on chickpea, Cicer arietinum (L.), to determine the efficacy of neem (Azadirachta indica A. Juss) products. Neem leaf extract, neem seed kernel extract and neem oil were used alone and in combinations at the concentrations of 5% of each treatment. The 2nd instar larvae were more susceptible to the neem products and after 72 hours the maximum mortality (50%) was observed in the treatment where the neem leaf extract+neem seed kernel oil was used. This treatment gave 40% of the mortality of 4th instar larvae of H. armigera at the same exposure interval. Yankanchi S. and Sachinkumar R. Patil (2009) studied that, efficacy of four plant extracts such as Vitex negundo L. (Verbenaceae), Clerodendrum inerme (L.) Gaertn. (Verbenaceae), Lantana camara L. (Verbenaceae) and Eupatorium odoratum L. (Asteraceae) were evaluated against the diamondback moth, Plutella xylostella L. and the cotton bollworm, Helicoverpa armigera Hub. larvae on cultivated cabbage. Treatments with 1% V. negundo and C. inerme extracts significantly reduced P. xylostella larval density, and the percentage of infested plants, proving to be more effective than a standard insecticide Challenger 10 EC (cypermethrin). Treatment with L. camara extract (1%) reduced the percentage of H. armigera infested plants and the intensity of cabbage damage. Two plant extracts, V. negundo and C. inerme at 1% significantly reduced the P. xylostella larval density and proved more effective than Challenger. The intensity of cabbage damaged caused by P. xylostella was significantly lower in L. camara and C. inerme than control and Challenger. Byrappa et al., (2012) evaluated certain bio-pesticides, NSKE 5%, HaNPV, Bt, Neem oil, Panchagavya, Clerodendron + Cow urine extract against pod borers of fieldbean. NSKE- HaNPV- Bt sequential spray was found more effective and on par with chemical spray with high grain yield (10.01 q ha-1). Deepthy et al., 2010 evaluated that, Helicoverpa armigera is a major pest of several crops in India, traditionally managed with chemical insecticides that harm beneficial organisms and the environment. To develop an eco-friendly alternative, the study evaluated crude extracts of Vitex negundo leaves prepared using methanol, hexane, and ethyl acetate. Laboratory bioassays against second-instar larvae showed LC_{50} values of 4.03%, 4.05%, and 5.02% for ethyl acetate, hexane, and methanol extracts, respectively, indicating both polar and non-polar compounds are active.

Feeding activity and larval development were significantly inhibited, and egg-laying was reduced by up to 52.35% at 5% methanol extract. Ethyl acetate extract also affected egg fertility, and oviposition deterrence was observed in adults. Further tests on Spodoptera litura revealed methanol extract as most toxic, causing 96.3% mortality with an LD_{50} of 423 ppm. Growth parameters such as larval duration, pupal weight, and pupation were adversely affected, confirming insecticidal and growth-inhibitory properties of V. negundo extracts. Sreekanth and mahalakshmi (2012) evaluated different bio-pesticides against Helicoverpa armigera (Hubner) and Maruca vitrata (Geyer) on Pigeonpea. The percent inflorescence damage due to legume pod borer was lowest in spinosad 45% SC @ 73 g a.i/ha (4.74%), followed by Bacillus thuringiensis-1 @ 1.5 kg/ha (10.52%) and Beauveria bassiana SC formulation @ 300 mg/Lt (14.15%) as against control (24.79%). The pod damage due to Maruca was the lowest in spinosad (17.38%), followed by Bt.-1 (27.57%) and B. bassiana (33.82%) as against control (45.84%). Bhushan et al., (2011) studied the bioefficacy of certain biopesticides against pod borer, H. armigera in Chickpea and recorded NSKE 5% was found most effective in reducing larval population and pod damage with maximum cost benefit ratio. David (2008) evaluated that bio-pesticides based on baculovirus group, the nucleopolyhedrosis (NPV) offers great scope against H. armigera. In Asia, H. armigera has developed high levels of resistance to organochlorine, organophosphates and synthetic pyrethroids. Which resulted in control failures and lack of confidence in insecticides. The tremendous increase in pesticide use on Pigeonpea is alarming and emphasizes farmers' concern with insect pests. The trends also highlight the need for safe and eco- friendly management strategies. The difficulty in managing insecticide – resistant populations of H. armigera has given impetus to the development and use of alternative and has less negative impact on beneficial organisms than conventional insecticides. At present the alternative is the biopesticides i.e. NPV, B. thuringiensis and B. bassiana for its ecofriendly management. Khanpara et al., (2011) studied the dose response of Bacillus thuringiensis var. kurstaki on feeding and oviposition behavior of Helicoverpa armigera on Pigeonpea. They reported that lowest number of eggs and larvae were observed in 2.0 g / litre B. thuringiensis var. kurstaki treatment, which exhibited the feeding deterrent effect of B. thuringiensis var. kurstaki. Mazid et al., (2011) found Chemical pest control agents are extensively used all over the world, but they are regarded as ecologically unacceptable. Therefore, there is increased social pressure to replace them gradually with bio-pesticides which are safe to humans and non-target organisms. Biopesticides include a broad array of microbial pesticides, biochemicals derived from micro-organisms and other natural sources, and processes involving the genetic modification of plants to express genes encoding insecticidal toxins. Khanapara and Kapadia (2011) studied laboratory efficacy of biopesticides alone and in combination with insecticides against H. armigera. Endosulfan 0.007 percent and Bt. @ 1.0 kg/ha + endosulfan 0.0035% were found to be more effective treatments with 96.58% and 95.60% larval mortality, respectively. Krishna et al., (2011) evaluated 11 biocides against two pod borers, H. armigera and M. vitrata in black gram. Among all biocides Neemazal – F (0.1%), NSKE 5% were found more effective with 11.00 and 10.73 q ha-1 respectively. Reena Sinha et al., (2012) reported that application of mature karanj seed methanolic extract 2.5% may be incorporated into integrated pest management programmes to take care of H. armigera menace on crop plants. Kpindou et al., (2012) studied pathogenicity of six isolates of M. anisoplia and two isolates of B. bassiana against H. armigera under laboratory conditions. M 13 isolate of M. anisoplia, Bb 11 isolate of B. bassiana were found more virulent against H. armigera. Jawad ali Shaha et al., (2013) investigated that based on total yield and lower toxicity to the environment as well as human being neem seed extract is the most promising insecticide for the effective management of tomato fruit worm larvae. Garlic, turmeric and henge extracts proved ineffective in control of H. armigera. Patel and Patel (2013) carried experiment on bio-efficacy of newer insecticides against pod borer complex on Pigeonpea (Cajanus cajan (L.) Millspaugh) and found that among the various insecticides, chlorantraniliprole @ 30 g a.i./ha was the most effective insecticide against gram pod borer and blue butterfly, while profenophos 50 EC @ 250 g a.i./ha was the most effective insecticide against tur plume moth. Chlorantraniliprole 18.5% SC @ 30 g a.i./ha registered the lowest pod damage due to borer and pod fly and recorded the highest yield of Pigeonpea. Shah et al., (2013) Investigated that based on total yield and lower toxicity to the environment as well as human being neem seed extract is the most promising insecticide for the effective management of tomato fruit worm larvae. Garlic, turmeric and henge extracts proved ineffective in control of H. Armigera. Bandi and Naik (2014) evaluated different insecticides against major pod borers (gram pod borer, plume moth and pod fly) in Pigeonpea. The results revealed that the treatment sequence comprising of nimbecidine 0.03EC (3ml/l), HaNPV (250 LE/ha) and flubendiamide 480 SC (0.1 ml/l) was found promising against gram pod borer by recording least pod damage (21.33 and 19.52%) and grain yield (888 kg/ha) during both the years of study. Similarly, the pod damage by plume moth and pod fly was lowest in the sequence, nimbecidine 0.03 EC (3 ml/l)-Beauveria bassiana (2x108 spores/g) (2g/l)-flubendiamide 480 SC (0.1 ml/l) with a record of 7.51 to 9.59% and 6.67 to 6.78 respectively. Anitha and Parimala (2014) revealed that, Bt and Spinosad were highly effective in controlling spotted pod borer in Pigeonpea recording least pod damage (5.1%), least seed damage (4.3-4.5%), highest yield (1235-1237 kg/ha) and high B : C ratio (3.2). Neem oil and Metarhizium fared next better recording 8.2 - 8.6% pod damage, 8.1 - 8.6% seed damage, yield level of 1101 - 1123 kg/ha and B : C ratio of 2.4 - 2.5. 17. The percent pod damage by H. armigera varied significantly which was minimum (27.84%) in Spinosad 45%ww @73 g.ai/ha followed by B. bassiana WP @ 1.5 kg/ha (28.58%) and B. bassiana DOR SC @ 1.89 gm/lit (28.73%) in comparison to control (51.68%). Grain yield varied from maximum of 1200 kg/ha in Spinosad 45%ww @73 g.ai/ha followed by 1191.67 kg/ha in B. bassiana DOR SC @ 1.89 gm/lit as compared to 708.33 kg/ha in untreated control. Neelima et al., (2014) evaluated that methanolic extract of Among Artemisia annua (leaf, stem, seed extract) and essential oil treatments the larval weight was reduced by diet containing essential oil (69.71%) and leaf extract of A. annua (60.21%) as compared to control. Rahman et al. (2014) showed that percent infestation reduction over control was the highest in neem seed kernel extract (30.08%) followed by tobacco leaf extract (26.68%). The highest yield (18.14 t/ha) and highest MBCR (2.99) were also obtained from neem seed kernel extract treated fruits. War et al. (2014) found that combining neem oil (1%) with endosulfan (0.01%) showed 85.34% antifeedant activity and significantly altered midgut enzyme functions in Helicoverpa armigera, suggesting neem oil can reduce endosulfan use. Bajya et al., (2015) evaluated efficacy of B. bassiana against H. armigera in Chickpea and found that B. bassiana 1.15% WP (1×108 colony forming units/ml) 3000 g/ha and 2500 g/ha were found highly effective. Gautam et al., (2018) conducted experiment and founds significantly superior over control, indoxacrb (14.5 SC) performed best among the treatments followed by Neem oil. The effectiveness of treatment determined in the terms of grain yield of Chickpea obtained in different treatments revealed that the Indoxacarb @ 14.5 SC, Neem seed oil @ 5ml and karanj oil @ 5ml were significantly superior over untreated control. Indoxacarb 14.5 @ SC, gave maximum grain yield of Chickpea in compared to other treatments as well as in managing the population of H. armigera. Besides Neem seed oil @ 5 ml and karanj oil @ 5 ml were found the second and third most effective treatments respectively. Agale et al., (2019) reported that, all the selected bio-pesticides treatments were found safer to natural enemies which helped to increase the activity of natural enemies' population in Pigeonpea crop. Singh et al. (2019) found methanol extract of Lantana camara caused strong antifeedant activity, 100% larval mortality, and reduced fecundity in Helicoverpa armigera. Gabriel et al. (2020) showed Tithonia diversifolia extract caused up to 80% mortality and strong antifeedant activity in Helicoverpa armigera. Subiyakto et al. (2020) found that a mixture of neem seed extract (75%) and citronella oil (25%) at 1.25 mL/L effectively controlled Helicoverpa armigera and Spodoptera litura, offering an eco-friendly alternative to synthetic insecticides. Ali et al., (2021) concluded that, the use of botanical extracts is an alternative to synthetic insecticide as they are cheap, easily available and relatively safe to the natural enemies and other non- target species. Therefore, it is recommended to use different plant based indigenous botanical insecticides for the sustainable management of H. armigera in tomato and other crops. Hanif et al. (2021) found spinosad + Azadirachta indica extract caused up to 88.9% grub and 77.6% adult mortality of hadda beetle.

IV. CONCLUSION

Majority of lepidopterans, including the gram pod borer (Helicoverpa armigera), are foliage feeders. In an integrated management strategy for pod borer, the harmonious implementation of various measures and practices is essential. This holistic approach includes the development and cultivation of resistant varieties, adoption of sound agronomic practices, habitat manipulation, use of plant extracts and incorporation of biological control methods. Therefore, the preferred approach is Integrated Pest Management (IPM), which focuses on pest management rather than complete eradication.

The synthesis of IPM options—coupled with the cultivation of resistant varieties, adherence to optimal agronomic practices, utilization of biological control agents, judicious chemical control when necessary, and incorporation of plant extracts in combination with insecticides—collectively mitigate the adverse effects of insecticides on natural enemies within the ecological niche. This comprehensive strategy protects the ecosystem and the environment from potential toxicological hazards. The present review highlights the efficacy of an integrative approach using insecticides in combination with plant extracts for sustainable pod borer management.

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