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Research Article

Field Evaluation of Biorational Insecticides against Brinjal Shoot and Fruit Borer (*Leucinodes orbonalis* Guen.) in Brinjal

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ABSTRACT

Brinjal shoot and fruit borer (BSFB), *Leucinodes orbonalis* Guenée, is one of the most destructive insect pests of brinjal, causing severe yield and quality losses. The present study evaluated the efficacy of different biorational insecticides against BSFB infestation and their impact on fruit yield and economic returns. The experiment included four biorational insecticidal treatments: Spinosad (T₁), Buprofezin (T₂), Pyriproxifen (T₃), and Emamectin benzoate (T₄), along with an untreated control. All tested insecticides significantly reduced shoot and fruit infestation compared with the untreated control. Among the treatments, Spinosad (T₁) consistently exhibited the highest efficacy, recording the lowest shoot infestation (5.60%) and fruit infestation (18.30%), whereas the untreated control showed the highest infestation levels of 15.03% and 46.08%, respectively. Spinosad also provided the greatest protection over control, with 60.74% shoot protection and 85.90% fruit protection. In addition, T₁ significantly reduced the number of holes per fruit (1.98), larval population per fruit (1.00), and extent of fruit damage (1.29 cm). Emamectin benzoate (T₄) ranked second in efficacy for most parameters evaluated. The highest marketable fruit yield was obtained from T₁ (26.6 t ha⁻¹), followed by T₄ (22.7 t ha⁻¹), whereas the untreated control produced the lowest yield (4.46 t ha⁻¹). Economic analysis further revealed that T₁ generated the highest net return and benefit-cost ratio (BCR = 3.30), indicating its superior economic feasibility. Overall, Spinosad and Emamectin benzoate proved highly effective and economically viable options for sustainable BSFB management in brinjal cultivation.

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Introduction

Brinjal (*Solanum melongena* L.), commonly known as eggplant, is more than just a staple vegetable in Bangladesh. It plays a vital role in ensuring food and nutritional security, particularly for rural communities. With over 8 million smallholder farmers involved in its cultivation, brinjal contributes significantly to household

income and national vegetable production (BBS, 2022). Its adaptability to different agro-climatic conditions, along with the availability of more than 20 regionally suited cultivars, has made it one of the most widely grown vegetable crops in the country (Shelton et al., 2018). The high consumer demand, short growing cycle, and suitability for year-round cultivation further

enhance its economic value in rural livelihoods (Hasan and Bai, 2016).

Despite its importance, brinjal production faces a major threat from the brinjal shoot and fruit borer (BSFB), scientifically known as *Leucinodes orbonalis* Guen. This insect pest is considered the most damaging pest of brinjal in South and Southeast Asia (FAO, 2011). The pest causes severe damage by boring into shoots, flowers, and fruits throughout the crop cycle, leading to wilting, fruit drop, and unmarketable produce. Studies have reported fruit damage ranging from 31 percent to 86 percent (Ahmed et al., 2024), and yield losses as high as 70 percent to 92 percent (Mainali, 2014; Tripura et al., 2017), with some extreme cases resulting in total crop loss (Srinivasan, 2012; Ahmed et al., 2024).

To control this pest, farmers in Bangladesh rely heavily on chemical insecticides. It is usual for them to spray 25 to 30 times per season (Singh et al., 2021). In some cases, the number of applications exceeds 140 within a single cropping season (Ahmed et al., 2021). Such excessive pesticide use contributes to about 32 percent of the total production cost. Unfortunately, this approach has led to serious problems including pesticide resistance in pests (Mane and Kulkarni, 2011), resurgence of secondary pests, presence of harmful residues in produce, environmental pollution, and human health risks (Pimentel, 2005; Devi et al., 2014). Moreover, farmers often apply pesticides based on recommendations from local input dealers instead of following proper guidelines, which further complicates the issue (Rahman and Rashid, 2020; Alam et al., 2022).

Given these challenges, the need for safer and more sustainable pest management options has become increasingly urgent. Biorational insecticides have emerged as a promising alternative. These are substances derived from natural sources such as plant extracts, microbial formulations, or biologically active compounds. Products like neem-based insecticides, *Bacillus thuringiensis* (Bt), and spinosad are known for their selective toxicity to target pests, rapid environmental breakdown, and minimal effect on non-target organisms (Copping and Menn, 2000). Such attributes make them ideal for use within Integrated Pest Management (IPM) and Biointensive IPM (BIPM) frameworks that emphasize ecological safety and sustainable agriculture (Koul and Walia, 2009).

Although laboratory studies have shown that biorational insecticides can effectively control BSFB (Amin et al.,

2025), there is limited field-based research in regions like Bangladesh. The performance of these products can vary depending on environmental factors such as temperature, humidity, and pest pressure, as well as on the timing of application (Patra et al., 2009). This underlines the importance of field trials to validate their effectiveness and provide reliable recommendations.

Furthermore, integrating biorational insecticides with other IPM tools such as pheromone traps, mechanical removal of infested plant parts, use of resistant varieties, and good cultural practices can enhance pest control outcomes (Srinivasan, 2012; Akter et al., 2018). Farmers who adopt such integrated approaches often benefit from reduced pesticide costs, healthier crops, and improved economic returns (Ahmed et al., 2024).

In light of this, despite the global relevance of biorational insecticides, there is a critical lack of field-validated, Bangladesh-specific efficacy and economic data for these compounds against BSFB. Most published studies have been conducted under different agro-climatic conditions, with limited applicability to Bangladesh's subtropical farming environment. Moreover, comparative economic analyses (benefit-cost ratios) integrating both biological efficacy and market economics are rarely reported for these compounds together in a single field trial. Addressing this gap, the present study was designed to evaluate the field efficacy of selected biorational insecticides against BSFB infestation in brinjal. The findings are expected to support the development of sustainable pest management strategies that reduce chemical input, improve crop quality, and contribute to environmentally responsible farming.

Materials and Methods

Experimental site and duration

Management of *L. orbonalis* Guenee infestation on brinjal through biorational molecules was conducted in the field condition at Entomology Field laboratory of Bangladesh Agricultural University, Mymensingh. The experimental field, located in the Old Brahmaputra Alluvial Tract (AEZ-9), had sandy loam soil with good irrigation and drainage. The soil was silty loam with a pH of 6.94, organic matter content of 1.62%, and a cation exchange capacity of 15.00 m. eq/100 g soil. The experiment was conducted during September 2020 to April 2021.

Experimental design

The study was laid out in a Randomized Complete Block Design (RCBD) with 3 replications and 5 treatments,

including control. The individual plot size was $2 \times 2 \text{ m}^2$. Two adjacent unit plots and blocks were separated by 60 cm and 80 cm apart respectively and standard agronomic practices were followed uniformly in all plots (Figure 1).

Treatments and their application

The following biorational insecticides were tested:

T_0 = Untreated control

T_1 = Spinosad (Tracer 45SC) @ 0.4 mL/L water

T_2 = Buprofezin (Award 40SC) @ 1.0 mL/L water

T_3 = Pyriproxifen 10.8 EC 1.0 mL/L water

T_4 = Emamectin benzoate (Suspend 5SG) @ 1.0 g/L water

Spraying was done using a hand-operated knapsack sprayer with a uniform spray volume (approximately 5 L to cover three plots) to ensure full plant coverage.

Insecticide application was initiated when the infestation reached an economic threshold level (ETL) of approximately 5% fruit infestation, assessed by examining five randomly selected shoots per plant from 10 plants per plot. The insecticides were applied at 7 days interval. Data were collected from 10 randomly selected plants per plot. For fruit infestation assessment, 20 fruits per plot were randomly sampled at each observation. Data were collected at 4 and 7 days of each spraying.

Planting material

Brinjal variety "Singnath" was used in this study, known for its susceptibility to BSFB. Seedlings were raised in seedbeds and transplanted at 30 days of age.

Data collection and observation

Data were collected from 10 randomly selected plants per plot. For fruit infestation assessment, 20 fruits per plot were randomly sampled at each observation after 4 and 7 days of each spraying.

Percentage protection of shoot and fruit infestation over control were calculated by the following formulae:

$$\% \text{ Protection of shoot infestation over control} = \frac{\text{No. of infested shoot in control} - \text{No. of infested shoot in treatment}}{\text{No. of infested shoot in control}} \times 100$$

$$\% \text{ Protection of fruit infestation over control} = \frac{\text{No. of infested fruit in control} - \text{No. of infested fruit in treatment}}{\text{No. of infested fruit in control}} \times 100$$

Number of holes per fruit

The fruits per plot were observed, and the number of BSFB entry/exit holes per fruit was recorded.

Number of larvae per fruit

From the same fruit sample, each fruit was dissected and the number of larvae presents were counted by the following formula:

$$\text{Average larvae per fruit} = \frac{\text{Total number of larvae}}{\text{Total number of infested fruits}}$$



Figure 1. Layout of the experimental plots. Unit plot Size = $2 \text{ m} \times 2 \text{ m}$, Row to Row Distance = 80 cm, Plant to Plant distance = 60 cm.

Fruit damage

The extent of fruit damage was determined by weighing infested and healthy fruits. Moreover, the length of the internally damaged portion of each sampled fruit was measured in cm using a ruler after longitudinal sectioning of the fruit along the larval feeding tunnel. For each fruit, the measurement was taken from the entry point to the furthest extent of larval damage within the fruit tissue.

$$\% \text{ yield increases over control} = \frac{\text{Wt. of healthy fruit in treatment} - \text{Wt. of healthy fruit in control}}{\text{Wt. of healthy fruit in treatment}} \times 100$$

Marketable Yield (t/ha) and % yield increase over Control

After harvesting, only healthy, disease-free, and marketable fruits from each treatment plot were collected and weighed separately. The recorded fruit weight was then converted into marketable yield expressed in t/ha

using the standard conversion method. The percentage increase in yield over the untreated control was also calculated to assess the effectiveness of different treatments in improving crop productivity. The yield increase over control was determined using the following formula as described by (Devi et al., 2015).

$$\text{Marketable Yield (t/ha)} = \left(\frac{\text{Total healthy fruit weight (kg)}}{\text{Plot area (m}^2\text{)}} \times 10000 \right) \div 1000$$

$$\text{Yield increase over control (\%)} = \left(\frac{\text{Yield of treatment} - \text{Yield of control}}{\text{Yield of control}} \right) \times 100$$

Overall protection of BSFB over control

Overall protection against BSFB over the untreated control was determined by calculating the average percentage reduction in all recorded BSFB infestation parameters in comparison with the control treatment.

The reduction percentage for each infestation metric was computed using the formula given below, and the mean of these values was considered as the overall protection efficiency of the treatment.

$$\text{Overall protection(\%)} = \left(\frac{\text{Mean Infestation in Control} - \text{Mean Infestation in Treatment}}{\text{Mean Infestation in Control}} \right) \times 100$$

Benefit-Cost Ratio (BCR)

The BCR was calculated per hectare by comparing total production costs with revenue generated.

Treatment wise cost of cultivation

BCR was determined by summing all labor and input costs, including the control, throughout the vegetative and fruiting stages. Yield was expressed in tons per hectare. Cost of cultivation included pesticide cost, labor cost for spraying, and other agronomic inputs, and all

costs were calculated on a per hectare basis.

Gross return and net return

This was calculated by multiplying the total yield by the unit price of brinjal (Tk 30/kg). Net return was determined by subtracting the management cost from the gross return.

Adjusted net return

The adjusted net return was calculated by subtracting the net return of the control plot from the net return of a specific treatment.

$$\text{Adjusted net return} = \text{Net return of a particular treatment} - \text{Net return of control plot}$$

Benefit cost ratio calculation

The BCR was calculated by dividing the adjusted net return by the total management cost for each treatment, using the formula described by Kahraman et al. (2000).

$$\text{Benefit cost ratio} = \frac{\text{Adjusted net return}}{\text{Total management cost}}$$

Statistical analysis

Data were analyzed using Analysis of Variance (ANOVA), and treatment means were compared with Tukey's Honest Significant Difference (HSD) test at a 5% significance level. Since observations were recorded at 4 and 7 days after each spray (DAS), data

from the two observation intervals were analyzed separately for each spray to avoid pseudo-replication. Grand means across all sprays were also calculated and subjected to ANOVA. The coefficient of variation (CV%) was reported for each analysis to indicate experimental precision.

Percentage data were subjected to arcsine square-root transformation before analysis to stabilize variance. Data recorded at multiple observation times (4 and 7 days after spraying) were analyzed considering repeated measures over time. All statistical analyses were performed using SPSS and R software. Results are presented as means $\pm$ standard deviation (SD).

Results

Efficacy of biorational insecticides on shoot infestation (%) and percentage protection over control

The comparative efficacy of different biorational insecticides on shoot infestation (%) caused by BSFB is presented in Table 1.

All biorational insecticides significantly reduced shoot infestation compared to the untreated control (Table 1). Among the selected treatments, T₁ had the highest efficacy showing the lowest grand mean shoot infestation (5.60%) followed by T₄ with the second highest efficacy (7.01%), while the untreated control treatment had the highest grand mean (15.03%) of shoot infestation (Table 1). In addition, the similar trend of efficacy of applied biorational insecticides up to 4th sprays both at 4 and 7 DAS. But after 5th spray, T₂ and T₃ showed statistically similar effect on the percentage shoot infestation where the lowest and similar efficacy was obtained against BSFB from the treatments T₁ and T₄. On the other hand, the control treatments had the highest level of infested shoots (21.67%) after 5th spray at 7 DAS. It can be concluded that, T₁ and T₄ demonstrated the most effective reduction in shoot infestation in brinjal compared to the untreated control.

The effect of biorational insecticides on percentage protection of shoot infestation over control is presented in Figure 2. Spinosad provided the highest shoot protection (60.74%), followed by Emamectin benzoate (48.84%), Pyriproxifen (30.33%), and Buprofezin (24.46%) over the untreated control.

Efficacy of biorational insecticides on fruit infestation (%) and percentage protection over control

Table 2 presents the comparative efficacy of biorational insecticides in controlling fruit infestation (%). All tested insecticides had a significant ($p < 0.05$) effect in reducing fruit infestation compared to the untreated control.

All biorational insecticides showed significant ($p < 0.05$) effects compared to the untreated control. Among the treatments, T₁ provided the highest efficacy, as it demonstrated the lowest average fruit infestation rate (18.30%) followed by treatment T₄ (25.24%). In contrast, the untreated control treatment had the highest average fruit infestation rate (46.08%) (Table 2). Furthermore, there was a consistent pattern of efficacy observed in the use of biorational insecticides up to the fourth spray, both at 4 and 7 DAS. But after 5th spray, T₂ and T₃ exhibited statistically similar effect on the

percentage fruit infestation where the lowest and similar efficacy was obtained against BSFB from the treatments T₁ and T₄. Conversely, the control treatments exhibited the highest level of infested fruits (58%) following the fifth sprays at 7 DAS. Overall, T₁ and T₄ showed the greatest reduction in fruit infestation percentage compared to the untreated control.

Figure 3 illustrates the impact of biorational insecticides on the percentage of fruit infestation protection compared to the control. Spinosad recorded the highest fruit protection (85.90%) over the untreated control, followed by Emamectin benzoate (62.09%). Buprofezin and Pyriproxifen provided moderate and comparatively low levels of protection, at 34.65% and 17.03%, respectively.

Efficacy of biorational insecticides on the number of holes/fruits

All the insecticides that were sprayed had a significant ($p < 0.05$) impact on reducing the number of holes/fruits compared to the untreated control. A comparison of the efficacy of different biorational insecticides based on the mean number of holes/fruits is provided in Table 3.

All biorational insecticides exhibited significant effects compared with the untreated control (Table 3). Among the treatments, T₁ showed the highest efficacy, recording the lowest mean number of holes per fruit (1.98), followed by T₂, which demonstrated the second-highest efficacy with a mean of 2.96 holes per fruit. In contrast, the untreated control exhibited the highest mean number of holes per fruit (7.95) (Table 3).

A consistent trend in the efficacy of the biorational insecticides was observed up to the fourth spray application at both 4 and 7 DAS. However, after the fifth spray application, T₃ and T₄ showed statistically similar effects on the number of holes per fruit, whereas T₁ and T₂ maintained the highest and comparatively similar efficacy against BSFB. On the other hand, the untreated control recorded the highest number of holes per fruit (11.67) following the fifth spray application at 7 DAS.

Efficacy of biorational insecticides on the number of larvae per fruit

Application of the biorational insecticides significantly reduced the larval population per fruit compared with the untreated control. Table 4 presents a comparative evaluation of the efficacy of different biorational insecticides, expressed as the mean number of larvae per fruit, in controlling BSFB infestation in fruits.

Table 1. Effect of biorational insecticides on the percentage of shoot infestation in brinjal.

Treatments	Pre-treatment	% shoot infestation after different sprays at 4 and 7 DAS										Grand Mean
		1 st		2 nd		3 rd		4 th		5 th		
		4DAS	7DAS	4DAS	7DAS	4DAS	7DAS	4DAS	7DAS	4DAS	7DAS	
T ₀	8.73	9.20	9.00a	9.50a	10.00a	13.33a	15.00a	19.44a	19.52b	20.95a	21.67a	15.03a
T ₁	7.90	7.50	6.50c	6.20c	6.2c	5.50b	5.40c	5.40c	5.00c	5.00b	4.90c	5.60c
T ₂	8.51	8.50	8.40a	8.20b	8.00b	8.50b	9.00b	8.89b	12.07a	10.22ab	12.89b	10.07b
T ₃	8.30	8.50	8.90a	8.90b	8.20b	8.30b	8.40b	9.44b	8.33b	13.33ab	16.67b	10.1b
T ₄	8.00	7.50	7.00c	7.50c	8.00bc	7.70b	7.50bc	7.50b	7.00b	6.50b	5.56c	7.01bc
SE (±)	2.04	2.17	2.19	2.07	2.18	2.29	2.38	2.70	2.35	3.10	2.99	2.44
CV (%)	4.08	3.03	5.17	3.13	6.58	14.76	11.39	4.31	14.04	8.17	15.99	4.2
LSD 0.05	0.47	0.37	0.64	0.37	0.81	1.91	1.53	0.66	1.86	7.43	19.51	2.00
Level of significance	NS	Ns	**	**	**	**	**	**	**	**	**	**

T₀ = Untreated control, T₁ = Spinosad (Tracer 45SC) @ 0.4 mL/L water, T₂ = Buprofezin (Award 40SC) @ 1.0 mL/L water, T₃ = Pyriproxifen 10.8 EC 1.0 mL/L water, T₄ = Emamectin benzoate (Suspend 5SG) @ 1.0 g/L water. *Significant at 5% level (p < 0.05), **Significant at 1% level (p < 0.01), and NS = Non-significant.

Table 2. Effect of biorational insecticides on % fruit infestation of brinjal

Treatments	Pre-treatment	% fruit infestation after different sprays at 4 and 7 DAS										Grand Mean
		1 st		2 nd		3 rd		4 th		5 th		
		4DAS	7DAS	4DAS	7DAS	4DAS	7DAS	4DAS	7DAS	4DAS	7DAS	
T ₀	32.00	34.44a	35.95c	42.86a	40.37a	48.00a	45.00a	51.11a	50.00a	55.56a	58.00a	46.08a
T ₁	35.00	30.00c	28.00b	27.19b	23.17b	20.07c	15.07c	12.32c	10.5c	8.33c	8.33c	18.30e
T ₂	34.00	35.00b	32.33a	25.22b	25.71b	33.04b	32.22b	31.75b	25.00b	35.00b	33.33b	30.86b
T ₃	33.00	31.00d	28.42c	30.41b	31.24ab	33.04b	31.31d	30.81b	32.22b	33.33b	34.63b	31.64c
T ₄	32.00	30.00c	28.08b	25.33b	25.12b	32.39b	30.67b	27.93b	22.22b	18.30b	12.33bc	25.24d
SE (±)	8.47	8.29	6.81	7.75	8.50	9.63	16.13	11.10	7.64	9.53	15.73	10.11
CV (%)	5.28	4.91	6.48	12.1	4.02	5.11	3.73	6.47	8.65	11.98	4.43	1.63
LSD 0.05	4.15	0.61	0.79	7.67	18.77	3.38	2.04	3.31	2.81	5.28	14.18	5.07
Level of significance	NS	NS	NS	*	**	**	**	**	**	**	**	**

T₀ = Untreated control, T₁ = Spinosad (tracer 45SC) @ 0.4 mL/L water, T₂ = Buprofezin (Award 40SC) @ 1.0 mL/L water, T₃ = Pyriproxifen 10.8 EC 1.0 mL/L water, T₄ = Emamectin benzoate (Suspend 5SG) @ 1.0 g/L water. *Significant at 5% level (p < 0.05), **Significant at 1% level (p < 0.01), and NS = Non-significant.

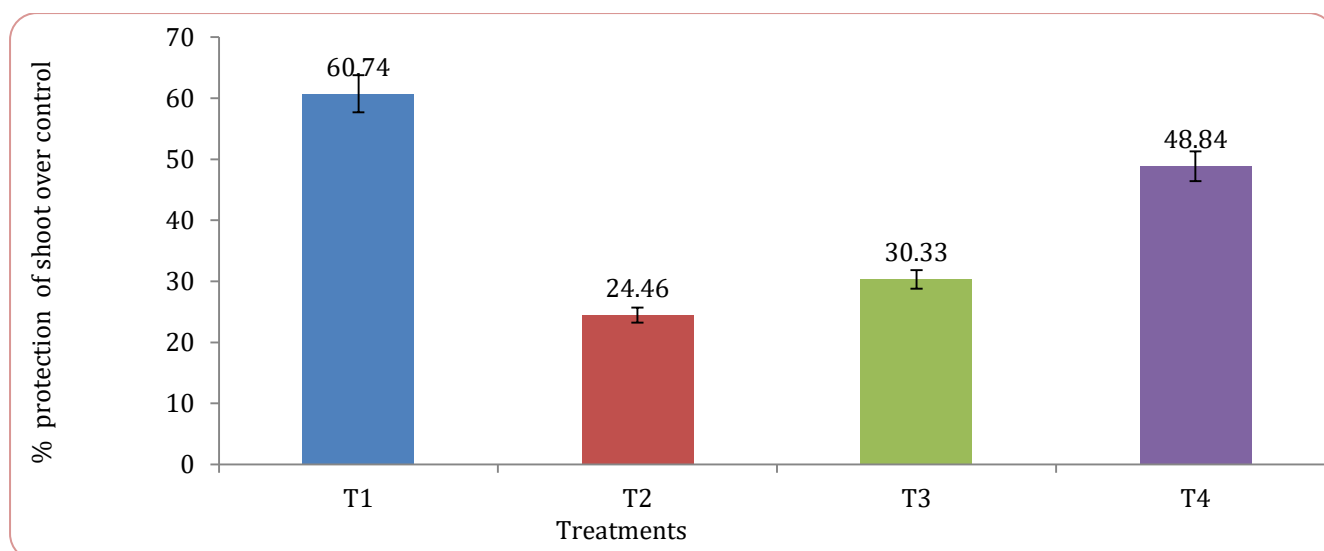


Figure 2. Effect of biorational insecticides on % protection of shoot infestation over control. T₁ = Spinosad (tracer 45SC) @ 0.4 mL/L water, T₂ = Buprofezin (Award 40SC) @ 1.0 mL/L water, T₃ = Pyriproxifen 10.8 EC 1 mL/L water, T₄ = Emamectin benzoate (Suspend 5SG) @ 1.0 g/L water.

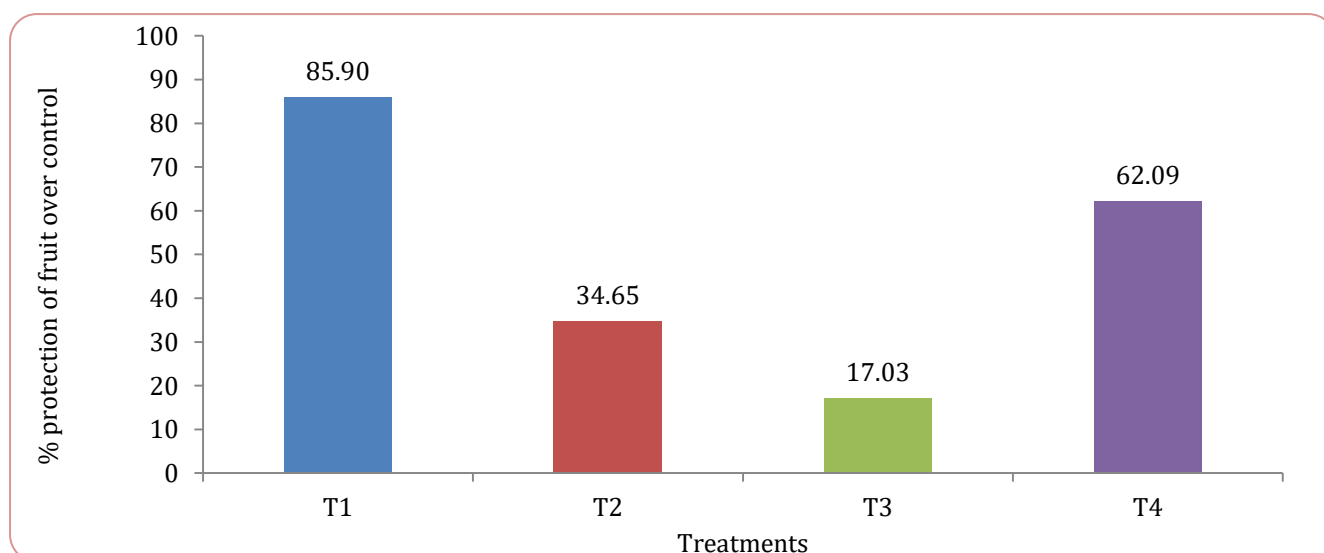


Figure 3. Effect of biorational insecticides on % protection of fruit infestation over control. T₁ = Spinosad (tracer 45SC) @ 0.4 mL/L water, T₂ = Buprofezin (Award 40SC) @ 1.0 mL/L water, T₃ = Pyriproxifen 10.8 EC 1 mL/L water, T₄ = Emamectin benzoate (Suspend 5SG) @ 1.0 g/L water.

Table 4 demonstrates that all biorational insecticides significantly reduced BSFB infestation compared with the untreated control. Among the tested treatments, T₁ showed the highest efficacy, recording the lowest mean number of larvae per fruit (1.00), followed by T₂, which exhibited the second-highest efficacy with a mean of 1.60 larvae per fruit. In contrast, the untreated control recorded the highest mean larval population (3.80 larvae per fruit) (Table 4).

A consistent trend in the efficacy of the biorational insecticides was observed up to the fourth spray at both 4 and 7 DAS. However, after the fifth spray, T₃ and T₄ showed statistically similar effects on the

number of larvae per fruit, indicating comparatively lower efficacy against BSFB than T₁ and T₂. Conversely, the untreated control exhibited the highest larval infestation, recording 6.67 larvae per fruit at 7 DAS following the fifth spray application.

Efficacy of biorational insecticides on the extent of fruit damage

Among all tested treatments, Spinosad and Emamectin benzoate demonstrated superior efficacy in minimizing fruit damage caused by BSFB. Table 5 presents the comparative effectiveness of different biorational insecticides in reducing the extent of fruit damage (cm).

Table 3. Effect of biorational insecticides on the mean number of holes/fruits.

Treatments	Pre-treatment	Number of holes/fruit after different sprays at 4 and 7 DAS										Grand Mean
		1 st		2 nd		3 rd		4 th		5 th		
		4DAS	7DAS	4DAS	7DAS	4DAS	7DAS	4DAS	7DAS	4DAS	7DAS	
T ₀	4.29	4.30	4.80a	5.33a	6.67a	9.67a	11.67a	8.00a	8.67a	9.67a	11.67a	7.95a
T ₁	3.13	3.00	2.90c	2.50c	2.00c	1.30c	1.20b	2.00d	1.50c	1.30c	1.20b	1.98d
T ₂	3.49	4.00	3.50bc	3.67bc	3.00b	3.00bc	2.33b	5.33ab	3.00b	3.00bc	2.33b	2.96c
T ₃	4.27	4.20	4.33ab	4.33ab	5.33a	3.67b	2.67b	5.33ab	4.00b	3.67b	2.67b	4.08b
T ₄	4.05	4.00	3.90b	3.70b	3.60b	3.40b	3.00b	3.50c	3.47b	3.40b	3.00b	3.50bc
SE (±)	0.99	1.03	0.98	1.02	1.09	1.10	1.00	1.29	1.02	1.10	1.00	1.07
CV (%)	3.14	1.95	3.78	6.06	13.61	9.08	8.19	8.1	9.66	9.08	8.19	3.37
LSD 0.05	0.50	0.16	0.49	0.88	2.08	1.39	1.44	1.33	1.28	1.39	1.44	0.39
Level of significance	NS	NS	**	**	**	**	**	**	**	**	**	**

T₀ = Untreated control, T₁ = Spinosad (tracer 45SC) @ 0.4 mL/L water, T₂ = Buprofezin (Award 40SC) @ 1.0 mL/L water, T₃ = Pyriproxifen 10.8 EC 1.0 mL/L water, T₄ = Emeactin benzoate (Suspend 5SG) @ 1.0 g/L water. *Significant at 5% level (p < 0.05), **Significant at 1% level (p < 0.01), and NS = Non-significant.

Table 4. Effect of biorational insecticides on the mean number of larva/fruits

Treatments	Pre-treatment	Number of larva/fruit after different sprays at 4 and 7 DAS										Grand Mean
		1 st		2 nd		3 rd		4 th		5 th		
		4DAS	7DAS	4DAS	7DAS	4DAS	7DAS	4DAS	7DAS	4DAS	7DAS	
T ₀	1.50	1.67	1.90	2.70a	3.00a	4.00a	4.33a	6.67a	6.00ba	6.67a	6.00ba	3.80a
T ₁	1.60	1.50	1.50	1.33b	1.00b	1.20c	0.98c	0.80c	0.75c	0.80c	0.75c	1.06b
T ₂	1.20	1.50	1.60	1.50b	1.60b	1.60bc	1.67bc	2.00b	1.50b	2.00b	1.50b	1.60b
T ₃	1.30	1.30	1.30	1.43b	2.03ab	2.33b	2.00b	2.50b	2.00b	2.50b	2.00b	1.83ab
T ₄	1.50	1.60	1.60	1.80b	1.67b	1.53bc	1.60bc	2.00b	1.50b	2.00b	1.50b	1.67b
SE (±)	0.35	0.39	0.39	0.46	0.65	0.59	0.45	0.61	0.30	0.61	0.30	0.48
CV (%)	28.45	25.94	18.64	41.13	63.35	56.22	34.64	49.95	27.45	49.95	27.45	29.52
LSD 0.05	0.22	0.63	0.19	1.14	0.88	0.96	0.53	1.14	0.07	1.14	0.07	0.26
Level of significance	NS	NS	NS	**	**	**	*	*	**	*	**	*

T₀ = Untreated control, T₁ = Spinosad (tracer 45SC) @ 0.4 mL/L water, T₂ = Buprofezin (Award 40SC) @ 1.0 mL/L water, T = Pyriproxifen 10.8 EC 1.0 mL/L water, T₄ = Emeactin benzoate (Suspend 5SG) @ 1.0 g/L water. *Significant at 5% level (p < 0.05), **Significant at 1% level (p < 0.01), and NS = Non-significant.

Table 5. Efficacy of biorational insecticides on extent of damage of fruit (cm).

Treatments	Pre-treatment	Extent of fruit damage (cm) after different sprays										Grand Mean
		1 st		2 nd		3 rd		4 th		5 th		
		4DAS	7DAS	4DAS	7DAS	4DAS	7DAS	4DAS	7DAS	4DAS	7DAS	
T ₀	2.50	2.60	2.70a	3.38a	4.14a	4.77a	7.09a	8.90a	11.96a	12.50	11.75	6.47a
T ₁	2.00	1.80	1.60c	1.40c	1.39c	1.31c	1.20c	1.10c	1.00c	1.5	1.0	1.29b
T ₂	1.90	2.03	1.75c	1.67bc	1.96bc	2.67b	3.67b	3.50bc	3.33b	4.5	3.5	2.68b
T ₃	2.60	2.33	2.73b	2.35b	2.92b	2.00b	2.76b	2.00b	2.33bc	2.5	2.0	2.68b
T ₄	2.20	2.10	2.00b	1.90bc	1.82bc	1.74bc	1.60bc	1.50bc	1.40bc	2.0	2.5	1.71b
SE (±)	0.58	0.61	0.52	0.52	0.61	0.74	0.94	0.85	1.08	1.12	0.95	0.73
CV (%)	4.92	3.83	8.27	6.56	8.21	11.09	4.76	7.51	7.07	6.5	6.33	2.57
LSD 0.05	2.53	2.53	0.55	0.83	0.88	1.26	0.52	2.02	1.35	1.50	1.20	1.10
Level of significance	NS	NS	**	**	**	**	**	**	**	**	**	**

T₀ = Untreated control, T₁ = Spinosad (tracer 45SC) @ 0.4 mL/L water, T₂ = Buprofezin (Award 40SC) @ 1.0 mL/L water, T₃ = Pyriproxifen 10.8 EC 1.0 mL/L water,

T₄ = Emeactin benzoate (Suspend 5SG) @ 1.0 g/L water. *Significant at 5% level (p < 0.05), **Significant at 1% level (p < 0.01), and NS = Non-significant.

All biorational insecticides significantly reduced the extent of fruit damage compared with the untreated control (Table 5). Among the treatments, T₁ exhibited the highest efficacy, recording the lowest overall mean damaged fruit portion (1.29 cm), followed by T₄, which showed the second-highest efficacy with a mean damaged portion of 1.71 cm. In contrast, the untreated control recorded the highest overall mean damaged fruit portion (6.47 cm) (Table 5). A similar trend in treatment efficacy was observed up to the fourth spray at both 4 and 7 DAS. However, after the fifth spray, T₂ and T₃ exhibited statistically similar effects on fruit infestation, whereas T₁ and T₄ maintained the highest and statistically comparable efficacy against BSFB. Conversely, the untreated

control exhibited the greatest level of fruit damage, with a damaged portion of 12.50 cm recorded at 4 DAS after the fifth spray.

Efficacy of biorational insecticides on marketable yield and percentage protection over control

All biorational insecticides had significant effects on the marketable yield (t ha⁻¹) of brinjal and on percentage protection over the untreated control. Figure 4 illustrates the marketable yield obtained under different treatments, while Figure 5 presents the percentage protection over control for each treatment.

As shown in Figure 4, treatment T₁ produced the highest marketable fruit yield (26.6 t/ha), followed by T₄, which recorded the second-highest yield

(22.7 t/ha). In addition, treatments T₂ and T₃ produced comparable marketable fruit yields of 19.9 t/ha and 18.7 t/ha, respectively. In contrast, the untreated control (T₀) resulted in the lowest marketable fruit yield (4.46 t/ha).

Efficacy of biorational insecticides in terms of percentage protection over control

The efficacy of biorational insecticides, expressed as percentage protection over the untreated control, is presented in Figure 5. Treatment T₁ exhibited the highest level of protection (83.23%), followed by T₄ with the second-highest protection (80.35%). Treatments T₂ and T₃ provided comparable levels of protection over the control, recording 77.59% and 76.15% protection, respectively.

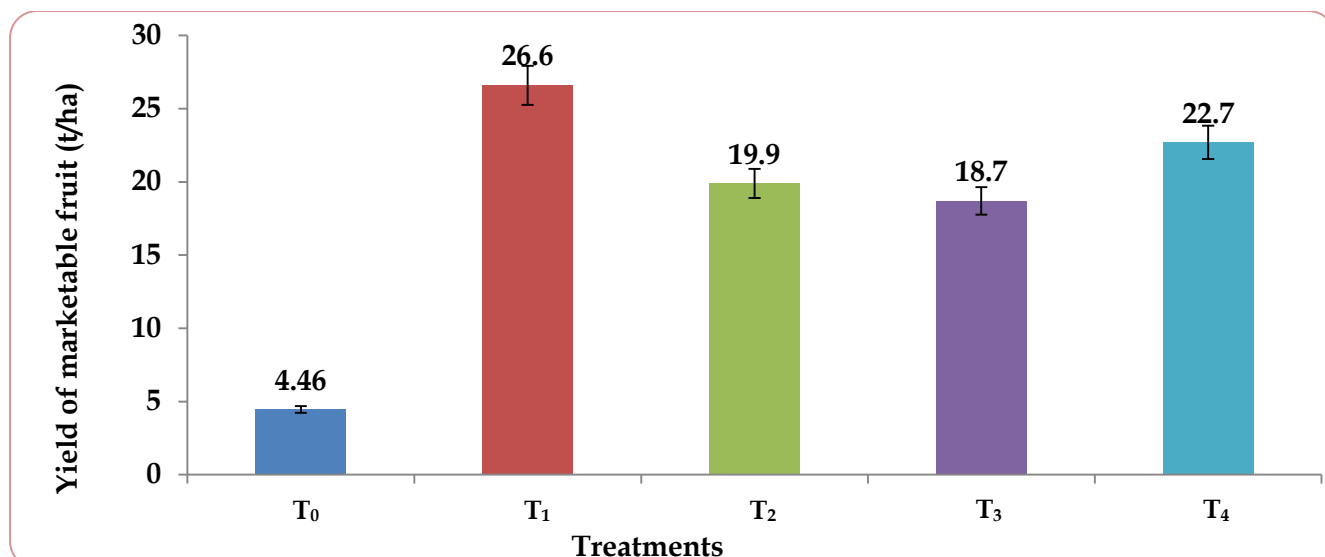


Figure 4. Effect of biorational insecticides on marketable yield (t/ha) of brinjal. T₀ = Untreated control, T₁ = Spinosad (tracer 45SC) @ 0.4 mL/L water, T₂ = Buprofezin (Award 40SC) @ 1.0 mL/L water, T₃ = Pyriproxifen 10.8 EC 1.0 mL/L water, T₄ = Emamectin benzoate (Suspend 5SG) @ 1.0 g/L water.

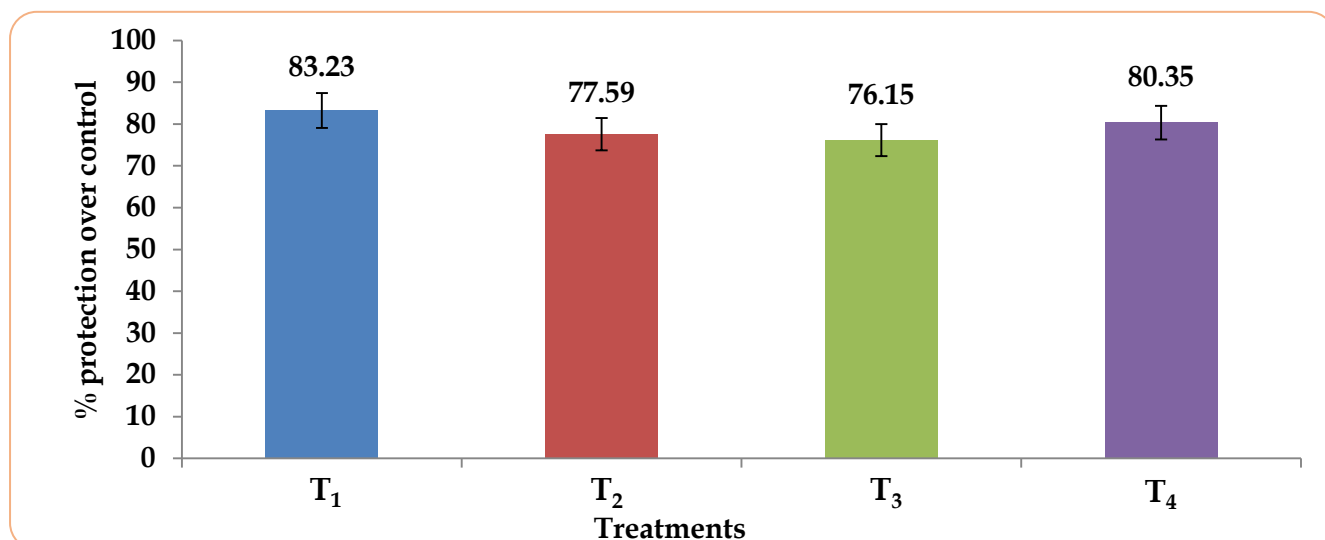


Figure 5. Effect of biorational insecticides on % protection over control. T₁ = Spinosad (tracer 45SC) @ 0.4 mL/L water, T₂ = Buprofezin (Award 40SC) @ 1.0 mL/L water, T₃ = Pyriproxifen 10.8 EC 1.0 mL/L water, T₄ = Emamectin benzoate (Suspend 5SG) @ 1.0 g/L water.

BCR Calculation

The effects of different treatments on the yield of marketable fruits are presented in Table 6. The market price of healthy brinjal fruits was Tk 30 kg⁻¹. The cost of applying Spinosad (Tracer 45SC) at 0.4 mL L⁻¹ water was Tk 20,000 ha⁻¹, with a total production cost of Tk 240,000 ha⁻¹ and a net return of Tk 785,700 ha⁻¹. The cost of Buprofezin (Award 40SC) applied at 1.0 mL L⁻¹ water was Tk 21,000 ha⁻¹, resulting in a total production cost of Tk 250,000 ha⁻¹ and a net return of Tk 597,000 ha⁻¹. Similarly, the application cost of Pyriproxifen 10.8 EC at 1.0 mL L⁻¹ water was Tk 19,000 ha⁻¹, while the total production cost and net

return were Tk 597,600 ha⁻¹ and Tk 342,600 ha⁻¹, respectively. In the case of Emamectin Benzoate (Suspended 5SG), the total production cost was Tk 230,000 ha⁻¹, and the net return obtained from the treated plot was Tk 681,000 ha⁻¹.

Table 6 also presents the Benefit-Cost Ratio (BCR) of the tested treatments. The highest BCR (3.30) was recorded in T₁, indicating that each unit of investment generated a return of 3.30 units, thereby demonstrating its superior economic feasibility and suitability for brinjal production. T₂, an insect growth regulator that inhibits chitin synthesis, produced a marketable yield of 19.90 t ha⁻¹ with a BCR of 2.38, reflecting satisfactory economic

returns despite being lower than T_1 . Likewise, T_3 , which acts by mimicking juvenile hormone and disrupting larval development, produced a yield of 19.20 t ha^{-1} with a BCR of 2.34. Although comparatively lower than the other treatments, it still provided positive economic returns and may serve as a viable management option.

T_4 showed effectiveness against a wide range of insect pests and produced a yield of 22.70 t ha^{-1} , which was higher than T_2 and T_3 but slightly lower than T_1 . The BCR of T_4 was 2.96, indicating favorable economic returns and highlighting its potential suitability for adoption by farmers.

Table 6. Comparative BCR under different treatments in managing BSFB.

Treatments	Yield (t/ha)	Total cost Tk /ha	Net Return Tk/ha	B:C
Spinosad (T_1)	26.19	240000	785700	3.30
Buprofezin (T_2)	19.90	250000	597000	2.38
Pyriproxifen 10 EC (T_3)	19.20	255000	597600	2.34
Emamectin Benzoate (T_4)	22.70	230000	681000	2.96

Discussion

Biopesticides represent an effective and environmentally compatible approach for pest management while minimizing risks to beneficial organisms. Their selective toxicity and compatibility with Integrated Pest Management (IPM) and Biointensive IPM (BIPM) programmes make them increasingly important alternatives to conventional synthetic insecticides in sustainable vegetable production systems. The present study evaluated four biorational insecticides, Spinosad, Emamectin benzoate, Buprofezin, and Pyriproxifen, against *Leucinodes orbonalis* under field conditions in Bangladesh. The results clearly demonstrated significant differences in efficacy among the tested compounds.

Spinosad (Tracer 45SC) acts by disrupting nicotinic acetylcholine receptors and GABA-gated chloride channels in the insect nervous system, resulting in rapid knockdown and prolonged residual activity. Emamectin benzoate similarly targets glutamate-gated chloride channels, causing paralysis and mortality in larval stages. Buprofezin, an insect growth regulator (IGR), inhibits chitin synthesis and disrupts moulting, whereas Pyriproxifen mimics juvenile hormone activity, thereby preventing normal larval development and adult emergence. Differences in the modes of action of these compounds likely explain the variation in field efficacy observed in the present study, with the neurotoxic compounds, particularly Spinosad and Emamectin benzoate, providing faster and more consistent suppression of actively feeding larvae.

All tested insecticides significantly reduced shoot and fruit infestation compared with the untreated control, supporting their inclusion in BIPM strategies for the management of brinjal shoot and fruit borer. Among the evaluated treatments, Spinosad (Tracer 45SC) proved to be the most effective insecticide under field

conditions, resulting in the lowest infestation levels, highest marketable fruit yield, and most favorable benefit-cost ratio (BCR = 3.30). The superior performance of Spinosad observed in the present study is consistent with numerous reports from South and Southeast Asia, although variation exists regarding the relative performance of other insecticides.

Tiwari et al. (2011) reported Emamectin benzoate as the most effective insecticide against BSFB, followed by Spinosad, Cypermethrin, Chlorpyrifos, neem oil, NSKE, and *Bacillus thuringiensis*. In contrast, the present study ranked Spinosad above Emamectin benzoate. Such discrepancies may arise from differences in formulation concentration, application timing, pest pressure, cropping season, and agro-climatic conditions between Bangladesh and other regions, highlighting the importance of region-specific field validation rather than direct extrapolation of findings across environments.

Naik et al. (2008) reported that Profenophos (0.1%) and Spinosad (0.015%) were highly effective in reducing shoot infestation of *L. orbonalis* and increasing aubergine yield, with Profenophos ranking slightly higher than Spinosad among the fifteen tested treatments. Yousafi et al. (2018) identified Flubendiamide and Emamectin benzoate as the most effective treatments against shoot infestation, while Anwar et al. (2015) recommended Emamectin benzoate for the management of brinjal fruit borer. Similarly, Gayathri et al. (2019) described BSFB as one of the most destructive pests of brinjal in South Asia and concluded that Spinosad 45SC was highly effective in reducing infestation and increasing yield.

Omprakash and Raju (2018) evaluated several novel insecticide molecules and reported that Spinosad exhibited the highest efficacy against *L. orbonalis*, followed by Triazophos, whereas combination

treatments showed moderate suppression of shoot and fruit damage. Ambulkar et al. (2020) also reported Spinosad as the most effective treatment, followed by Emamectin benzoate, Flubendiamide, and neem oil. Likewise, Atwal et al. (1976) observed that Tracer 45SC produced the highest number of healthy fruits per plant and the greatest brinjal yield per hectare.

Niranjana et al. (2019) demonstrated the high efficacy of Spinosad 2.5 SC and Flubendiamide 20WG against *L. orbonalis*, with Chlorantraniliprole 18.5 SC ranking second. Akter et al. (2018) reported the lowest shoot infestation in plots treated with Tracer 45SC (2.5%), followed by Proclaim 5SG (4.06%), compared with the untreated control (17.37%). Tracer 45SC reduced shoot infestation by 85.60% over the control, whereas Proclaim 5SG reduced infestation by 76.62%. Devi et al. (2014) similarly reported that Spinosad at 50 g ha⁻¹ was the most effective biorational insecticide against shoot and fruit infestation.

Tripura et al. (2017) found Chlorantraniliprole to be the most effective insecticide for reducing both shoot and fruit infestation. Islam et al. (2016) reported that the combined application of Buprofezin and Emamectin benzoate effectively reduced shoot and fruit infestation, while Spinosad, Abamectin, and Emamectin benzoate also provided satisfactory control. Kalawate and Dethe (2012) concluded that Spinosad was highly effective in reducing fruit infestation and increasing brinjal yield. Similarly, Khare and Sneha (2021) identified Spinosad as the most effective treatment against BSFB, while Emamectin benzoate also exhibited substantial efficacy. Patra et al. (2009) reported that Spinosad 2.5 SC resulted in the lowest infestation rates. Awal et al. (2017) demonstrated that Tracer 45SC reduced shoot infestation by 88.22% and 84.41% over the control during summer and winter seasons, respectively. Adiroubane and Raghuraman (2008) found Oxymatrine 1.2 EC and Spinosad 45SC effective during early vegetative and fruiting stages, respectively. Overall, the findings of the present study are in close agreement with the majority of earlier reports, confirming the consistent efficacy of Spinosad against BSFB.

A notable contribution of the present study is the simultaneous evaluation of biological efficacy and economic returns under Bangladesh field conditions. The higher BCR obtained with Spinosad (3.30), compared with Emamectin benzoate (2.96) and Buprofezin (2.38), indicates that the superior pest suppression achieved by Spinosad translated directly into greater economic returns for smallholder brinjal farmers. This finding is particularly important because

minimizing production costs while maximizing marketable yield remains a major concern for resource-limited farmers in Bangladesh.

In contrast, the comparatively lower BCR values recorded for Pyriproxifen and Buprofezin, despite their significant reduction of pest infestation, suggest that these compounds may be more suitable as rotational components within an insecticide resistance management program rather than as stand-alone treatments. From a resistance management perspective, continuous reliance on a single active ingredient such as Spinosad may increase selection pressure and accelerate resistance development in BSFB populations. Therefore, rotation among insecticides with different modes of action, such as alternating Spinosad (Group 5) with Emamectin benzoate (Group 6), while incorporating insect growth regulators such as Buprofezin (Group 16) and Pyriproxifen (Group 7C), would be advisable within a structured BIPM program. Furthermore, integrating biorational insecticides with other IPM practices, including pheromone trap-based monitoring, mechanical removal of infested shoots and fruits, field sanitation, and the use of resistant or tolerant brinjal varieties, could further reduce dependence on chemical insecticides and enhance the long-term sustainability of BSFB management programs.

Conclusions

In conclusion, the present field study clearly demonstrated the effectiveness of biorational insecticides in managing *L. orbonalis* infestation in brinjal. Among the evaluated treatments, Spinosad (Tracer 45 SC) provided the highest level of control by significantly reducing shoot and fruit infestation, larval population, and fruit damage, while simultaneously maximizing yield and economic return. Emamectin benzoate also exhibited high efficacy in suppressing pest infestation and improving profitability. Although Pyriproxifen and Buprofezin showed comparatively moderate effectiveness, both treatments performed substantially better than the untreated control.

These findings highlight the potential of biorational insecticides as an important component of sustainable pest management strategies in brinjal cultivation. Their adoption can contribute to reduced environmental contamination, conservation of beneficial arthropods, and safer food production systems.

Future Perspectives

Future research should focus on integrating biorational insecticides with other eco-friendly approaches,

including biological control agents, host plant resistance, and pheromone-based monitoring and trapping systems. Such an integrated pest management approach would further strengthen the development of sustainable, environmentally sound, and long-term management strategies for brinjal shoot and fruit borer in Bangladesh and other affected regions.

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Author Contributions

MMU and KMBH conceptualized and designed the experiment. KMBH conducted the field investigations and executed the experimental work. MMU provided overall supervision and ensured methodological and analytical consistency throughout the study. MAH and GD contributed as co-supervisors, offering critical guidance on experimental design, data interpretation, and research refinement at various stages of the project. KMBH, TT, EZE, MMK, and SD were involved in the preparation of the initial manuscript draft, including structuring the content, compiling results, and integrating preliminary interpretations. Subsequently, all authors critically reviewed the manuscript, contributed to intellectual refinement, cross-checked the data and analyses, and approved the final version for submission.

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Conflict of Interest

The authors declare no conflict of interest.

Sustainable Development Goals Targeted

SDG 2: Zero Hunger

SDG 12: Responsible Consumption and Production

SDG 13: Climate Action

Policy Addressed

This study supports Integrated Pest Management

(IPM) and sustainable crop protection policies by promoting biorational insecticides for eco-friendly management of *Leucinodes orbonalis* in brinjal. The findings align with the recommendations of the Food and Agriculture Organization and the International Plant Protection Convention for reducing chemical pesticide use and promoting environmentally sustainable agriculture.

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