

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 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, 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 due to 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 (*S. 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 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).

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

61 Additionally, frozen or fresh brinjal is exported. With a productivity of 29 tons per hectare and a
62 production of 54077210 tons, eggplant is grown over 1864556 hectares worldwide. Region wise, Asia
63 accounts for the largest portion of eggplant production (93.6%), with Africa coming in second (3.8%),
64 Europe in second place (1.8%), America in third place (0.7%), and Oceania placing last (0%). In terms of
65 both area and global brinjal production, India is ranked second only to China. With a productivity of 17.43
66 tons/hectare, eggplant is grown on 736000 hectares of land in India, where it is produced in 12826000 tons.
67 From the nursery stage to harvesting, a number of insect pests and mites attack eggplants. These pests
68 include Thrips palmi (Karny), Eublemma olivacea (Walker), Leucinodes orbonalis (Guenee), Bemisia tabaci
69 (Gennadius), Amrasca biguttula biguttula (Ishida), Henosepilachna vigintioctopunctata (Fab.), Amrasca
70 biguttula biguttula biguttula (Ishida), and Tetranychus macfarlanei (Baker and Pritchard) (Srinivasan R
71 2009), and Tetranychus macfarlanei (Koch) (Muhammad *et al.*, 2018).

72 *L. orbonalis* is the harmful pest found in Asia, (Patil *et al.*, 2008), (Thapa RB 2010) among them
73 (Latif *et al.*, 2010), (Chakraborty *et al.*, 2011), and (Saimandir *et al.*, 2012). According to reports, this
74 infamous pest limits the growth of brinjal in India, resulting in losses of 37–63% (Dhankar DS 1988), up to
75 90% (Jagginavar *et al.*, 2009), as high as 70–92% (Patil PD 1990), and up to 100% damage if management
76 measures are not implemented (Rahman MM 2007). Losses of up to 67% have been observed in
77 Bangladesh (Dhandapani *et al.*, 2003), 31 to 90%, and 50–70% have been reported in Pakistan. Because
78 of the borer's severe infestation and the reduced yields, many farmers are reluctant to cultivate brinjal (Patel
79 *et al.*, 2015). Because moderate temperatures and high humidity encourage population growth and result
80 in significant losses during hot and humid conditions, the losses in agricultural yield decrease caused by
81 pests vary from season to season and from place to location (Shukla *et al.*, 2010), (Bhushan *et al.*, 2011),
82 (Gautam *et al.*, 2019). Unpredictable weather, such as sudden drops in temperature, droughts, or floods,
83 can also lower fruit quality and production (Taher *et al.*, 2017), (Netam *et al.*, 2018). Presently, farmers
84 apply numerous insecticides, sometimes up to 140 times or more during a cropping season, which typically
85 spans 6–7 months and incurs costs amounting to 32% of all agricultural production (Alam *et al.*, 2006).

86 In Bangladesh, a significantly high amount of pesticides, approximately 180 times the usual, were
87 utilized in a single year to protect brinjal against the Brinjal Fruit and Shoot Borer (BFSB), as reported in an
88 insecticide survey (40). There exists an economic threshold level for shoot and fruit borer in brinjal,
89 indicating that 0.5% shoot damage, 5% fruit damage, and 8–10 moths per day per trap are considered
90 significant (Dhaliwal *et al.*, 2003). To combat BFSB, farmers in Bangladesh often resort to applying broad-
91 spectrum insecticides two or three times a week, and occasionally even twice a day. Insecticide usage is
92 common, yet farmers still lose between 30 and 60 percent of their crop production to BFSB (Shelton *et al.*,
93 2018). The results of using 25–30 insecticidal sprays by farmers to control this pest are not good enough
94 (Sajjan *et al.*, 2015). Consequently, a season may see the application of more than 100 sprays, leaving
95 heavy residues on the fruit. Thirty-five to forty percent of the entire expense of cultivating brinjal is incurred
96 in pesticide treatments. Such an insecticide-dependent approach raises issues for farmers' and consumers'
97 health and the environment (Shelton *et al.*, 2018). Furthermore, improper insecticide treatment is leading
98 to the emergence of secondary pests, the devastation of natural enemies, and a pest rebound. The current
99 focus is on developing alternative management methods for this insect in order to prevent these issues.
100 The larval stage of this insect is the only dangerous phase, as it feeds inside the fruit and creates large exit
101 holes for the pupae once it has completed development. This reduces the fruit's market value and makes

102 it unsuitable for human eating (Alam et al., 2003). Damage starts when the seedlings are planted and
103 lasts until the fruit is harvested. During the early stages of the plant's life, larvae pierce the petioles and
104 midribs of large leaves and early shoots. This caused the entrance pores to close with their frass and the
105 shoot to begin feeding inside (Butani and Jotwani, 1984), which ultimately caused the shoot to droop and
106 wither (Alam and Sana, 1962). The larva pierces the fruit and flowerbuds through the calyx during the last
107 stages of fruit formation. The fruits have one or more sizable circular exit holes. Fruits that are impacted
108 become internally rotten and lose their market value.
109

110 **Biology of *L. orbonalis***

111 **Egg**

112 A single female may deposit anywhere between 5 and 242 eggs over her lifetime, according to studies by
113 (Alam et al., 1982) and (Kavitha et al., 2008). Most of the time, eggs were placed individually, albeit
114 occasionally in groups of two or four. The bottom surface of fragile leaves, plant twigs, blooms, or fruit
115 calyces was the favored location for females to deposit their eggs. Before hatching, the creamy white, oval
116 shaped or slightly elongated eggs became orange with a noticeable black mark (Harit et al., 2005 and Singh
117 et al., 2001). (Ali et al., 1962), (Jat et al., 2003), Mehto et al., 1983), (Raina et al., 2017), and (Singh et al.,
118 2001) have all documented the pre-oviposition, oviposition, and post-oviposition periods, which are,
119 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
120 reported by (Muthukumaran et al., 2007), to be 3 to 4 days. The highest hatching rate (38.2%) was observed
121 on the third day after oviposition, followed by significant rates on the fourth and fifth days, respectively
122 (Raina et al., 2017).
123

124 **Larva**

125 According to (Jat et al., 2003), (Harit et al., 2005), (Patial et al., 2007), (Raina et al., 2017), and (Singh et al.,
126 2001), larvae progressed through five instars before reaching the pupal stage. The typical durations of the
127 first, second, third, fourth, and fifth larval instars were found to be 1-2, 2-3, 2-3, 2-4, and 2-4 days,
128 respectively. The newly hatched larva was small, creamy or dirty white in color, with three pairs of thoracic
129 legs, five pairs of prolegs, and a distinct dark brown or light black head. Larvae in their second instar were
130 similar to those in their first, except they were bigger and had a somewhat darker color. Compared to the
131 previous instars, the third instar larvae were substantially longer and darker, with a unique pattern on the
132 prothoracic shield and dark brown thoracic legs. The fourth instar had a color that was somewhat pink. The
133 fifth instar had three distinct thoracic segments, five pairs of well-developed prolegs, and a cylindrical,
134 pinkish-brown color. Still, six larval instars of the shoot and fruit borer were documented by (Alam et al.,
135 1982) and (Saxena et al., 1965). The typical larval phase was found to extend between 12.3 and 14.0 days,
136 according to reports from (Das et al., 1970) and (Jat et al., 2003).

137 The pupal time was observed by Pupa (Butani et al., 1976) and (Mehto et al., 1983) to vary between
138 7 and 10 days. They saw that the pupae had eight hook-shaped, fine spines at the posterior end of the
139 abdomen, a small anal end, and a broader cephalic lobe. The pupae were dark brown in color. According to
140 (Alam et al., 1982), (Jat et al., 2003), and (Mathur et al., 2006), pupation occurred on glass jars, earth, muslin
141 fabric, fruits, and occasionally on plant leaves. (Raina et al., 2017) report that the pupal duration was found
142 to vary from 6 to 8 days. They didn't notice the adult emerging until the fifth day following pupation.
143 According to (Jat et al., 2003), (Harit et al., 2005), (Patial et al., 2007), (Raina et al., 2017), and (Singh et
144 al., 2001), larvae progressed through five instars before reaching the pupal stage. The typical lengths of
145 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,
146 sequentially. On the sixth day following pupation, the adult began to emerge, and it did so until the eighth
147 day. Maximum adult emergence was noted on the seventh day following pupation, with an average of 14%,
148 30%, and 10% emerging on the sixth, seventh, and eighth-days following pupation. The average adult
149 emergence rate was shown to be 54%.
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151 **Adult**

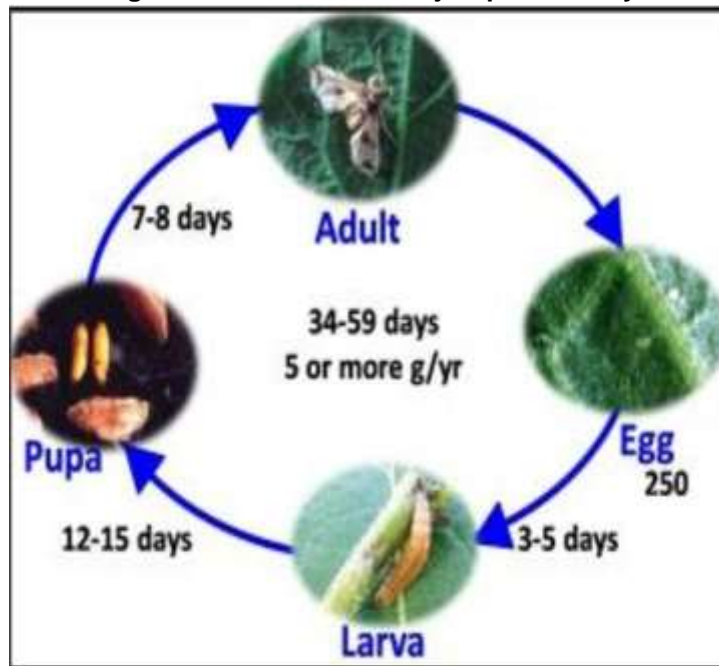
152 Male moths were found to have a lifespan of one to three days, while female moths typically lived for two
153 to five days, as indicated by studies conducted by Singh et al. (2001), Jat et al. (2003), and Alam et al.
154 (1982). The moth had a blackish brown head and thorax and was white in color. The pinkish brown patterns
155 on the white wings were larger on the forewings. As per (Jat et al., 2003), the females had a rounded
156 posterior end and a larger abdomen with greater wing spread than the males, who were smaller in size and

157 had a narrower abdomen that tapered posteriorly. (Patial et al., 2007) report that the patial sex ratio was
158 determined to be 1.0:2.0 in favor of females and 1.0:1.3 in favor of males, respectively.

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

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Fig. 1. Fruit borer and brinjal sprout life cycle



166 **Population dynamics of *L. orbonalis***

167 In Kanpur, during the fourth week of August, 47 days after transplanting, Singh et al. (2009) discovered
168 the first infestation of shoot and fruit borer. As the temperature increased, the incidence steadily
169 decreased from its peak, which occurred 114 days after transplanting, during the second week of
170 September. It was shown that there was little or no correlation between the shoot damage and the
171 meteorological conditions. In an experiment conducted at Manipur University, Singh et al. (2009)
172 discovered that during the second week of April in 2003 and 2004, shoots became infected with fruit
173 borer, resulting in damage percentages of 11.6% and 9.7%, respectively. The second week of June 2003
174 and the third week of May 2004 recorded the highest infection levels on shoots, with 25.8% and 31.4%
175 of the shoots affected. The percentage of *L. orbonalis* infestation was favorably linked with both R.H. (80.5-
176 87.2%) and temperature (22.93-25.45°C). In the first year of the experiment, maximum relative humidity,
177 rainfall, and wind speed showed positive correlations with brinjal shoot and fruit borer infection.
178 Conversely, in the second year, maximum relative humidity and sunshine hours exhibited positive
179 correlations with the infection rates, according to Varma et al. (2009). The population incidence of the
180 fruit borer, *L. orbonalis*, and brinjal shoot on *S. melongena* L c.v. Pusa Purple long was investigated by
181 Singh et al. (2011) during the two cropping seasons (2003 and 2004) in Manipur. They observed that the
182 incidence of shoot and fruit borer began in April and persisted through the end of June. During the first
183 and second cropping seasons, the pest on shoot peaked in the first week of June (29.45%) and the
184 fourth week of May (25.24%), respectively. Conversely, the second week of June 2003 (67.16%) and
185 the third week of June 2004 (72.25%) exhibited the highest prevalence of this insect on fruit.

186 Correlation studies revealed that average sunlight had a significant negative correlation with pest
187 infestation on brinjal, while average temperature and relative humidity showed a significant positive

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

209 The brinjal shoot borer exhibited positive multiplication rates at higher temperatures, while a negative
210 correlation was observed between minimum temperature and relative humidity. There was no discernible
211 relationship between wind speed and rainfall, although evaporation rate had a beneficial influence on the
212 infesting shoot's ability to multiply. In their study on the population dynamics of brinjal shoot and fruit
213 borer in Hisar during the summer of 2009–10, Kaur *et al.* (2014) discovered that the 39th and 40th
214 standard weeks of the year had the highest number of larvae (10 larvae per 90 plants), while the 48th
215 standard week had the lowest mean population (0.0 larvae per 90 plants). Larval population was shown
216 to be inversely connected with percent and positively correlated with temperature, according to
217 correlation analysis. In 2014, R.H. (Raina *et al.*, 2017) from Hisar experimented on brinjal (var. BR-112)
218 from June to October. They discovered that whereas fruit infestation first appeared in July, *L. orbonalis*
219 infestation first appeared in shoots in June. The third week of September saw the highest prevalence of
220 fruit borer and shoot borer. The third week of September reported the highest shoot damage (48.75%),
221 fruit damage (40.00%) based on the number of fruits, and the greatest larval population (12 larvae per
222 20 plants). The maximum temperature was 35.3°C, the minimum was 25.0°C, and the relative humidity
223 was 87% in the morning and 45% in the evening. After that, both the incidence of *L. orbonalis* in fruits
224 and shoots began to decline. Additionally, correlation analysis indicated that there was no significant
225 association between abiotic parameters and the mean larval population, fruit damage, and the
226 percentage of shoot damage. Regression study, however, revealed that abiotic variables account for
227 68% of population variance.

228 229 **Nature of damage**

230 The main food source for the almost monophagous brinjal shoot and fruit borer is eggplant. Although the
231 pest is thought to be hosted by *Solanum melongena*, several plants in the solanaceae family are frequently
232 implicated in this regard. Major hosts are *S. Melongena* (L.) and *S. tuberosum* (L.), while minor and alternate
233 hosts are *S. indicum* L. and *S. myriacanthum* Dunal) (Poonam *et al.*, 2018), Sweet potato (*Ipomoea batatas*
234 L.), Green pod of Austrian winterpea (*Pisum sativum* var. *arvense* L.) (Atwal *et al.*, 2008), Dark nightshade
235 (*S. nigrum* L.), Turkey berry (*S. torvum* Swartz) (Gautam *et al.*, 2019), and Gilo (*S. gilo* Raddi). The wild
236 hosts of *L. orbonalis* include Black nightshade (*S. anomalum* Thonn) (Singh *et al.*, 1997), African eggplant
237 (*S. macrocarpon* L.) (Kumar *et al.*, 1996), Tropical Soda Apple (*S. viarum* Dunal), Indian nightshade or
238 Kantakari (*S. xanthocarpum* Schrad) (Sunita *et al.*, 2013), Cape gooseberry (*Physalis peruviana* L.), Pygmy
239 groundcherry (*Physalis minima* L.), and Forest Bitter Berry (*Solanum anguivi* Lam.) (Elekofehinti *et al.*,
240 2013). For brinjal, the most virulent internal feeder pest is the Shoot and Fruit Borer (FSB). By creating
241 holes in the fruits and shoots, it not only reduces the production (number and quality) but also the fruit's
242 vitamin C content by up to 80% and its aesthetic value. When the larvae first hatch, they promptly bore into

243 the nearest tender shoot, petioles, developing bud, and flower. Subsequently, as the fruits develop, they
244 penetrate into the fruit and consume its mesocarp, leading to the destruction of the fruit tissue. The larvae
245 created a dead heart when they bored into fruits, and they frequently filled in the feeding tunnel's opening
246 with their excrement, called frass. Though fading entry hole depressions are evident, the fruit's entry holes
247 are hidden because they have either healed or been covered with frass. Only the injured fruits display the
248 big circular exit holes, one or more of which are visible.

249 Fruits that are impacted become deformed and internally decay, rendering them unsuitable for selling
250 or eating (Baralet *et al.*, 2006), (Raina *et al.*, 2018). One fruit can have up to 20 larvae, according to research
251 from Ghana. According to (Jayaraj *et al.*, 2010), a single larva may ruin four to seven good fruits. The primary
252 cause of damage to the plant is fruit feeding by the larvae, which bores into the tender shoots. Consequently,
253 the affected twigs, flowers, and fruits undergo drying, withering, and sometimes premature falling off. This
254 ultimately results in the wilting of young shoots and dieback of the branch terminals, thereby reducing the
255 plant's ability to bear fruit. As a result, there are fewer and smaller fruits on the plants. Although new shoots
256 can emerge, this postpones crop maturation and exposes the newly developed shoots to harm from larvae.
257 Damaged blooms that are fed on by larvae do not develop into fruit.
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260 **Fig 2: Nature of damage due to fruit borer**

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264 **Host plant resistance**

265 Numerous researchers have studied the screening of brinjal genotypes against the fruit borer, *L. orbonalis*,
266 and shootborer, *L. esculentus*, using host plant resistance mechanisms such as tolerance, antixenosis, and
267 antibiosis. Insect resistance in brinjal plants is known to be correlated with several morphological and
268 biochemical characteristics. Table 1 below details the methods of host plant resistance to brinjal. In contrast
269 to resistant cultivars, susceptible kinds displayed greater levels of shoot infestation. (Kale *et al.*, 1986). A
270 thin stem, numerous branches, the length and width of the lower third of the leaf, more spines, a rough leaf
271 surface area, a thick cuticle heavily lignified, a broad and thick hypodermis, a closely packed vascular
272 bundle, and a small pith area are characteristics of antixenosis that may indicate a lower infestation or,
273 conversely, a higher infestation. Numerous researchers have examined the antixenosis mechanism of
274 various plant characteristics. Their findings have shown that the biophysical characteristics of shoot and
275 fruit borer insect populations are reduced, as shown in Table 2.

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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

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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 <i>et al.</i> , 2011) [44]
2.	Leaf thickness and trichome density	(Naqvi <i>et al.</i> , 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 <i>et al.</i> , 2018) [95]

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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.

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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 <i>et al.</i> , 2002) [9]; (Preneetha 2002) [81]; (Jat and Pareek 2003) [42]; (Thangamani 2003) [111]
2.	Polyphenol oxidase activity, total phenol content and solasodine content	(Prabhu <i>et al.</i> , 2009) [78]
3.	Phenolics content	(Elanchez-hyan <i>et al.</i> , 2009) [29]; (Prasad <i>et al.</i> , 2014) [80]
4.	Polyphenol oxidase (PPO), Phenylalanine ammonium lyase (PAL) and Lignin	(Khorshed-uzzaman <i>et al.</i> , 2010) [48]

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303 **Management of *L. orbonalis***

304 **Organic manure**

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

319 **Pheromone traps**

320 Alam *et al.* (2003) discovered that the output of marketable fruit was higher in the pheromone-treated
321 plots compared to the control plots. They also found that, compared to the 1.5 m height, the 0.5 m
322 height had a significantly higher number of insects caught. According to Cork *et al.* (2003), delta and
323 wing traps baited with synthetic *L. orbonalis* female sex pheromone were observed to capture and retain
324 ten times more moths compared to either Spodoptera or uni-trap designs. Additionally, "windows" were
325 incorporated into the side panels of delta traps, and the performance of locally constructed water and
326 funnel traps was found to be comparable to that of delta traps. However, the trap catches significantly
327 increased from 0.4 to 2.3 moths per trap each night. When wing traps were positioned at crop height,
328 they captured significantly more moths than when positioned 0.5 m above or below the canopy. However,
329 according to Chatterjee *et al.* (2009), deploying pheromone traps at a rate of 75 traps per hectare
330 provided considerable protection against *L. orbonalis* in terms of production (28.67%), fruit damage
331 (33.73%), and shoot damage (58.35%) in brinjal crops. Using sex pheromone traps, Rani (2013) studied
332 fruit borer, *L. orbonalis*, and brinjal shoot in nine villages in and around the Bangalore rural area between
333 2012 and 2013. The best trap heights for catching BSFB moths were assessed for each of the four
334 variations. The findings showed that the greatest number of moth captures (499 moths) were found in
335 traps at the highest elevation of 0.6 m above the crop canopy. Like-wise, five other trap densities (i.e., 8,
336 16, 24, 32, and 40 traps/acre) were evaluated as well; the findings indicated that, at 16 traps/acre, the
337 greatest number of moth captures (1097 moths) and the least degree of fruit damage (6.48%) were
338 recorded.

339 **Biopesticides and botanicals**

340 In order to combat brinjal shoot and fruit borer, (Puranik *et al.*, 2002) compared several *B. thuringiensis*
341 (Bt) formulations with neem and other pesticides. Among the various treatments, the greatest yield of
342 marketable fruits (196.96 q/ha) and the smallest shoot (9.56%) and fruit (11.78%) infection were obtained
343 with five sprays of Dipel 8L @ 0.2 percent spaced ten days apart. In their evaluation of novel insecticides
344 against *L. orbonalis*, the aubergineshoots and fruit borer, Deshmukh and Bhamare (2006) contrasted
345 them with traditional pesticides. To achieve a decrease in shoot infestation to 4.20%, reduce fruit
346 infestation to 23.72% on a numerical basis and 25.30% on a weight basis, and increase fruit output to
347 78.73 q/ha, researchers found that cartap hydrochloride at a concentration of 0.1% was the most
348 effective. Spinosad at a concentration of 0.01% was the next most effective option.

349 According to (Patra *et al.*, 2009), plots treated with Spinosad 2.5 SC (50g a.i/ha) had the lowest levels of
350 fruit and shoot infestation (7.47 and 9.88%) throughout the West Bengalkharif season. The Spinosad
351 treatment resulted in the highest marketable fruit production at 143.50 q/ha, followed by indoxacarb
352 at 126.90 q/ha and emamectin benzoate at 121.30 q/ha. Anil and Sharma (2010) investigated the bio
353 efficacy of several pesticides on brinjal *c. v* Arka Nidhi in 2007 and 2008 in Palampur against the shoot

354 and fruit borer, *L. orbonalis*. They discovered that in the case of emamectin benzoate, there were
355 comparatively few droopingshoots and fruit infection. However, agrospray oil T (0.2%) was determined
356 to have the highest cost-benefit ratio.

357 According to (Wankhede et al., 2010), In the kharif trials of 2007 and 2008, the most effective treatment
358 was emamectin benzoate, which resulted in 5.0% and 4.8% shoot damage, respectively. During the
359 course of the two cropping seasons, emamectin benzoate was also shown to have the lowest fruit
360 infestation (11.51, 11.44, and 12.39, 12.44) and the best output of healthy fruits (24.06, 23.14 t ha⁻¹).
361 In Meerut, Uttar Pradesh, an experiment was conducted by Gangwar et al. (2014). Spinosad 45 SC
362 demonstrated the highest success in reducing shoot and fruit damage, resulting in the highest yield of
363 253.30 q/ha, followed by novaluron 10EC with a yield of 242.30 q/ha. However, they found that the
364 highest cost-benefit ratio for no-valuron was 1:8.50, whereas the highest ratio for carbosulfan was 1:7.34.

365 **Chemical control**

366 According to Singh et al. (2007), using deltamethrin at a rate of 25 g a.i./ha was found to be more effective
367 than chlorpyrifos at 500 g a.i./ha in reducing fruit damage in brinjal on both a number and weight basis
368 while also increasing the production of healthy fruits. Misra (2008) conducted field evaluations in
369 Bhubaneshwar during the winter of 2007 and the summer of 2008 to assess the effectiveness of two
370 recently developed insecticides, namely rynaxypyr 20SC and flubendiamide 480 SC, on brinjal cultivar
371 "Utkal Anushree" against the shoot and fruit borer, *L. orbonalis* [61]. Ten days after the fourth spray,
372 Rynaxypyr 20SC @40 and 50g a.i./ha reduced shoot damage by 95–97%, fruit damage by 87–90% on
373 a numerical basis, and weight damage by 88–90% when compared to the untreated control. During both
374 seasons, the plots treated with rynaxypyr20SC @ 40 and 50g a.i. ha⁻¹ had the maximum healthy fruit
375 output. Insecticides were tried by (Naik et al., 2008) in the Bapatla district of Andhra Pradesh against the
376 shoot and fruit borer. In comparison to the untreated control (6666.66 kg/ha), they discovered that
377 Profenofos (0.1%) boosted fruit yields (14312.05 kg/ha) and provided the largest decrease (42.7%) of *L.*
378 *orbonalis* shoot damage. In their 2003 and 2004 study at Palampur, (Patil et al., 2009) evaluated the
379 effectiveness of ten insecticidal treatments against the fruit borer and brinjal shoot. They found that
380 acetamprid had the lowest levels of fruit and shoot infestation along with the highest profit and cost-
381 benefit ratios (Rs 24,146/ha and 1:13.24). The most successful insecticide in lowering the weight-based
382 number of *L. orbonalis* shoots (39.91%) and fruit infestations (18.21 and 17.48%) as well as increasing
383 fruit yield (310.50 q/ha) was found to be Profenofos @ 0.1% in a chemical control trial carried out at
384 Kanpur by Singh et al., (2009). In brinjal, (Kumar et al., 2010) found that cypermethrin 0.0075% was
385 more effective than endosulfan 0.05% at controlling *L. orbonalis*. This finding is mostly consistent with the
386 current research. In Pusa, Bihar, (Singh et al., 2011) conducted bio efficacy studies against *L. orbonalis*
387 on brinjal. They found that the most effective treatments were imidacloprid at 0.025 kg a.i. ha⁻¹ and
388 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
389 ha⁻¹, respectively. However, the highest ICBR (1:14.41) was noted for fenvalerate @ 0.150 kg a.i. ha⁻¹,
390 with imidacloprid(1:12.99) and cypermethrin (1:13.85) coming next. In Jalna during the kharif seasons of
391 2009 and 2010, (Shirale et al., 2012) evaluated that flubendiamide 39.35SC and chlorantraniliprole
392 18.50SC outperformed other insecticides in decreasing *L. orbonalis* infestation and produced higher yield
393 efficacy on Mahyco brinjal hybrid MHB 39. Insecticides against shoot and fruit borer were assessed by
394 (Saha et al., 2014) from Sabour (Bihar) in the kharifs 2010–11 and 2012–13. In areas where rynaxypyr
395 20 SC was applied, minimal levels of shoot infestation (5.67%), fruit infestation (12.59%), larvae per plot
396 (2.36), and holes per fruit (0.40) were reported. Additionally, they observed that rynaxypyr had the
397 greatest mean yield (346.69 q/ha). After conducting controlled field trials in two cropping seasons at
398 Coimbatore, (Krishnamoorthy et al., 2014) discovered that flubendiamide 20 WG @ 75 g a.i./ha was the
399 most efficient pesticide in reducing fruit and shoot damage. In both the winter and summer seasons,
400 flubendiamide exhibited the most significant reduction in shoot damage (96.8% and 97.2%), fruit damage
401 (98.2% and 98.1%), and resulted in the highest yield (21.7 and 26.3 tons/ha). According to (Raina et al.,
402 2016), deltamethrin was the most successful in lowering fruit damage (88.89%) and shoot damage
403 (60.40%) when compared to the control on both a number and weight basis. With 132.27 q/ha,
404 deltamethrin had the largest marketable fruit yield, whereas nimbecidine had the lowest (33.53 q/ha).
405 The cost-benefit ratios for the insecticides were as follows: deltamethrin had the highest ratio at 1:8.7,
406 followed by cypermethrin at 1:6.5, fenvalerate at 1:8.5, chlorpyrifos at 1:4.5, Preempt at 1:1.9, malathion
407 at 1:0.6, and nimbecidine at 1:0.3.

408 Integrated pest management

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

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

431

432 CONCLUSION

433 Brinjal Fruit and Shoot borer (*L. orbonalis* Guinee), is a monophagous insect that mainly feeds on Brinjal
434 and other vegetables of Solanaceae family. Due to its short life cycle and boring nature, it heavily infests on
435 the Brinjal plants and it has resulted in huge losses in several nations of the world including Nepal. The
436 management of this insect is of utmost importance to increase the yield of Brinjal and other Solanaceae
437 vegetables. The successful management of this pest can be brought about only by effective IPM practices.
438 Apart from chemical pesticides bio-pesticides like Neem oil and Neem Leaf extract have great effectiveness
439 against *L. orbonalis*. Botanical oils and extract of different plants such as Neem, Pungam, etc. are found to
440 be very effective against the pests and insects. Biocontrol agents such as *Bacillus thuringiensis*,
441 *Trichogramma chilonis* which is an egg parasitoid and larval parasitoid-*Trathala flavo-orbitalis* (Cameron) can
442 also be utilized as means of potential parasitoids of this pest since they also show significant result in the
443 reduction of shoot and fruit damage of Brinjal. Eco-friendly management of brinjal shoot and fruit borer can
444 be done by integrated pest control measure tactics such as breeding resistant cultivars, adopting good
445 agronomic practices, mechanical, physical and biological control, and biorational control. Some cultural
446 practices such as proper spacing, followed by clipping and burning of infested twig/ fruits/ stem, removal of
447 alternate host, inter/trap crops (viz., coriander, cluster bean, fennel, chilly, radish, marigold, mint, onion,
448 clover, fenugreek and cereal including maize) uses of organic amendment, and installing animated bird
449 perches of T-shaped are optimal for getting high yields beside with eco-friendly management of the pest.
450 Given this, the present review concluded that the use of IPM options, along with growing resistant varieties,
451 good agronomic practices, biological control and chemical control (only if necessary) etc., reduce the
452 unenthusiastic force of insecticides on the natural enemies, beneficial insect, pollinators, animal and human
453 being that are present in the appropriate ecological niche and will defend the flora and fauna and the
454 atmosphere from toxicological hazards contents.

455

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

462 and holistic management approaches for sustainable brinjal production.

463

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