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TOMATO FRUIT BORER *(HELICOVERPA ARMIGERA)* A PEST OF COSMOPOLITAN IMPORTANCE: A REVIEW

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ABSTRACT

A serious pest known as tomato fruit borer [*Helicoverpa armigera* Hubner (Lepidoptera: Noctuidae)] which is responsible for causing up to 14-100% damage as well as quality and quantity loss in tomato due to its regular occurrence from the vegetative growth to the fruit formation stage. Its management rely only on pesticides but indiscriminate use of pesticides resulted in many problems like residues, phytotoxicity, pesticide resistance, pest resurgence and secondary pest outbreak, in addition to causing side effects on non-targeted beneficial organisms and the environment. Sustainable approaches to diminish the incidence of fruit borer and accomplish sustainability in tomato production through the implementation of integrated approach involving host plant resistance, good agricultural practices (GAP), physical and biological methods are reviewed. This review highlights examples of successful management approaches from the past studies that were implemented in experimental trials and farmers' fields. The tactis can reviewed here be explored as reproducible practices for running the pest management programme at different locations with similar concerns. Integrated approach over the sole practices is the most effective for long-term sustainable management programs for fruit borer.
Keywords: *Helicoverpa armigera*, Tomato pest, Resistant varieties, Biorational control and IPM.

Introduction

Tomato (*Solanum lycopersicum* L.) is an important vegetable crop of the family Solanaceae/Nightshade, Solanoideae subfamily. Tomato is grown practically in every country of the world in polyhouses, greenhouses, net houses and outdoor fields, and it is the 3rd largest vegetable crop of the world next to potato and onion. Globally, tomato is grown over an area of 5.05 million hectares with a production of 186821216 tonns and productivity of 36.97 tonns per ha (FAOSTAT 2022). The major tomato producing countries (Fig. 1) are China (34.72%), India (11.01%), Turkey (7.06%), USA (6.54%), Egypt (3.60%), Italy (3.34), Iran (3.09%) and other *i.e.*, Spain (2.30), Maxico (2.21) and Brazil contribute (2%) (FAOSTAT, 2022).

Commercially grown tomato fruit can vary in colour, size and shape (OECD, 2017). The fruit of tomato contains a large quantity of water (93- 95%) and solid matter content ranges from 5.5-9.5%. of which about 1% is seed and skin (Frusciante, 2007). Nutritionally, 100gram tomato contains 18 calories, carbohydrates 2.19-3.55g, protein 0.9 grams, fiber 1.2 grams, fat 0.2 grams (Nasir *et al.,* 2015). Other elements like 48 mg calcium, 0.4 mg iron, 356 mg carotene, 0.12 mg vitamin B_1, 0.06 mg vitamin B_2 and 27 mg vitamin also found in each 100 g edible ripen tomato (Afreen *et al.,* 2017). Two main carotenoids are present in tomato *i.e.,* lycopene, (80-90%) and beta carotene (7-10%) which gives the fruit colour as red and orange, respectively.

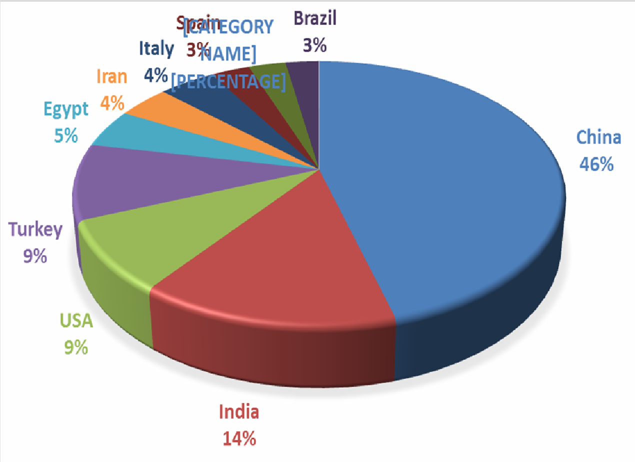

Fig. 1 : Major tomato-producing countries

There are ten different insect-pests reported as the main damaging pests of the tomato crop (Katroju *et al*., 2014). Among the different insects, *Helicoverpa armigera* Hubner (Lepidoptera: Noctuidae) is considered to be the most notorious: like other insect species. *H. armigera* ia a polyphagous (Manjunath *et al*., 1987) with host range of over 360 plant species (Lalruatsangi *et al*., 2010) including cultivated crops of economic importance (Duraimurugan and Regupathy, 2005). It is widely distributed in Asia, Africa, Southern Europe, Australia, Pacific, Philippines, Indonesia, Japan, Mediterranean region and Oceania (Guo 1997; EPPO 2006) except desert and very humid region (Singh, 1972) and in Brazil (Czepak *et al.,* 2013). The global distribution of this pest is shown in Fig. 2.

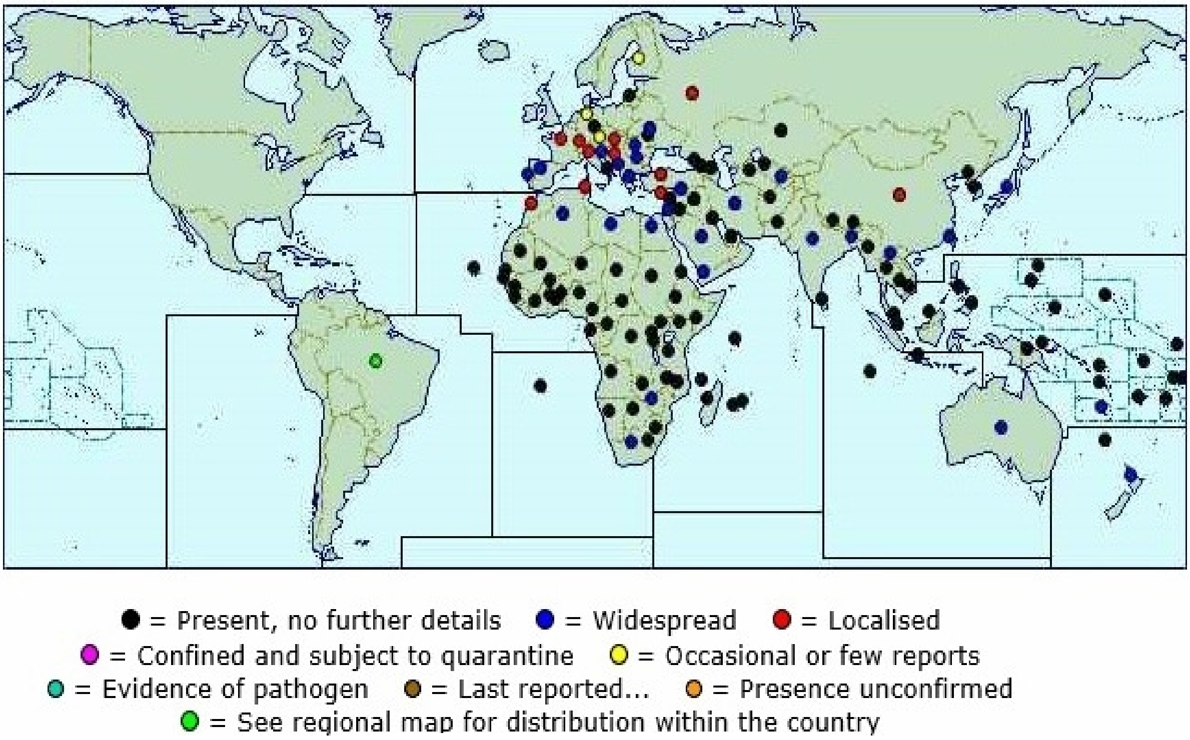

Fig 2: Distribution map of *H. armigera*

(Source: Image courtesy of http://www.cabi.org/cpc/?compid=1&dsid=26757&loadmodule=datasheet&page=868&site=161)

The tomato fruit borer is causing on an average 22–40% yield loss (Dhandapani *et al*., 2003) which may increase upto 100% under favorable condition (Ujagir, 1990; Sachan and Katti, 1994). The extent of damage to crops and the consequent losses in yield due to this pest varies considerably amongst varieties, crops, regions, locations and seasons (Wakil *et al*., 2010). Monetary losses result from the direct decline in crop yield and the cost of monitoring and managing pests. The monetary loss due to this pest in India has been estimated over one thousand crore rupees per year (Sharma, 2005). 14-100% yield losses in tomato have been documented in India (Yadav, 1980; Kakar *et al*., 1980), according to Kalita (2017), infestation and yield loss due to fruit borer was found more in tomato cultivated inside polyhouse (25.17- 28.46%) than open field condition (17.22-20.50%) in Sikkim. There are several reasons of global outbreaks of this pest including crop rotation with a similar host crop, introduction of new varieties, late sowing of crop, migration of pest from one crop to another crop and the excessive use of irrigation and fertilizer contributed (Hariri, 1981; White, 1987). Various worker has been reported yield loss in varius countries given in table 1.

Table 1 : Worldwide presence of *H. armigera*

Sr No	Countries	Yield loss	References
1	Bangladesh,	46.85 %	Alam *et al*., 2007)
2	Pakistan	12.30-37.69%	(Sajjad *et al*., 2011)
3	Nepal,	90%	Rijal and Dahal, 2019)
4	Brazil	US$ 0.8 billion	(Buen and Sosa-Gomez, 2014).
5	Spain	destined for industry	(Arno *et al*., 1999)

Biology of tomato fruit borer: A female can lay 730 to 1702 eggs, with a maximum of 4394 eggs within 10-23 days (Fowler and Lakin, 2001). Female lay egg singly and scattered, usually on or near leaflets, floral buds, or young fruit. They prefer to oviposit on hairy surfaces of plants with peak egg laying before or during host flowering (King, 1994). The eggs hatch in 3 days at 25°C and may take 10-11 days at low temperatures (CABI, 2016a). Upon hatching, neonate larvae are creamy white with dark brown or black heads with prominent spines on the body. Older larvae vary in color from pale green to brown to black with lateral stripes on the body. The larval period is about 15–25 days; there are six instars. Later larval instars are found singly on fruit or on other plant parts, as they are known to be cannibalistic (Kakimoto *et al*., 2003). Pupation occurs in the soil, and lasts about 10-14 days. Pupae are dark brown. The female moths typically emerge first during the season, and live longer than males. Males' adult of *H. armigera* are usually pale yellow with an olive-green color, while adult females are reddish-brown (Fig.3). Pearson (1958) reported that longevity varied from 1 to 23 days for males and 5-28 days for females, while Bhatt and Patel (2001) reported a lifespan of about 51 days for males and 54 days for females.

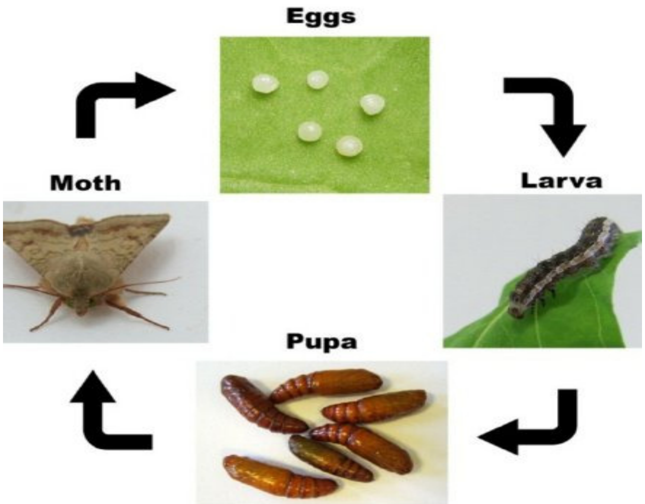

Fig. 3 : Life cycle of *Helicoverpa armigera* (source: infonet-biodivision.org and CABI 2013)

Management Approaches

Management of fruit borer mainly depends on different insecticides to manage fruit borer. Insecticides are costly and their excessive use has induced pesticide resistance, pest resurgence, and secondary pest out and caused environmental pollution (Cothran *et al*., 2013; Singh and Mandal, 2013). In view of the above point, it is necessary to bring sustainable/eco-friendly pest management practices such as breeding resistant varieties, varietal resistance, agronomic practices/cultural practices, mechanical control, biological control, biopesticides and integrated approaches etc.

Host-Plant Resistance: Developing resistant varieties provides a base to buildup an integrated control system against many insect-pests. The reduction in pest number by the use of resistant plants is steady and cumulative and incurs almost no additional cost to the farmers. Therefore, the breeding purpose should be to identify, characterize and utilize a genetic mechanism that confers a durable resistance to fruit borers (i.e., multiple factor resistance). Developing improved cultivars with resistance to fruit borer is straight forward tool if a good source of resistance is available and an efficient and practical screening procedure exists that can provide good selection pressure, adoption of standard selection procedures can be depends on the crop's reproductive system. Planting *H. armigera*-resistant tomato cultivars would reduce pest damage, however, commercial tomato cultivars with appreciable levels of resistance are not available. Germplasm screening at AVRDC in Taiwan revealed the presence of high levels of *H. armigera* resistance only in wild *Solanum* species, particularly *Solanum habrochaites* and *Solanum pennellii* Correll. Efforts on introgressing resistance from wild species into cultivated tomato resulted in resistant accessions, but with small fruits (Talekar *et al*., 2006). Leaves and fruits of transgenic tomato plants, that were transformed using a synthetic Cry1Ac gene coding for an insecticidal crystal protein of *Bacillus thuringiensis* (*Bt*) Berliner and highly specific to *H. armigera*, were demonstrated to be highly resistant to the larvae of *H. armigera* (Mandaokar *et al*., 2000). The first commercially produced genetically modified (GM) food crop was tomato, called as the *Flavr Savr* developed by Theh Calgene Company in 1992 with the two problems i.e., susceptible to bruising and bursting during transportation and handling and tasteless and less acceptable to consumers than the conventional types (Kato *et al*., 2010). Among other genetic studies, the GroEL homolog XnGroEL protein of *Xenorhabdus nematophila* in tomato (Kumari *et al*., 2015) and host-induced RNA interference (HI-RNAi) by chitinase genes were demonstrated to enhance resistance of tomato to *H. armigera* (Mamta *et al*., 2015).

Varietal resistance to *H. armigera*: Many screening experiment was conducted by scientists on tomato genotypes for resistance and tolerance to fruit borer (Canerday *et al*., 1969; Kashyap and Verma, 1986; Singh and Narang, 1990; Sundeep *et al*., 2000; Kumar 2002) and same sources of resistance to tomato fruit borer, *H. armigera* are given below in the table 2 and some described here Lalruatsangi *et al*. (2019) studied on 8 cultivars, out of the 8 cultivar, Selection-2 and MT-2 with low fruit borer damage (19%) were found to be useful in the breeding programs for fruit borer resistance during 2015 and 2016. Sajjad *et al*. (2011) evaluated thirty genotypes of tomato against fruit borer and observed that the percentage of fruit infestation and larval population per plant on tested genotypes of tomato varied significantly. Populations of larva were found in ranged 0.42 to 1.02 per plant with fruit infestation from 12.30 to 37.69%. Sahil, Pakit and Nova Mecb declared as resistant genotypes and could be used as a source of resistance for developing tomato genotypes resistant to tomato fruit borer. Silva *et al*. (2016) found that when resistance to the *H. armigera* was evaluated in tomatoes which obtained from the interspecific cross of *S. lycopersicum* × *S. galapagense*, the F_2 population genotypes, showing a high density of type IV glandular trichomes, showed higher resistance levels by both mean i.e., antibiosis and antixenosis than genotypes presenting low glandular trichome density. The study is in same line with the other workers (Zarea-Fizabady and Ghodsi 2004; Golabadi *et al*., 2006) who stated that higher density of trichomes (type IV and type VI) on tomato favour to increase resistance to *H. armigera*. Followings are the varieties of tomato tolerant/resistant to *H. armigera* developed by scientists of different countries indicated in table 3.

Table 2 : Characters with different resistance mechanisms in tomato

	Mechanism (s)	Character (s)
1	Antixenosis (non-preference)	Fruit shape and diameter, pericarp thickness, trichomes, leaf size
2	Antibiosis	Protein, vitamin C and E, fiber, potassium, folate (B_9), low fat, cysteine proteinase inhibitors, cellulose, hemicelluloses, lignin, lycopene, beta-carotene, naringenin, chalorogenic acid and carotenoid.
3	Avoidance (escape)	Earliness with cold tolerance

Table 3 : Sources of resistance to fruit borer, *Helicoverpa armigera* in Tomato

Location	**Tolerant/resistant genotype(s)**	**Reference**
India	*Lycopersicon hirsutum, f. glabratum*, WIR 402 and B 6013	Kashyap and Verma (1987)
	Tomato Royal FM and WIR 4285 and L274.	Sharma *et al*. (2003)
	Pusa early dwarf, Akra Vikas and Pusa Gourva	Gajendra *et al*. (1998)
	J.K. 25 and Prabhav	(Laxman, 2017).
	Solan Lalima	Thakur *et al*. (2017)
	Paiyur-1 and X-44	Sivaprakasam (1996)
Pakistan	Chinar, Sourabh and Sultan	Usman *et al*. (2013)
Bangladesh	BARITomato-1, BARI Tomato-4, BARI Tomato-10, BARI Tomato-11 and BARI Tomato-15	(Amin *et al*., 2016)
Nepal	Altair FI (90-5225), Mercur FI (90-5223), FI 958930	Gc *et al*. (1997)
	LA1310 and LA 1320	Rijal and Dahal (2019)

Cultural practices: Cultural manipulation is one of the elementary procedures which create hygienic condition in field that is unfavorable for pest development which include deep summer ploughing, time of sowing, seed rate, judicious and proper application fertilizers, weed and water management, inter/mixed cropping and trap crops etc. Few cultural practices illustrated below.

Sowing time: Sowing of crop at the optimum time is one of the most important factors influencing crop yield. Weather factors, such as maximum and minimum temperatures, maximum and minimum humidity, sunshine hours, rainfall and wind speed are important in regulating the fruit borer population. Several studies have been conducted by many scientists on the different crops which sown later, suffered most from the fruit borer infestation, as compared with that was sown earlier (Parihar and Singh 1986; Kethran *et al.*, 2014; Rahman *et al.*, 2017). Sharma *et al.* (1997) reported that seedlings transplanted on 28th March produce lowest yield of tomato due to high infestation by fruit borer as compare to seedlings transplanted on 27 April. Maximum borer infestation was reported at the end of March in each year and minimum was in January-February (Lal and Lal 1996; Gupta *et al.*, 1998) while in Haryana, Kalra (1992) registered the maximum borer infestation in May and infestation was comparatively low in early planted tomato but increased as planting of crop delayed by 15 days but in month of June the pest population has declined but fruits damage remained still quite high which might be due to the sharp reduction in fruit formation as the crop approaches maturity. Chakraborty *et al.* (2011) reported in late sown crop maximum damage was 24.43 per cent at 16 Standard Meteorological Week (SMW). It was observed that average incidence was significantly highest in late sown crop (17 per cent) and the lowest (7.65 per cent) in early sown crop. At Parbhani, Sapkal *et al.* (2018) observed similar trends under protected condition. Afreen *et al.* (2017) suggested that planting of tomato seedling at 10 December was found more effective for reduction of insect pest of tomato and also for highest yield (55.91 tonn per hactare) instead of planting at 25 December with no support also with lower yield (45.39 tonn per hactare).

Intercropping: Intercropping practice is of economic benefit and one of the best cultural practices that have potential of reducing insect pest infestation by increasing crop diversity (Willey, 1985; Trenbath, 1993). Effect of intercropping on pest problems have been reviewed by many authors (Vandermeer, 1989; Ogenga-Latigo *et al.*, 1993). Abad (2020) suggested that intercropping of tomato and Persian clover, especially in 1T : 2C and 2 T : 2C patterns are more profitable in tomato fruit borer management programs as compare to 3 T: 2C and 4 T: 2C (row ratio) as densities of tomato fruit borer's eggs and larvae were recorded lower in 1 T: 2C and 2 T: 2C. Degri and Samaila (2014) revealed that fruit borer larvae holes per plant was found minimum when tomato was intercropped with maize and maximum in sole crop tomato. Higher fruit damaged per plant and lower undamaged fruits were recorded in sole crop tomato than intercrop tomato and this supported the higher fruit weight and total fruit yield in intercrop tomato than sole tomato. This indicates that intercropping tomato and maize has a potential of reducing tomato fruit borer incidence (Patil *et al.*, 1997; Hugar and Palled, 2008: Degri *et al.*, 2014). Devi and Singh (2019) recorded border crops (maize, sesamum, broad bean, niger and buck wheat) in tomato field help in reducing the incidence and damage of fruit borer. And out of all border crops, maize as border crop recorded significantly lower incidence of *H. armigera* at 8.61 per percent than the other crops.

Traps crops: Traps crop are the crops grown in between the target main crop to attract insects or pathogens to protect the main crop insects. Pest reduction in main crop may be due to the preventing the pest from reaching the main crop and the pests are diverted away from the main crop (Shelton and Badenes-Perez, 2006). Trapping crops selected to grow should be attractive than the main crop and the space accommodation usually need to be minimum. Fast growing, early establishing natured trap crops can be selected. Several research has been done on trap cropping and several crops were used as trap crops such as marigold, okra, field bean, pigeon pea, chilli, brinjal, sunflower, and maize for the management of fruit borer, *H. armigera* (Hubner) on tomato crop (Srinivasan *et al.*, 1994; Sridhar *et al.*, 2001; Virk *et al.*, 2004), Hussain and Bilal, 2007) and mustard as trap crop in cabbage (Srinivasan and Moorthy, 1991). Therefore, the use of trap crops for the management of the fruit borer is of dominant importance in achieving sustainable production of tomato.

Bird perches: Birds are natural regulators of insect population and their mobility allows them to respond numerically to pest increase. In this respect, they look like insecticides and other catastrophes, which destroy a large proportion of insect-pest population quickly (Woods, 1974). Several species of insectivorous birds have been found to feed on crop insect-pests (Chakravarthy 1988), which have been known to reduce the larval population to the extent of 84% in Punjab, India. Among the predatory birds, *Acridotheres tristis, Cissa erythrorhyncha, Copsychus saularis, Corvus macrorhynchos, Dicrurus adsimilis, Parus major, Passer domesticus, Pycnonotus cafer, Pycnonotus leucogenys, Saxicola caprata and Turdoides striatus* were found feeding on *H. armigera* larvae in tomato crop. *P. cafer* and *A. tristis*, used the T- shaped perches more frequently than other species. In plots where T- shaped perches were installed, the larval survival was less in comparison to netted and control plots. Due to higher survival of larvae in netted plots less fruit yield (8.83 kg) was recorded in comparison to control plots (11.33 kg) (Mehta *et al*., 2010). Population of *H. armigera* larvae in perch control and netted plots were counted at weekly interval in 10 randomly selected plants and converted into percentage larval survival according to the Parasharya *et al*. (1996). Gregory and Sieving (2005) reported predatory birds like black drongo, house sparrows, blue jays, cattle egret, rosy pastor, and mynah have been commonly recorded as predators on large numbers of *H. armigera* and lepidopteran insect pests on vegetables, and pigeonpea, (Gopali and Lingappa, 2002a), groundnut (Patil *et al*., 2002) and cotton (Rao *et al*., 2002). Though the world is bestowed with a rich heritage of avian diversity (Ali and Dillon, 1983), the beneficial role of insectivorous birds in insect-pest management has not received much recognition beyond faunistic documentation. This is mainly due to the over dominance of broad-spectrum insecticides in the plant protection scenario (Gopali *et al*., 2007, 008).

Monitoring *Helicoverpa* through pheromone traps: Pheromone trap is an effective monitoring tool among various monitoring techniques and is one of the important components in the integrated pest management (IPM) (Samiayyan and Gajendran, 2009; Mahmudunnabi *et al*., 2013). Moth of *H. armigera* becomes active in March-April which coincides with fruiting period of tomato. Thus, monitoring of *H. armigera* in that period gives fruitful results. This approach of pest control has been studied extensively by many workers in tomato (Malik *et al*., 2003; Hussain and Bilal, 2007: Mohapatra, *et al*., 2007) in pigeonpea (Sandeep *et al*., 2017), and chickpea (Sharma *et al*., 2012). However, the pest monitoring is only trustworthy, if the relationship between the pheromone trap catches and the corresponding field population estimate are good and steady across time. Helicoverpa has been successufully managed using 50 pheromones traps /ha by Shah *et al*., 2017. Pheromone traps can be incorporated to develop predictive models designed to provide information on probable oviposition patterns, and population abundance of fruit borer of tomato.

Mechanical practices: Mechanical practices include handpicking of larvae, bagging of fruits, shaking of plant and exclusion device such as row cover, net, paper collar, fencing and other activities that disturb insect feeding and breeding. Handpicking is an easiest method for large size larva at the time of harvesting especially when a few plants are infested (Singh and Lal, 2011). Usman *et al*. (2015) tested IPM modules, the module M6 (Pheromone trap + Mechanical eggs destruction + T. chilonis @ 75000 parasitized eggs ha^{-1} (twice at weekly interval) + Chlorantraniliprole @ 80ml $acre^{-1}$) as one of the components, was found to be most effective, with lowest fruit damage (5.74%). Moreover, fruit bagging has proven to be an effective technique in preventing the infestation by borers, especially in vegetables including tomato (Leite and Fialho, 2018). Filgueiras *et al*. (2017) studied bagging of tomato flowers and/or fruits using a non-woven fabric (NWF) for the control of *Helicoverpa* spp., and found effective but these techniques (i.e. hand picking and fruit bagging) are not feasible in many country as they are time consuming and costly.

Biological control: Utilization of natural enemies of insect like predators, parasites and pathogens by man to manage pest population below economic injury level is called biological control of insect. It is safe and eco-friendly approaches, and in the absence of chemical insecticides, natural enemies, like predators and parasites have the potential to manage *H. armigera* populations at the sub-economic levels (King and Jackson, 1989). The predators (at least 127 species) are generalised in 7 orders of arthropods (Araneae, Coleoptera, Dermaptera, Hemiptera, Hymenoptera, Mantodea, and Neuroptera) with most of the species occurring in Hemiptera and Coleoptera. Predators primarily attack eggs and larvae are three species of family Carabidae and Labiduridae attack the pupal stage, and two species of spiders have been reported to prey on the adult stage of *H. armigera* (Ahmad, 2003). Near about 382 parasitoids emerged from *H. armigera* larvae were collected from tomato farmers' fields. They were classified into Hymenoptera-Braconidae (331), Hymenoptera-Chalcididae (1), Hymenoptera-Eulophidae (10), Hymenoptera- unidentified parasitoids (32), or Diptera-Tachinidae (8) (Diatte *et al*., 2018). Egg parasitoids (*Trichogramma pretiosum* Riley) and larval parasitoids (*Campoletis chlorideae* Uchida) can be conserved and/or released in tomato fields at regular intervals to control the buildup of *H. armigera* population (Romeis and Shanower, 1996). An experiment was conducted in Ranchi, Bihar (India) to determine the effect of IPM modules on tomato pests and diseases. Two releases of *T. pretiosum* at 100,000 parasitized eggs/ha at 15-day intervals was found to be effective (Kumar *et al*., 2003) and five releases of *T. pretiosum* at 50,000/ha weekly was found effective against *H. armigera* in tomato crop (Singh *et al*., 2003; Vijayalakshmi, 2007). During an investigation carried out in Karnataka (India), an IPM module consisting of *T. pretiosum* (45,000/ha) as one of the components was found to be significantly superior to the rest of the modules, such as farmers' practice, insecticides tested in restricting the larval population of *H. armigera*, lowering fruit damage (11.87%), increasing marketable fruit yield (224.56 q/ha), and yielding additional net profit (Rupees 22,915/ha). Kumar *et al*. (2004) conducted an experiment on evaluation of *Trichogramma chilonis* Ishii, *T. pretiosum* and *Trichogramma brasiliense* Ashmead at three different dosages (50,000, 75,000 and 100,000/ha) against *H. armigera* (Hiibner) on tomato and significant difference was observed in larval population and lowest mean larval population (0.5 larvae/5 plants) and highest parasitism (41.07%) was recorded in *T. chilonis* @ one lakh/ ha dosage. Highest (261.07q/ha) yield was from treatment of *T. chi/onis* @ one lakh/ha, followed by *T. chi/onis* 75,000/ha (248.27q/ha). A study was undertaken by Karabhantanal *et al*. (2005) to determine the efficacy of *T. pretiosum* (five releases weekly at 50,000/ha) as a component of IPM for the management of the tomato fruit borer, *H. armigera* and recorded egg parasitism was very high (36.32–61.00%) in plots where *T. pretiosum* was released as compared to other components. In Tamil Nadu (India), Amutha and Manisegaran (2006) evaluated *T. chilonis* released six times at weekly interval and recorded minimal *H. armigera* damage (10.0%), the highest yield (29.90 t/ha), with highest CBR (1:2.99) compared with insecticides alone. In Uttar Pradesh (India), safer management tools against major insect pests of tomato and garden pea were evaluated and it was found that four releases of *T. chilonis* at 50,000/ha at 10-day intervals from the flower initiation stage was most promising (Sushil *et al*., 2006). The augmented release of *T. chilonsis* @ 30 cards/ha (Gouli, 2008), *T. chilonis* released at 130,000/ha (Khan, 2011) was found effective against *H. armigera* in tomato crop. Abbas *et al*. (2020) in experiment used 16000 eggs (T1), 14000 eggs (T2), 12000 eggs (T3) of the parasitoid *T. chilonis,* per hectare in tomato against *H. armigera.* The maximum fruit yield (5533.1 kg ha^{-1}) was recorded in T1 (16000 tricho release) followed by T2 (14000 tricho release) and T3 (12000 tricho release) which gave 4820.6 and 4735.8 kg ha^{-1} fruit yield respectively. The lowest fruit yield of (2820.5 kg ha^{-1}) was found in control treatment (T4) where no trichocards were installed. Significant increase in tomato fruit yield as compared to control (T4) might be due to the effectiveness of *T. chilonis*. in parasitizing the eggs when released in higher population parasitized the host very efficiently. Similar results were obtained by Usman *et al*. (2012), Jalali *et al*. (2016) and Sharma *et al*. (2016) who reported that maximum number of tricho-eggs installed in field gives minimum infestation of fruit borer and maximum yield. Bagheri *et al*. (2019) studied the treatments consisted of releasing *Habrobracon hebetor* (Say), *Trichogramma evanescence* Westwood and combination of *H. hebetor* + *T. evanescence* (HABROBRACON-TRICO). The results revealed significant differences in the number of infested tomato fruits among treatments and harvesting times. The infested fruits were the lowest (2.68 ± 0.14%) in plots treated by habrobracon-trico. Moreover, the highest (3.36 ± 0.50%) and the lowest (2.88 ± 0.22%) damaged fruits was recorded in the second and fourth harvesting times, respectively. Diatte *et al*. (2018) studied on parasitoid control of the tomato fruitworm, *H. armigera,* in small land holder farmer fields in Senegal and revealed that the parasitoid species, *Meteorus laphygmarum* Brues was highly dominant with 80.1% occurrence. Among emerged wasps, *Euplectrus* sp. is a gregarious parasitoid and 1–3 wasps emerged from one parasitized larva.

Biopesticides: *Helicoverpa armigera* has developed resistance to multiple classes of chemical/inorganic insecticides (Qayyum *et al.*, 2015a). However, commercially available biopesticides based on *Bacillus thuringiensis* (Bibi *et al*., 2013), *Helicoverpa armigera* nucleopolyhedrovirus (HaNPV) (Jayewar and Sonkamble, 2015), *Beauveria bassiana* (Shah and Pell, 2003) and neem (*Azadirachta indica*) (Yadav *et al*., 2015) can be used against *H. armigera* in tomato crop.

Bacterial-based insecticides: *Bacillus thuringiensis* (Bt), a gram positive and spore forming bacterium, which is the most widely used microbial agent to control insect pests of agriculture, forestry and even in public health. The *Bt* toxins are chemical free, eco-friendly, and highly specific against target insects due to the presence of specific receptors in the midgut, while being non-toxic to beneficial insects and vertebrates owing to the lack of the receptors for toxin interaction and binding (Pigott and Ellar 2007; Bravo *et al*., 2011). Various *Bt* strains produce different pesticidal protein toxins which are used as insecticides and have specific host range and used for the control of *helicoverpa* population (Fortier *et al*., 2007; Pigott and Ellar 2007; Wade *et al*., 2020). Several authors studied the effect of *Bt*-toxins with different formulations such as Biolep, Dipel, Lipel etc., for the management of *H. armigera* in tomato crop, other crops and recorded good results (Paneru and Aryal, 2004). The application of *Bt* toxins for insect pest resistance could be a powerful tool as it is highly specific against target insect (Kumar and Kumar 2004, Devi *et al*., 2014). The transgenic *Bt* tomato plants expressing a Cry1Ab protein of *B. thuringiensis* suffered significantly lower damage by *H. armigera* than the non-transgenic control plants in the laboratory, greenhouse and field. The modified truncated *Bt- Cry1Ab* gene of *B. thuringiensis* has been used for the development and selection of over expressing transgenic events in a commercially important variety of tomato by *Agrobacterium*-mediated leaf-disc transformation procedure (Koul *et al.* 2014). Kumar *et al.* (2017) studied the bio-efficacy of different insecticides against fruit borer in tomato and reported *B. thuringiensis* @25 g a.i. per hectare against *H. armigera* proved to be effective. Sathish *et al.* (2018) revealed that the 25.40 per cent fruit damage in *Bt var kurstaki* as compared to untreated check (53.40%) in bringing down the fruit infestation. Sajjad (2011) conducted an experiment on various control methods in which *B. thuringiensis* @ 2 kg/ha, was used alone and in combination with other practices, and revealed *B. thuringiensis* treated plots gave better results for the management of *H. armigera* in tomato crop. Prabhukarthikeyan *et al.* (2014) worked on a bioformulation containing a mixture of *Beauveria bassiana* (B2) and *Bacillus subtilis* (EPC8) was tested against *Fusarium* wilt and fruit borer in tomato under glasshouse and field conditions. The bioformulation with B2 and EPC8 isolates effectively reduced the incidence of *Fusarium* wilt (*Fusarium oxysporum* f. sp. *lycopersici*) and fruit borer *H. armigera* under glasshouse and field conditions compared with the individual application of B2 and EPC8 isolates and control treatments. Wade *et al.* (2020) revealed that among the different treatments, effect of *Bt* @ 1.5ml per literon fruit borer of tomato infestation on number and weight basis were lowest by (17.74% number and 15.86% on weight basis), followed by *Beauveria bassiana* @ 5ml/lit (22.67% number and 20.75% on weight basis), *Metarhizium anisopliae* @ 5ml per liter (25.36% number and 23.18% on weight basis), *Lecanicillium lecanii* @ 5ml per liter (29.67% number and 27.18% on weight basis). On the basis of yield, in *B. thuringiensis* plot yielded highest was 30.75 t/ ha followed by *B. bassiana* @ 5ml per liter (30.36 t ha-1) and *M. anisopliae* @ 5ml per liter (29.35 t ha-1).

Virus-based insecticides: A wide variety of viruses have been identified for their characteristic to kill insect hosts. More than 350 viruses cause disease to 400 arthropod species. Many viruses have been identified in insect hosts such as baculoviruses (large, covalently closed, circular DNA genomes), poxiviruses (large, covalently closed DNA genome); cytoplasmic polyhedrosis viruses (segmented, double stranded RNA genome); picornaviruses (small, single-stranded RNA genome). But, Baculoviruses are most infectious only to insect hosts and this makes them useful as insect biocontrol agents (King and Possee, 1994). The best-known virus for management of fruit borer is *Helicoverpa armigera* Nuclear Polyhedrosis Virus (HaNPV) (Jones *et al.*, 1998). However, their application has been limited because HaNPV is more susceptible to inactivation by various environmental factors like UV spectrum of solar radiation and leaf pH and competition from other effective and quick biorationals. Elamathi *et al.* (2012) tested the HaNPV for its insecticidal action against *H. armigera* in natural and artificial diets. The bioassay results of inoculated *H. armigera* nucleopolyhedrosis virus (HaNPV) with different concentrations indicate that the 4.0 g/l dosage caused maximum mortality (70.3% and 60.54%), and minimum mortality 46.83% and 44.08% was recorded in the 0.5 g/l dosage under laboratory and pot culture conditions, respectively. Singh (2001) has advocated the applications of HaNPV at 250 LE/ha for successful management of this pest in tomato. Kalita *et al.* (2017) reported HaNPV @ 1 ml/l also showed effective result which was at par with Spinosad 45 EC. Deb and Barpoda (2017) studied on biopesticides, spinosad 45 SC @ 0.025 per cent proved to be most effective treatment by recording lower infestation of *H. armigera* in terms of egg (0.73/3 twigs), larvae (0.36/3 twigs), fruit damage (7.68%) with higher tomato fruit yield (179.50 q/ ha) and net realization (65,120/ ha) without interfering natural enemies followed by *Ha*NPV @ 250 LE/ ha and Neemazal 5 EC @ 0.1%. However, Patil *et al.* (2018) studied the bio-efficacy of biopesticides against tomato fruit borer *H. armigera* (Hubner) infesting tomato and reported HaNPV (250 LE/ha) was least effective as compared to other biopesticides.

Fungi based insecticide: The entomopathogenic fungi are used for causing disease in insects. There are 400-500 species of fungi known to have insect pathogenic properties (Whitten and Oakeshott, 1991; Starnes *et al.*, 1993). Among the various entomopathogenic fungi, *Beauveria bassiana*, *Lecanicelium lecanii*, *Metarrhizium anisopliae, Nomuraea rileyi, Hirsutella thompsonii and Paecelomyces fumosoroseus* has been used for the control of wide range of insect pests (Lepidoptera, Homoptera, Hymenoptera, Coleoptera and Diptera) (Shahid *et al.*, 2012). But entomopathogenic fungi, *B. bassiana* is used extensively for the control of insect pests especially *H. armigera* (Sandhu *et al.*, 2001; Shah and Pell 2003). There are several studies emphasized by many workers and found successful results of reducing the larvae of fruit borer in tomato crop. Although, entomopathogenic fungi are unlikely to capture any major part of the pesticide or biopesticide market but they do have a future in specialized applications and integrated approaches to control insect pests. The entomopathogenic fungi, *B. bassiana* and *M. anisopliae* could be effectively used as pest management option in production of tomato to reduce the *H. armigera* population and increased yield (Raijal *et al.,* 2008; Wraight *et al*., 2010). Prabhukarthikeyan *et al*. (2013) studied on fifteen isolates of *B. bassiana* were isolated from soil and infected insects collected from different places. These isolates were tested for their efficacy against tomato fruit borer. Among the 15 isolates, B2 (Arachalore) isolate caused 73.33 per cent mortality of *H. armigera* under in vitro conditions. The results of Devi *et al*. (2014) showed *B. bassiana* (11.01%) and *V. lecanii* (11.41%), respectively providing highest fruit protection of tomato against *H. armigera* over control. Phukon *et al* (2014) revealed the reduction in fruit damage by *H. armigera,* was upto 92.20 per cent in cypermethrin treated plot followed by 91.12 per cent, 88.74 per cent and 87.01 per cent in the plots treated with Neem oil, *B. Bassiana* and *M. Anisopliae*, respectively. Sathish *et al*. (2018) revealed that 32.10 per cent tomato fruit damage in *M. anisoplea* treatments was compared to untreated check (53.40%) in bringing down the fruit infestation. Wade *et al*. (2020) revealed that among the different biorational insecticide treatments, effect on fruit borer of tomato infestation on number and weight basis were lowest by *B. bassiana* @ 5ml per liter (22.67% number and 20.75% on weight basis), followed by *M. anisopliae* @ 5ml per liter (25.36% number and 23.18% on weight basis), *L. lecanii* @ 5ml per liter (29.67% number and 27.18% on weight basis) and *Pongamia pinnata* 2 EC @ 0.1 per cent (30.27% number and 27.85% on weight basis). Patil *et al.* (2018) in his study used *M. anisopliae* 1.15 WP and *B. bassiana* 1.15 WP against tomato fruit borer *H. armigera* (Hubner) infesting tomato.

Plant based extracts: Botanical insecticides are often slow acting crop protectants that are usually safer to humans, non-targeted pests and environment than conventional pesticides (Mehta and Sood 2010; Chauhan *et al*., 2013). The most well-known and commonly used plant extract is azadirachtin which is isolated from the wood, bark, seed, leaves, and fruits of the neem tree (*Azadirachta indica*). Azadirachtin, salanin and meliantriol are chemical compounds found in seed kernel of neem which attributes bitter principle; thus, they show deterrents and adverse effects on *H. armigera* (Hegde, 2004). Neem derivatives works as a repellent, growth disturbance, antifeedants and act as deterrents of oviposition for *H. armigera* in tomato crop, studied by many workers (Mamoon-Ur-Rashid *et al.,* 2012; Rahman *et al*., 2014; Sherad and Kalyan, 2014; Matharu and Mehta, 2016) and it has growth retarding properties and can lead to death at any stage in the life cycle, probably by interfering with the neuroendocrine control of metamorphosis in insects. *Mustafiz et al*. (2015) revealed that tomato fruit infestation reduction was estimated highest (69.71%) infestation reduction over control from the treatment neem oil and the lowest value (18.59%) recorded from the treatment neem leaf extract. From the findings it is revealed that treatment Neem oil has maximum healthy fruit and lowest % of fruit infestation in weight whereas in control treatment the situation is reverse. Thakur *et al*. (1998) also reported that neem seed kernel extract (NSKE) @ 5% gave an effective control of *H. armigera*. Moreover, *Vitex negundo* methanol, *Acorus calamus* methanol, *Adhatoda vasica* Methanol, and Aloe vera extract are the plant extracts. Vitricin, flavonoid-penducularisin, negundoside and adhavasinone active ingredient found in leave extract of *V. negundo* and *A. vasica* (Rastogi and Mehrotra 1993), and β-asarone, cis-asarone, trans-asarone and acoramone are present in the rhizome extract of *A. calamus* (Balasubramanian *et al*., 2008; Sahare *et al*., 2008; Patil and Chavan, 2010; Kumar *et al*., 2013; Singh and Nongmaithem, 2013), reduced the maximum larval population of *H. armigera*. Mallapur and Ladaji (2010) also reported that the 56 per cent reduction of *H. armigera* population in the treatment of *V. negundo*, *A. indica* and *Aloe vera* extract. Yankanchi and Patil (2009) found that leaf extract of *V. negundo* @ 1% significantly reduces the larval population of *H. armigera*. Kumar and Prasad (2002) similarly reported the 5% extracts of *A. indica*, *A. calamus*, *V. negundo* and *A. vasica* caused high mortality against *H. armigera*. Raja *et al.* (2005) found that β-asarone, cis-asarone, trans-asarone and acoramone are biological active substances present in the rhizome extract of *A. calamus.* Similarly, vitricin, flavonoid-penducularisin, negundoside and adhavasinone active ingredient found in leave extract of *V. negundo* and *A. vasica* by Rastogi and Mehrotra (1993). Field efficacy of botanical insecticides obtained from *Acorus calamus* (rhizome), *Vitex negundo* (leaves), *Adhatoda vasica* (leaves) and *Dioscorea deltoidea* (tuber) was tested against *H. armigera* on tomato. Amongst the all-tested extracts, hexane extract of *A. calamus* caused 48.91% mortality followed by hexane extract of *V. negundo* (42.75%), ethyl acetate extract of *A. calamus* (36.54%) and hexane extract of *A. vasica* (36.14%) at 5% concentration. Therefore, the use of botanical insecticides has been recommended more as a suitable alternative of chemical/inorganic plant protection methods with minimum negative effects (Isman, 2006; Pavela, 2007).

Integrated management practice: At present, concerns related to environmental pollution, human health, pesticide residue in food commodities, pest resurgence and pest outbreak are a result of the inappropriate use of synthetic pesticides/insecticides. Host-plant resistance, biological control agents (like predators and parasitoids), biorational insecticides, pheromone traps, mechanical control and all agronomic practices recommend opportunity for integrated pest management (IPM). These practices are relatively safe for non-target organisms, natural enemies, and human beings. When these practices used alone does not give more good results but when used in combination as integrated form gives better results. Report of Nazim *et al*. (2002) revealed that about 75% control of *H. armigera* larvae is possible by mechanical control following every alternate day during marble size tomato to before ripen period but its result could be better by combination of two techniques i.e., mechanical method + spraying of botanical pesticides. Brar *et al*. (2003) concluded from their study that the treatment combination of *T. pretiosum* + *H. armigera* nucleopolyhedrosis virus (HaNPV) + endosulfan was the most effective for *H. armigera* control. In Tamil Nadu (India), Praveen and Dhandapani (2003) studied the sustainable modules comprising the release of *T. chilonis*, *Chrysoperla zastrowi sillemi*, *B. thuringiensis*, and *Ha*NPV in tomato crop. This module effectively controlled *H. armigera* with higher fruit yield (23,292 kg/ha) than untreated control (13, 689 kg/ha) with higher CBR (1.00:3.21). Similarly, Karabhantanal *et al*. (2005) studied effective IPM module composed of trap crop (15 rows of tomato: 1 row marigold) + *T. pretiosum* (45,000/ha) + NSKE (5%) + HaNPV (250 LE/ha) + endosulfan 35 EC (1250ml/ha) was significantly superior in restricting the larval population of *H. armigera* in tomato with highest net profit (Rs. 22915/ha) as compare to the module comprising of *T. pretiosum* + HaNPV with net profit of only Rs. 10080/ha. Tyagi *et al*. (2010) used four sprays of *B. thuringiensis* at 1 kg/ha with release of *T. pretiosum* at 50,000 parasitoids at 10-day intervals proved to be the most effective treatment in terms of reduction in fruit damage, net return, and yield but four sprays of NPV at 250 larval equivalent (LE)/ha along with release of *T. pretiosum* at 50,000 parasitoids at 10-day intervals proved to be the most cost-effective treatment for management of tomato fruit borer. Siddique *et al*. (2010) studied the evaluation of *T. pretiosum*, HaNPV, and endosulfan alone and in combination for the control of tomato fruit borer. Based on the mean fruit damage and marketable yield, it was found that the bioagents and endosulfan alone were less effective but the combination of *T. pretiosum* (thelytokous) (five releases at weekly intervals at 50,000/ha), HaNPV (three sprays at 10-day intervals at 1.5×10^{12} polyhedral occlusion bodies (POBs)/ha) and endosulfan (three sprays at 15-day intervals at 700 g a.i./ha) proved most effective for the management of *H. armigera*. Rahman (2011) also studied on evaluation of different treatments comprising of combination and solo practices, and recorded good results in combinations viz., *T. evanescense* @ 0.25g/6M^2 at 7 days' interval + Neem oil @ 4ml/l of water at 7 days' interval applied against tomato fruit borer over the solo practices. Sajjad (2011) conducted an experiment on various control methods, viz., biological control (release of *Chrysoperla carnea* and *Bracon hebetor*, each @ 1card/5-m2), botanical control (NSKE spray, Neemosol @ 1480 ml/ha), chemical control (Spinosad, Tracer 240 SC @ 197.6 ml/ha), and biorational control (*B. thuringiensis* @ 2 kg/ha) alone and in all of their possible combinations and recorded significant results in combinations over the sole practices for the management of *H. armigera* on the tomato crop. Reddy and Miller (2014) studied and found significantly lower fruit damage (5%) by *H. armigera* was recorded in plots treated with the IPM package (Petroleum spray oil (PSO), *B. bassiana*, *azadirachtin* and *B. thuringiensis*) at 15, 30, 45 and 60 DAT, compared to the carbaryl, malathion treated plots and to both controls at both locations were recorded on an average of 50% and 65% damage, correspondingly. Fruit damage in the plots that received two applications each of PSO and *azadirachtin* and *B. bassiana* and *B. thuringiensis* was significantly lower than in the control treatments. Prabhukarthikeyan *et al.* (2014) worked on a bioformulation containing a mixture of *Beauveria bassiana* (B2) and *Bacillus subtilis* (EPC8) was tested against *Fusarium* wilt and fruit borer in tomato under glasshouse and field conditions. The bioformulation with B2 and EPC8 isolates effectively reduced the incidence of *Fusarium* wilt (*Fusarium oxysporum* f. sp. *lycopersici*) and fruit borer under glasshouse and field conditions compared with the individual application of B2 and EPC8 isolates and control treatments. Bala and Sarkar (2017) studied on application of *B. bassiana* 1.50% LF (Bio-Power) at three different doses along with neem and quinalphos and revealed that upto 80% pest mortality over untreated control.

Conclusion

Eco-friendly management of fruit borer can be done by integrated pest control measure or practices such as breeding resistant cultivars or varieties, adopting good practices, mechanical and biological control, and biorational control. Some cultural practices such as early sowing of a resistant/tolerant variety with the balance use of fertilizer and irrigation, plant density, inter/trap crops (viz., marigold, African marigold cotton, okra, field bean, pigeon pea, sunflower and maize), installing animated bird perches of T-shaped and bagging of fruits (butter paper bags, waxed-paper, translucent plastic bags) are optimal for producing high tomato yields alongside the eco-friendly and sustainable management of fruit borer. Approaches with any single method to pest control may not be practicable; hence, the best alternative is the integrated pest management (IPM) approach, which is based on the principles of managing the pest population rather than aiming at its full obliteration. In view of this, the present review concluded that the use of IPM options, along with growing resistant varieties, good agricultural practices, mechanical, biological control, biorational and chemical control (only if necessary) etc., reduce the unenthusiastic force of insecticides on the natural enemies, beneficial insect and pollinators that are present in the appropriate ecological niche and defend the flora and fauna.

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