Review Article

Bio-ecology and management of Brinjal shoot and fruit borer

ABSTRACT

The most important and commonly grown vegetable for both raw and cooked purposes is brinjal, or *Solanum melongena* Linnaeus. It is a member of the solanaceae family and is also known as eggplant or baingan. Nevertheless, it faces significant threat from a prominent pest known as the eggplant shoot and fruit borer, scientifically termed, *Leucinodes orbonalis* Guenee, capable of inflicting damage ranging from 37% to 100%. This pest can also diminish both the quantity and quality of eggplant produced. Farmers persist in depending on pesticides to address this problem; nevertheless, excessive pesticide application has resulted in negative impacts on the environment, unintended beneficial organisms, phytotoxicity, pesticide resistance, pest resurgence, bioaccumulation, and secondary pest outbreaks. In different regions of the world, it has been discovered that a number of insects, including ~~Various~~ various pests such as the Fruit and Shoot Borer, White Fly, Leaf Hopper, Thrips, Mites, Leaf Roller, and Red Spider Mite contribute to losses in eggplant. Moreover, *L. orbonalis* ~~this insect~~ can also cause severe harm to other vegetables within the Solanaceae family, acting as an alternative host. The adult insect can eventually withstand the problems of chemical pesticides and find it challenging to control the insect population in standing crops due to the larva's unique ability to subsist on a monophagous diet supported by homing and tunneling behavior. It results in a decrease in both yield and vitamin C content. This is dueto the fact that high humidity and moderate temperatures encourage the population growth of the Brinjal Fruit and Shoot Borer, which results in significant losses in hot, humid weather. Farmers primarily use chemical insecticides, which they apply carelessly to manage this pest. A lot of farmers also employ biological control techniques and home-based remedies like: marigold barriers, cow urine, ashes, and so forth. Farmers are unable to totally manage the infestation, though, and the measures cost more to produce than they really bring.

***Keywords:** Brinjal, shoot and fruit borer, Integrated pest management.*

1. INTRODUCTION

The most prominent vegetable crop and tender perennial plant cultivated for its tasty fruit is the eggplant (*Solanum*~~.~~ *melongena* L.)~~,~~ belonging to the Solanaceae/Nightshade family and the Solanoideae subfamily. It ~~is~~ referred ~~to~~ as brinjal in South Africa and Southeast Asia, eggplant in the United States, Australia, New Zealand, and Canada, aubergine or guinea squash in the United Kingdom, Ireland, and Quebec, and garden egg in Quebec. Because of its widespread use and adaptability, brinjal, also known as baingan, is referred to be the "King of vegetables" and is utilized in Indian cuisine on both regular and festive occasions. Brinjal fruits are widely utilized in various culinary dishes, including sliced bhaji, packed curry, bertha, chutney, vangnibath, and pickles. Commercially produced brinjal fruit comes in a variety of shapes, sizes, and colors, including round, rectangular, pendulum, egg shaped, green, white, and yellow, as well as striated tones (Herbst ST 2001). Its skin exhibits a smooth and shiny texture. Brinjal stands out as a leading vegetable in terms of oxygen radical absorption capacity and serves as a significant source of vitamins, minerals, proteins, cancer-preventive agents, dietary fiber, and factors conducive to weight training (Matsubara *et al*., 2005).Nutritionally speaking, 100 grams of cooked fruit has a very low-calorie value of 25.0%, 92.7% moisture, 8.29 grams of carbohydrates (of which 3.04 are sugar), 0.2 grams of fat, 1 gram of protein, 21.1 µg of beta-carotene, and 3.4 grams of fiber. Other elements include 213.0 mg of potassium, 10.6 mg of magnesium, 13.0 mg of sodium, and 0.7 mg of iron (Nonnecke IBL 1989). The ripened fruit, per 100g, also contains 12.0 mg of calcium, 26.0 mg of phosphorus, 8.93 mg of choline, 13.4g of folate, 5.0 mg of ascorbic acid, and 27 International Units of vitamin A. Additionally, it contains

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0.89 mg of vitamin B, 2.2 mg of vitamin C, 0.30 mg of vitamin E, and 3.5 µg of vitamin K (Tindall D 1978).

The peel of brinjal types with rich blue or purple colors has a substantial number of anthocyanins, which are phenolic flavonoid phytochemicals that help prevent neurological illnesses, aging, and cancer (Plazas *et al.,* 2013), (Stommel *et al.,* 2015). Apart from serving as a popular appetizer, aphrodisiac, cardiac tonic, laxative, and anti-inflammatory, brinjal has also been cited in Ayurveda as a remedy for treating diabetes (Nandi *et al.,* 2017). It is also a great therapy for people with liver issues. While often associated with Middle Eastern or Mediterranean cuisines, brinjal has been cultivated in the region for the past 4,000 years. A warm weather crop, brinjal is grown in subtropical areas worldwide. Nonetheless, it is extensively grown throughout the world in tropical and temperate climates, mostly during the warm season (Rahman MM 2007). Although less renowned, the Gboma eggplant (*S. macrocarpon* L.) and the scarlet eggplant (*S. aethiopicum* L.), two other cultivated eggplant species, hold significant importance locally in Sub-Saharan Africa (Daunay *et al*., 2012). Brinjal is grown in outdoor fields, polyhouses, net houses, kitchen gardens, and commercial gardens across the globe during the Rabi and Kharif seasons. It ranks as the fifth most important solanaceous crop economically, trailing behind tobacco, tomato, potato, and pepper. According to Frary *et al*. (2007), eggplant is among the top five vegetable crops cultivated in Asia and the Mediterranean.

Additionally, frozen or fresh brinjal is exported. With a productivity of 29 tons per hectare and a production of 54077210 tons, eggplant is grown over 1864556 hectares worldwide. Region wise, Asia accounts for the largest portion of eggplant production (93.6%), with Africa coming in second (3.8%), Europe in second place (1.8%), America in third place (0.7%), and Ocenia placing last (0%). In terms of both area and global brinjal production, India is ranked second only to China. With a productivity of 17.43 tons/hectare, eggplant is grown on 736000 hectares of land in India, where it is produced in 12826000 tons. From the nursery stage to harvesting, a number of insect pests and mites attack eggplants. These pests include *Thrips palmi* (Karny), *Eublemma olivacea* (Walker), *Leucinodes orbonalis* (Guenee), *Bemicia tabaci* (Gennadius), *Amrasca biguttula biguttula* (Ishida), *Henosepilachna vigintioctopunctata* (Fab.), *Amrasca biguttula biguttula biguttula* (Ishida), and *Tetranychus macfarlanei* (Baker and Pritchard) (Srinivasan R 2009), and *Tetranychus macfarlanei* (Koch) (Muhammad *et al.,* 2018).

Leucinodes~~L.~~ orbonalis is the harmful pest found in Asia, (Patial *et al.,* 2008), (Thapa RB 2010) among them (Latif *et al.,* 2010), (Chakraborty *et al.,* 2011), and (Saimandir *et al.,* 2012). According to reports, this infamous pest limits the growth of brinjal in India, resulting in losses of 37–63% (Dhankar DS 1988), up to 90% (Jagginavar *et al.,* 2009), as high as70-92% (Patial PD 1990), and up to 100% damage if management measures are not implemented (Rahman MM 2007). Losses of up to 67% have been observed in Bangladesh (Dhandapani *et al.,* 2003), 31 to 90%, and 50 -70% have been reported in Pakistan. Because of the borer's severe infestation and the reduced yields, many farmers are reluctant to cultivate brinjal (Patel *et al.,* 2015). Because moderate temperatures and high humidity encourage population growth and result in significant losses during hot and humid conditions, the losses in agricultural yield decrease caused by pests vary from season to season and from place to location (Shukla *et al.,* 2010), (Bhushan *et al.,* 2011), (Gautam *et al.,* 2019). Unpredictable weather, such as sudden drops in temperature, droughts, or floods, can also lower fruit quality and production (Taher *et al.,* 2017), (Netam *et al.,* 2018). Presently, farmers apply numerous insecticides, sometimes up to 140 times or more during a cropping season, which typically spans 6-7 months and incurs costs amounting to 32% of all agricultural production (Alam et al., 2006).

In Bangladesh, a significantly high amount of pesticides, approximately 180 times the usual, were utilized in a single year to protect brinjal against the Brinjal Fruit and Shoot Borer (BFSB), as reported in an insecticide survey (40). There exists an economic threshold level for shoot and fruit borer in brinjal, indicating that 0.5% shoot damage, 5% fruit damage, and 8–10 moths per day per trap are considered significant (Dhaliwal *et al.,* 2003). To combat BFSB, farmers in Bangladesh often resort to applying broad-spectrum insecticides two or three times a week, and occasionally even twice a day. Insecticide usage is common, yet farmers still lose between 30 and 60 percent of their crop production to BSFB (Shelton *et al.,* 2018). The results of using 25-30 insecticidal sprays by farmers to control this pest are not good enough (Sajjan *et al.,* 2015). Consequently, a season may see the application of more than 100 sprays, leaving heavyresidues on the fruit. Thirty-five to forty percent of the entire expense of cultivating brinjal is incurred in pesticide treatments. Such an insecticide-dependent approach raises issues for farmers' and consumers' health and the environment (Shelton *et al.,* 2018). Furthermore, improper insecticide treatment is leading to the emergence of secondary pests, the devastation of natural enemies, and a pest rebound. The current focus is on developing alternative management methods for this insect in order to prevent these issues. The larval stage of this insect is the only dangerous phase, as it feeds inside the fruit and creates large exit holes for the pupae once it has completed development. This reduces the fruit's market value and makes it unsuitable for human eating (Alam et al., 2003). Damage starts when the seedlings are planted and lasts until the fruit is harvested. During the early stages of the plant's life, larvae pierce the petioles and midribs of large leaves and early shoots. This caused the entrance pores to close with their frass and the shoot to begin feeding inside (Butani and Jotwani, 1984), which ultimately caused the shoot to droop and wither (Alam and Sana, 1962). The larva pierces the fruit and flowerbuds through the calyx during the last stages of fruit formation. The fruits have one or more sizable circular exit holes. Fruits that are impacted become internally rotten and lose their market value.

Biology of *Leucinodes* L. *Orbonalis* :

Egg:

A single female may deposit anywhere between 5 and 242 eggs over her lifetime, according to studies by (Alam et al., 1982) and (Kavitha et al., 2008). Most of the time, eggs were placed individually, albeit occasionally in groups of two or four. The bottom surface of fragile leaves, plant twigs, blooms, or fruit calyces was the favored location for females to deposit their eggs. Before hatching, the creamy white, oval shaped or slightly elongated eggs becameorange with a noticeable black mark (Harit *et al.,* 2005 and Singh *et al.,* 2001). (Ali *et al.,*1962), (Jat *et al.,*2003), Mehto *et al.* ,1983), (Raina *et al.,* 2017), and (Singh *et al.,* 2001) have all documented the pre-oviposition, oviposition, and post-oviposition periods, which are, respectively, 1.1 to 2.1 days, 1.4 to 4.0 days, and 1.0 to 2.0 days. In contrast, the incubation period was reported by (Muthukumaran *et al.,* 2007), to be 3 to 4 days. The highest hatching rate (38.2%) was observed on the third day after oviposition, followed by significant rates on the fourth and fifth days, respectively (Raina *et al.,* 2017).

Larva:

According to (Jat *et al*., 2003), (Harit *et al*., 2005), (Patial *et al*., 2007), (Raina *et al*., 2017), and (Singh *et al*., 2001),larvae progressed through five instars before reaching the pupal stage. The typical durations of the first, second, third, fourth, and fifth larval instars were found to be 1-2, 2-3, 2-3, 2-4, and 2-4 days, respectively. The newly hatched larva was small, creamy or dirty white in color, with three pairs of thoracic legs, five pairs of prolegs, and a distinct dark brown or light black head. Larvae in their second instar were similar to those in their first, except they were bigger and had a somewhat darker color. Compared to the previous instars, the third instar larvae were substantially longer and darker, with a unique pattern on the prothoracic shield and dark brown thoracic legs. The fourth instar had a color that was somewhat pink. The fifth instar had three distinct thoracic segments, five pairs of well-developed prolegs, and a cylindrical, pinkish-brown color. Still, six larval instars of the shoot and fruit borer were documented by (Alam *et al.,* 1982) and (Saxena *et al.,*1965). The typical larval phase was found to extend between 12.3 and 14.0 days, according to reports from (Das *et al.,* 1970) and (Jat *et al.,* 2003).

The pupal time was observed by Pupa (Butani *et al.,*1976) and (Mehto *et al.,* 1983) to vary between 7 and 10 days. They saw that the pupae had eight hook-shaped, fine spines at the posterior end of the abdomen, a small anal end, and a broader cephalic lobe. The pupae were dark brown in color. According to (Alam *et al.,* 1982), (Jat *et al.,* 2003), and (Mathur *et al.,*2006), pupation occurred on glass jars, earth, muslin fabric, fruits, and occasionally on plant leaves. (Raina *et al.,*2017) report that the pupal duration was found to vary from 6 to 8 days. They didn't notice the adult emerging until the fifth day following pupation. According to (Jat *et al*., 2003), (Harit *et al*., 2005), (Patial *et al*., 2007), (Raina *et al*., 2017), and (Singh *et al*., 2001), larvae progressed through five instars before reaching the pupal stage. The typical lengths of the first, second, third, fourth, and fifth larval instars were determined to be 1-2, 2-3, 2-3, 2-4, and 2-4 days, sequential-ly. On the sixth day following pupation, the adult began to emerge, and it didso until the eighth day. Maximum adult emergence was noted on the seventh day following pupation, with an average of 14%, 30%, and 10% emerging on the sixth, seventh, and eighth-days following pupation. The average adult emergence rate was shown to be 54%.

Adult:

Male moths were found to have a lifespan of one to three days, while female moths typically lived for two to five days, as indicated by studies conducted by Singh *et al*. (2001), Jat *et al*. (2003), and Alam *et al*. (1982). The moth had a blackish brown head and thorax and was white in color. The pinkish brown patterns on the white wings were larger on the forewings. As per (Jat *et al*., 2003), the females had a rounded posterior end and a larger abdomen with greater wing spread than the males, who were smaller in size and had a narrower abdomen that tapered posteriorly. (Patial *et al*., 2007) report that the patial sex ratio was determined to be 1.0:2.0 in favor of females and 1.0:1.3 in favor of males, respectively.

According to Raina and Yadav (2017), mature L. orbonalis insects typically mate at night or in the early morning. Pre-mating hours ranged from 6 to 9 (with an average of 7.1 hours). The adults spent between thirty and forty-nine minutes (avg. 41.2 minutes) in the mating posture. The post-mating time averaged 5.0 days, ranging from 4-6 days. It was also mentioned by (Mehto et al., 1983) that mating often occurs in the early morning and lasts for 43 minutes. According to records kept by (Lall *et al*.,1965), (Alam *et al.,* 1982), the life cycle of the brinjal shoot and fruit borer takes between 19.0 and 43.0 days to complete.

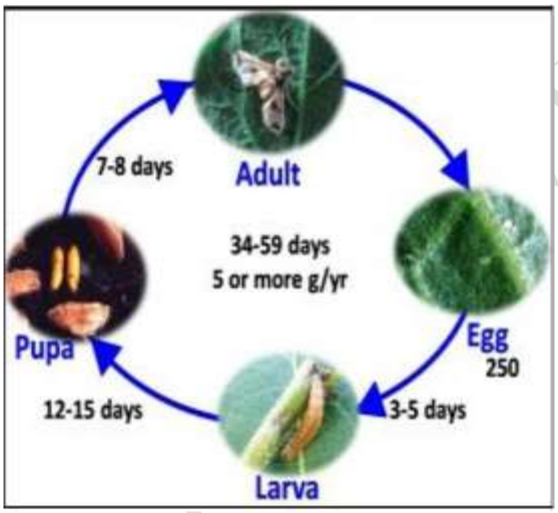

Fig. 1. Fruit borer and brinjal sprout life cycle

Population dynamics of *Leucinodes orbonalis*~~L. orbonalis~~

In Kanpur, during the fourth week of August, 47 days after transplanting, Singh et al. (2009) discovered the first infestation of shoot and fruit borer. As the temperature increased, the incidence steadily decreased from its peak, which occurred 114 days after transplanting, during the second week of September. It was shown that there was little or no correlation between the shot damage and the meteorological conditions. In an experiment conducted at Manipur University, Singh et al. (2009) discovered that during the second week of April in 2003 and 2004, shoots became infected with fruit borer, resulting in damage percentages of 11.6% and 9.7%, respectively. The second week of June 2003 and the third week of May 2004 recorded the highest infection levels on shoots, with 25.8% and 31.4% of the shoots affected. The percentage of *L. orbonalis* infestation was favorably linked with both R.H. (80.5-87.2%) and temperature (22.93-25.45ºC). In the first year of the experiment, maximum relative humidity, rainfall, and wind speed showed positive correlations with brinjal shoot and fruit borer infection. Conversely, in the second year, maximum relative humidity and sunshine hours exhibited positive correlations with the infection rates, according to Varma et al. (2009). The population incidence of the fruit borer, *L. orbonalis*, and brinjal shoot on *S. melongena* L c.v. Pusa Purple long was investigated by Singh et al. (2011) during the two cropping seasons (2003 and 2004) in Manipur. They observed that the incidence of shoot and fruit borer began in April and persisted through the end of June. During the first and second cropping seasons, the pest on shoot peaked in the first week of June (29.45%) and the fourth week of May (25.24%), respectively. Conversely, the second week of June

2003 (67.16%) and the third week of June 2004 (72.25%) exhibited the highest prevalence of this insect on fruit.

Correlation studies revealed that average sunlight had a significant negative correlation with pest infestation on brinjal, while average temperature and relative humidity showed a significant positive correlation. In rabi 2009 in Durgapur, Mathur *et al*. (2012) investigated the impact of abiotic conditions on the seasonal occurrence of the shoot and fruit borer, *L. orbonalis*. The findings indicated that shoot damage had a negative correlation with mean relative humidity (ranging from 21.8% to 75.3%) and a positive correlation with both maximum temperatures (ranging from 18.1°C to 37.88°C) and lowest temperatures (ranging from 4.6°C to 20.84°C), rainfall (ranging from 0 mm to 2.6 mm), and wind speed (ranging from 2.5 km/hr to 7.3 km/hr). On the contrary, the percentage of fruit infestation showed a negative correlation with mean relative humidity and a non-significant correlation with maximum and lowest temperatures, rainfall, and wind speed. According to (Meena *et al.,* 2012), the highest percentage of shoot infestation was noted during the ninth standard week (5.4%), followed by the seventh standard week (4.6%) and the eighth standard week (4.5%). Fruit borer was first observed in the tenth standard week and persisted until the final harvest. Fruit borer infestation peaked in the 18th and 17th standard weeks (43.3 and 40.1%,respectively). According to (Kumar *et al.,* 2013) from Kanpur, throughout the vegetative phase of the crop up till the third week of September, there was a higher seasonal prevalence of the fruit borer, *L. orbonalis*, on the shoot. The infection on shoots steadily decreased as the fruit grew, and by the end of October, when the crop was ripening, it had vanished as the borer infestation had shifted to the fruits during the second week of October. As winter arrived, it progressively became worse and by the end of November, it was totally gone. Temperature, precipitation, and RH (morning) all had a very positive impact on the amount and intensity of infection on the shoots and fruits; however, RH (evening) had the opposite effect. On forty brinjal germplasm samples from Kalyanpur, (Malik *et al.,* 2013) investigated the seasonal occurrence of the fruit and shoot borer, *L. orbanalis*. The shoot borer infection first surfaced during the 43rd standard week (18–24 October).

The brinjal shoot borer exhibited positive multiplication rates at higher temperatures, while a negative correlation was observed between minimum temperature and relative humidity. There was no discernible relationship between wind speed and rainfall, although evaporation rate had a beneficial influence on the infesting shoot's ability to multiply. In their study on the population dynamics of brinjal shoot and fruit borer in Hisar during the summer of 2009–10, Kaur *et al*. (2014) discovered that the 39th and 40th standard weeks of the year had the highest number of larvae (10 larvae per 90 plants), while the 48th standard week had the lowest mean population (0.0 larvae per 90 plants). Larval population was shownto be inversely connected with percent and positively correlated with temperature, according to correlation analysis. In 2014, R.H. (Raina *et al.,* 2017) from Hisar experimented on brinjal (var. BR-112) from June to October. They discovered that whereas fruit infestation first appeared in July, *L. orbonalis* infestation first appeared in shoots in June. The third week of September saw the highest prevalence of fruit borer and shoot borer. The third week of September reported the highest shoot damage (48.75%), fruit damage (40.00%) based on the number of fruits, and the greatest larval population (12 larvae per 20 plants). The maximum temperature was 35.3°C, the minimum was 25.0°C, and the relative humidity was 87% in the morning and 45% in the evening. After that, both the incidence of *L. orbonalis* in fruits and shoots began to decline. Additionally, correlation analysis indicated that there was no significant association between abiotic parameters and the mean larval population, fruit damage, and the percentage of shoot damage. Regression study, however, revealed that abiotic variables account for 68% of population variance.

Nature of damage

The main food source for the almost monophagous brinjal shoot and fruit borer is eggplant. Although the pest is thought to be hosted by Solanum melongena, several plants in the solanaceae family are frequently implicated in this regard. Major hosts are *S. Melongena* (L.) and *S. tuberosum* (L.), while minor and alternate hosts are *S. indicum* L. and *S. myriacanthum* Dunal) (Poonam *et al.,* 2018), Sweet potato (*Ipomoea batatas* L.), Green pod of Austrian winter pea (*Pisum sativum* var. arvense L.) (Atwal *et al.,* 2008), Dark nightshade (*S. nigrum* L.), Turkey berry (S. torvum Swartz) (Gautam *et al.,* 2019), and Gilo (*S. gilo* Raddi). The wild hosts of *L. orbonalis* include Black nightshade (*S. anomalum* Thonn) (Singh *et* *al.,* 1997), African eggplant (*S. macrocarpon* L.) (Kumar *et al.,* 1996), Tropical Soda Apple (*S. viarum* Dunal), Indian nightshade or Kantakari (*S. xanthocarpum*_Schrad) (Sunita *et al.,* 2013), Cape gooseberry (*Physalis peruviana* L.), Pygmy groundcherry (*Physalis minima* L.), and Forest Bitter Berry (*Solanum anguiviLam*.) (Elekofehinti *et al.,* 2013). For brinjal, the most virulent internal feeder pest is the Shoot and Fruit Borer (FSB). By creating holes in the fruits and shoots, it not only reduces the production (number and quality) but also the fruit's vitamin C content by up to 80% and its aesthetic value. When the larvae first hatch, they promptly bore into the nearest tender shoot, petioles, developing bud, and flower. Subsequently, as the fruits develop, they penetrate into the fruit and consume its mesocarp, leading to the destruction of the fruit tissue. The larvae created a dead heart when they bored into fruits, and they frequently filled in the feeding tunnel's opening with their excrement, called frass. Though fading entry hole depressions are evident, the fruit's entry holes are hidden because they have either healed or been covered with frass. Only the injured fruits display the big circular exit holes, one or more of which are visible.

Fruits that are impacted become deformed and internally decay, rendering them unsuitable for selling or eating (Baral*et al.,* 2006), (Raina *et al.,* 2018). One fruit can have up to 20 larvae, according to research from Ghana. Accordingto (Jayaraj *et al.,* 2010), a single larva may ruin four to seven good fruits. The primary cause of damage to the plant is fruit feeding by the larvae, which bores into the tender shoots. Consequently, the affected twigs, flowers, and fruits undergo drying, withering, and sometimes premature falling off. This ultimately results in the wilting of young shoots and dieback of the branch terminals, thereby reducing the plant's ability to bear fruit. As a result, there are fewer and smaller fruits on the plants. Although new shoots can emerge, this postpones crop maturation and exposes the newly developed shoots to harm from larvae. Damaged blooms that are fed on by larvaedo not develop into fruit.

Fig 2: Nature of damage due to fruit borer

Host plant resistance:

Numerous researchers have studied the screening of brinjal genotypes against the fruit borer, *L. orbonalis*, and shootborer, L. esculentus, using host plant resistance mechanisms such as tolerance, antixenosis, and antibiosis. Insect resistance in brinjal plants is known to be correlated with several morphological and biochemical characteristics. Table 1 below details the methods of host plant resistance to brinjal. In

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contrast to resistant cultivars, susceptible kinds displayed greater levels of shoot infestation. (Kale *et al.,* 1986). A thin stem, numerous branches, the length and width of the lower third of the leaf, more spines, a rough leaf surface area, a thick cuticle heavily lignified, a broad and thick hypodermis, a closely packed vascular bundle, and a small pith area are characteristics of antixenosis that may indicate a lower infestation or, conversely, a higher infestation. Numerous researchers have examined the antixenosis mechanism of various plant characteristics. Their findings have shown that the biophysical characteristics of shoot and fruit borer insect populations are reduced, as shown in Table 2.

Table 1: Characters with different resistance mechanisms in brinjal

Mechanism (s)	Character (s)
Antixenosis (non-preference)	Fruit colour, shape and diameter, size, Calyx size, pericarp thickness, surface wax, glandular and non-glandular trichomes, leaf size
Antibiosis	Total phenol, sugar content, polyphenol oxidase and peroxidase enzyme, solasodine contents, flavonols and potassium
Avoidance (escape)	Earliness with cold tolerance

Table 2: Antixenosis characters which shows the resistance/ reduction to brinjal shoot and fruit borer

S.No	Biophysical Varietal Characters	Reference
1.	Leaf trichomes, stem thickness and stem hair density	(Javed *et al.,* 2011) [44]
2.	Leaf thickness and trichome density	(Naqvi *et al.,* 2008) [65]
3.	Number of shoots per plant, spines of leaves, branches, petioles, calyx of fruits, fruit skin thickness, shoot thickness and long fruited varieties	(Shaukat *et al.,* 2018) [95]

Pubescent types characterized by dense and lengthy upright hairs on their surface obstruct adult insects from laying eggs and hatching them. Varieties, including the wild type and other resistant types, possess high levels of silica and crude fiber, along with lower levels of ash and crude fat protein in the stem, which impede larval feeding and digestion. It is evident that biochemical factors play a more crucial role than morphological and physiological factors in deterring insects through non-preference and antibiosis. Numerous biochemical elements are recognized for their association with insect resistance in agricultural plants. Some of these constituents may serve as feeding cues for insects. The occurrence at lower concentrations or the total absence of such biochemical constituents leads to insect resistance. Biochemical constituents such as glycoalkaloid (solasodine), phenols, and phenolic oxidase enzymes, namely polyphenol oxidase and peroxidase, are present in brinjal. These biochemical constituents possess insect-resistant properties, as outlined in Table 3. Achieving complete borer resistance would be challenging, and therefore, the development of tolerant genotypes is considered. When selecting genotypes for shoot and fruit borer resistance, apart from their performance, consideration may also be given to the quantity of biochemical constituents and the isozyme banding pattern.

Table 3: Antibiosis characters which shows the resistance/ reduction in brinjal to brinjal shoot and fruit borer population

S. No	Biochemical Characters	Reference
1.	Solanine content and total phenols	(Asati *et al.,*2002) [9]; (Preneetha 2002) [81]; (Jat and Pareek 2003) [42]; (Thangamani 2003) [111]
2.	Polyphenol oxidase activity, total phenol	(Prabhu et al., 2009) [78]

	contentand solasodine content	
3.	Phenolics content	(Elanchez-hyan *et al.,* 2009) [29]; (Prasad *et al.,* 2014) [80]
4.	Polyphenol oxidase (PPO), Phenylalanineammonium lyase (PAL) and Lignin	(Khorshed-uzzaman *et al.,* 2010) [48]

Management of *L. orbonalis*:

Organic manure:

The effects of applying neem and pongamia to various plants on vegetables were evaluated by (Krishnamoorthy *et al.,* 2001). In insecticide-treated plots, the incidence of fruit borer and shoot borer in brinjal was initially between 30 and 50%, but it reduced to 6–10% following treatment. Research by Sreenivasa Murthy *et al*. (2001) demonstrated that the application of neem cake at a rate of 250 kg/ha increased the yield by approximately 68% and decreased the incidence of borer to 8%. According to (Prakash *et al*., 2002), okra treated with FYM and vermicompost had lower percentages of fruit borer infestation. (Go-dase *et al*., 2003) observed the impact of organic manures and fertilizers on the incidence of the fruit borer *L. orbonalis* and the brinjal shoot borer. Neem cake had the lowest incidence of fruit borer, 1.700 kg per hectare (6.08%). Nonetheless, it was discovered to be on par with vermicompost at 4000 kg per hectare, double the K2O dose, and half the FYM + half the fertilizer dose. According to (Shobha Rani *et al.,* 2004), *L. orbonalis* incidence in potatoes may be effectively decreased with a single application of neem cake at 240 kg/ha. Ven-katesh *et al*., (2004) looked at the effects of applying five different organic manures on L. orbonalis in brinjal: neem cake, pongamia cake, castorcake (all at 1.0 t/ha), farmyard manure, and vermicompost (10.0 t/ha). Neem was found to be the best cake of all.

Pheromone traps:

Alam *et al*. (2003) discovered that the output of marketable fruit was higher in the pheromone-treated plots compared to the control plots. They also found that, compared to the 1.5 m height, the 0.5 m height had a significantly higher number of insects caught. According to Cork et al. (2003), delta and wing traps baited with synthetic *L. orbonalis* female sex pheromone were observed to capture and retain ten times more moths compared to either Spodoptera or uni-trap designs. Additionally, "windows" were incorporated into the side panels of delta traps, and the performance of locally constructed water and funnel traps was found to be comparable to that of delta traps. However, the trap catches significantly increased from 0.4 to 2.3 moths per trap each night. When wing traps were positioned at crop height, they captured significantly more moths than when positioned 0.5 m above or below the canopy. However, according to Chatterjee *et al*. (2009), deploying pheromone traps at a rate of 75 traps per hectare provided considerable protection against *L. orbonalis* in terms of production (28.67%), fruit damage (33.73%), and shoot damage (58.35%) in brinjal crops. Using sex pheromone traps, Rani (2013) studied fruit borer, *L. orbonalis*, and brinjal shoot in nine villages in and around the Bangalore rural area between 2012 and 2013. The best trap heights for catching BSFB moths were assessed for each of the four variations. The findings showed that the greatest number of moth captures (499 moths)were found in traps at the highest elevation of 0.6 m above the crop canopy. Like-wise, five other trap densities (i.e.,8, 16, 24, 32, and 40 traps/acre) were evaluated as well; the findings indicated that, at 16 traps/acre, the greatest number of moth captures (1097 moths) and the least degree of fruit damage (6.48%) were recorded.

Biopesticides and botanicals:

In order to combat brinjal shoot and fruit borer, (Puranik *et al.,* 2002) compared several *B. thuringiensis* (Bt) formulations with neem and other pesticides. Among the various treatments, the greatest yield of marketable fruits (196.96 q/ha) and the smallest shoot (9.56%) and fruit (11.78%) infection were obtained with five sprays of Dipel 8L @ 0.2 percent spaced ten days apart. In their evaluation of novel insecticides against *L. orbonalis*, the aubergine shoots and fruit borer, Deshmukh and Bhamare (2006) contrasted them with traditional pesticides. To achieve a decrease in shoot infestation to 4.20%, reduce fruit infestation to 23.72% on a numerical basis and 25.30% on a weight basis, and increase fruit output to 78.73 q/ha, researchers found that cartap hydrochloride at a concentration of 0.1% was the most effective. Spinosad at a concentration of 0.01% was the next most effective option.

According to (Patra *et al.,* 2009), plots treated with Spinosad 2.5 SC (50g a.i/ha) had the lowest levels of fruit and shoot infestation (7.47 and 9.88%) throughout the West Bengal kharif season. The Spinosad treatment resulted in the highest marketable fruit production at 143.50 q/ha, followed by indoxacarb at 126.90 q/ha and emamectin benzoate at 121.30 q/ha. Anil and Sharma (2010) investigated the bio efficacy of several pesticides on brinjal c. v Arka Nidhi in 2007 and 2008 in Palampur against the shoot and fruit borer, *L. orbonalis*. They discovered that in the case of emamectin benzoate, there were comparatively few drooping shoots and fruit infection. However, agrospray oil T (0.2%) was determined to have the highest cost-benefit ratio.

According to (Wankhede *et al*., 2010), In the kharif trials of 2007 and 2008, the most effective treatment was emamectin benzoate, which resulted in 5.0% and 4.8% shoot damage, respectively. During the course of the two cropping seasons, emamectin benzoate was also shown to have the lowest fruit infestation (11.51, 11.44, and 12.39, 12.44) and the best output of healthy fruits (24.06, 23.14 t ha -1). In Meerut, Uttar Pradesh, an experiment was conducted by Gangwar *et al.* (2014). Spinosad 45 SC demonstrated the highest success in reducing shoot and fruit damage, resulting in the highest yield of 253.30 q/ha, followed by novaluron 10EC with a yield of 242.30 q/ha.However, they found that the highest cost-benefit ratio for no-valuron was 1:8.50, whereas the highest ratio for carbosulfan was 1:7.34.

Chemical control

According to Singh *et al.* (2007), using deltamethrin at a rate of 25 g a.i./ha was found to be more effective than chlorpyriphos at 500 g a.i./ha in reducing fruit damage in brinjal on both a number and weight basis while also increasing the production of healthy fruits. Misra (2008) conducted field evaluations in Bhubaneshwar during the winter of 2007 and the summer of 2008 to assess the effectiveness of two recently developed insecticides, namely rynaxypyr 20SC and flubendiamide 480 SC, on brinjal cultivar "Utkal Anushree" against the shoot and fruit borer, *L. orbonalis* [61]. Ten days after the fourth spray, Rynaxypyr 20SC @40 and 50g a.i./ha reduced shoot damage by 95–97%, fruit damage by 87–90% on a numerical basis, and weight damage by 88–90% when compared to the untreated control. During both seasons, the plots treated with rynaxypyr20SC @ 40 and 50g a.i. ha-1 had the maximum healthy fruit output. Insecticides were tried by (Naik *et al.,* 2008) inthe Bapatla district of Andhra Pradesh against the shoot and fruit borer. In comparison to the untreated control (6666.66 kg/ha), they discovered that Profenofos (0.1%) boosted fruit yields (14312.05 kg/ha) and provided the largest decrease (42.7%) of *L. orbonalis* shoot damage. In their 2003 and 2004 study at Palampur, (Patial *et al.,* 2009)evaluated the effectiveness of ten insecticidal treatments against the fruit borer and brinjal shoot. They found that acetamprid had the lowest levels of fruit and shoot infestation along with the highest profit and cost-benefit ratios (Rs 24,146/ha and 1:13.24). The most successful insecticide in lowering the weight-based number of *L. orbonalis* shoots (39.91%) and fruit infestations (18.21 and 17.48%) as well as increasing fruit yield (310.50 q/ha) was found to be Profenofos @ 0.1% in a chemical control trial carried out at Kanpur by Singh et al., (2009). In brinjal, (Kumar et al., 2010) found that cypermethrin 0.0075% was more effective than endosulfan 0.05% at controlling L. orbonalis. This finding is mostlyconsistent with the current research. In Pusa, Bihar, (Singh et al., 2011) conducted bio efficacy studies against *L. orbonalis* on brinjal. They found that the most effective treatments were imidacloprid at 0.025 kg a.i. ha-1 and fenvalerate at 0.150 kg a.i. ha-1. The maximum fruit yield was recorded at 290.25 q ha 1 and 268.5 q ha-1, respectively. However, the highest ICBR (1:14.41) was noted for fenvalerate @ 0.150 kg a.i. ha-1, with imidacloprid(1:12.99) and cypermethrin (1:13.85) coming next. In Jalna during the kharif seasons of 2009 and 2010, (Shirale *et al.,* 2012) evaluated that flubendamide 39.35SC andchlorantraniliprole 18.50SC outperformed other insecticides in decreasing *L. orbonalis* infestation and produced higher yield efficacy on Mahyco brinjal hybrid MHB 39. Insecticides against shoot and fruit borer were assessed by(Saha *et al.,* 2014) from Sabour (Bihar) in the kharifs 2010–11 and 2012–13. In areas where rynaxypyr 20 SC was applied, minimal levels of shoot infestation (5.67%), fruit infestation (12.59%), larvae per plot (2.36), and holes per fruit (0.40) were reported. Additionally, they observed that rynaxypyr had the greatest mean yield (346.69 q/ha). After conducting controlled field trials in two cropping seasons at Coimbatore, (Krishnamoorthy *et al.,* 2014) discovered that flubendamide 20 WG @ 75 g a.i/ha was the most efficient pesticide in reducing fruit and shoot damage. In both the winter and summer seasons, flubendiamide exhibited the most significant reduction in shoot damage (96.8% and 97.2%), fruit damage (98.2% and 98.1%), and resulted in the highest yield (21.7 and 26.3 tons/ha). According to (Raina *et al.,* 2016), deltamethrin was the most successful in lowering fruit damage (88.89%) and shoot damage (60.40%) when compared to the control on both a number and weight basis. With 132.27 q/ha, deltamethrin had the largest marketable fruit yield, whereas nimbecidine had the lowest (33.53 q/ha). The cost-benefit ratios for the insecticides were as follows: deltamethrin had the highest ratio at 1:8.7, followed by cypermethrin at 1:6.5, fenvalerate at 1:8.5, chlorpyriphos at 1:4.5, Prempt at 1:1.9, malathion at 1:0.6, and nimbecidine at 1:0.3.

~~Integerated~~Integrated **pest management:**

A combination of plant products and herbicides can effectively inhibit fruit borer and brinjal shoots, according to Singh *et al.* (2003). Among the various treatments evaluated, the study identified that the basal application of neem cake at 20 q/ha combined with a foliar spray of quinalphos at 0.05% was effective in reducing the incidence of fruit borer to 20.63%. Additionally, according to Asmita et al. (2006), the combination of spinosad at 0.01%, Metarhizium anisole, chelating agent Fe-EDTA, and cartaphydrochloride at 0.1% proved to be the most effective Integrated Pest Management (IPM) approach against the fruit borer, *L. orbonalis*, resulting in the lowest shoot infection (7.47%) and the highest yield (81.82 q/ha). According to (Dutta*et al*., 2011), mechanical removal of contaminated fruits and shoots combined with a pheromone trap and neem was determined to be the most efficient IPM module in decreasing shoot damage (86.69%).

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Following a sequence, a reduction in shoot damage of 79.24%, 78.75%, and 78.55% was observed immediately after the implementation of pheromone traps mixed with neem, mechanical removal of contaminated fruits and shoots combined with pheromone traps, and traditional farmer's practices, respectively. Conversely, neem had the lowest effectiveness, with 54.46% of shoot infection. The greatest protection against fruit infestation was found when infested fruits and shoots were mechanically re-moved along with a pheromone trap and neem (59.36% reduction). Subsequently, the methods employed by farmers resulted in a reduction of 54.13%, while the mechanical removal of infected fruits and shoots using a pheromone trap led to a reduction of 52.77%. These were then succeeded by the following techniques: pheromone trap combined with neem, mechanical removal of infested fruits and shoots with neem, and mechanical removal of infested fruits and shoots with protection, resulting in reductions of 47.70%, 43.69%, and 42.93%, respectively. On the other hand, installing merely traps reduced fruit damage by at least 38.17%.

CONCLUSION

Brinjal Fruit and Shoot borer (*L. orbonalis* Guinee), is a monophagous insect that mainly feeds on Brinjal and othervegetables of Solanaceae family. Due to its short life cycle and boring nature, it heavily infests on the Brinjal plantsand it has resulted huge losses in several nations of the world including Nepal. The management of this insect is of utmost importance to increase the yield of Brinjal and other Solanaceae vegetables. The successful management of this pest can be brought about only by effective IPM practices. Apart from chemical pesticides bio-pesticides like Neem oil and Neem Leaf extract have great effectiveness against *L. orbonalis*. Botanical oils and extract of differentplants such as Neem, Pungam, etc. are found to be very effective against the pests and insects. Biocontrol agents such as *Bacillus thuringiensis*, *Trichogramma chilonis* which is an egg parasitoid and larval parasitoid-*Trathala flavo-orbitalis* (Cameron) can also be utilized as means of potential parasitoids of this pest since they also show significantresult in the reduction of shoot and fruit damage of Brinjal. Eco-friendly management of brinjal shoot and fruit borer can be done by integrated pest control measure tactics suchas breeding resistant cultivars, adopting good agronomic practices, mechanical, physical and biological control, andbiorational control. Some cultural practices such as proper spacing, followed by clipping and burning of infested twig/ fruits/ stem, removal of alternate host, inter/trap crops (viz., coriander, cluster bean, fennel, chilly, radish,

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marigold, mint, onion, clover, fenugreek and cereal including maize) uses of organic amendment, and installing animated bird perches of T-shaped are optimal for getting high yields beside with eco-friendly management of the pest. Given this, the present review concluded that the use of IPM options, along with growing resistant varieties, good agronomic practices, biological control and chemical control (only if necessary) etc., reduce the unenthusiasticforce of insecticides on the natural enemies, beneficial insect, pollinators, animal and human being that are present in the appropriate ecological niche and will defend the flora and fauna and the atmosphere from toxicological hazardscontents.

Research gap: The bio-ecology and management of brinjal shoot and fruit borer pertains to the development and implementation of integrated pest management (IPM) strategies tailored to the specific needs and ecological context of brinjal cultivation. While conventional chemical pesticides are commonly used, there is a need for sustainable alternatives that minimize environmental impact and preserve natural ecosystems. Additionally, further investigation into the biology and behavior of the pest, as well as its interaction with the brinjal plant and surrounding environment, is warranted to inform the design of effective and holistic management approaches for sustainable brinjal production.

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