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Assessing Microbial Insecticides for Controlling Eggplant Shoot and Fruit Borer (*Leucinodes orbonalis* Guenee)

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ABSTRACT

The fruit borer and eggplant shoot is a major pest in Bangladesh, causing significant damage to crops. Farmers often rely on chemical insecticides for control, which can have adverse environmental and health effects. This study aimed to evaluate the efficacy of microbial insecticides as an alternative approach for managing ESFB and improving yield. The treatments with abamectin 1.2% + emamectin benzoate 1%, spinosad 45 SC, and *Bacillus thuringiensis* var. *kurstaki* 5% WP significantly reduced shoot damage compared to the untreated control. Similarly, fruit infestation was significantly reduced in both quantity and weight with these treatments. The use of spinosad 45 SC and abamectin 1.2% + emamectin benzoate 1% led to a remarkable increase in marketable yield. In addition, spinosad 45 SC showed a prominent effect in boosting overall production. This study highlights that microbial insecticides, especially spinosad 45 SC and abamectin 1.2% + emamectin benzoate 1%, are effective in limiting ESFB damage to shoots and fruits while enhancing marketable fruit production by increasing the proportion of healthy fruit and minimizing losses due to infestation.

Keywords: Microbial insecticides, *Leucinodes orbonalis*, Spinosad, Abamectin, *Bacillus thuringiensis*, Emamectin benzoate

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Introduction

Eggplant (*Solanum melongena* L.), commonly known as aubergine or brinjal, ranks as the 5th most economically significant crop in the Solanaceae family, following potatoes, tomatoes, peppers, and tobacco [1]. Widely cultivated in the Indian subcontinent [2], Central America, and parts of Africa [3], it thrives in warm, humid climates [4]. Other varieties such as the scarlet eggplant (*S. aethiopicum* L.) and African eggplant (*S. macrocarpon* L.) are also cultivated in sub-Saharan Africa, where they hold local significance [5]. With global production nearing 50 million tons annually, eggplant generates over US$10 billion in revenue each year [6]. Rich in bioactive compounds essential vitamins and minerals, eggplants provide significant nutritional value while being low in calories [7, 8]. Notably, phenolic compounds like anthocyanins in the skin and chlorogenic acid in the flesh enhance the health benefits of eggplants, contributing to their bioactive properties [9-12].

Increased fruiting and extended harvest periods, alongside higher yields and nutritional value, have led to a rise in eggplant cultivation [13-15]. In Bangladesh, brinjal is grown on 50,955 hectares with a production volume of

507,000 metric tons [16], making it the 2nd most important vegetable crop in the country. However, eggplant production faces significant challenges due to rising costs associated with managing various insect pests that affect plants from seedling to fruiting stages [17]. Eggplant is vulnerable to a range of pests, including mites, whiteflies, aphids, leafhoppers, spotted beetles, thrips, stem borers, blister beetles, and notably, the eggplant shoot and fruit borer (*Leucinodes orbonalis* Guenee) [17]. Among these, the eggplant shoot and fruit borer (ESFB) is the most damaging pest, especially in South Asia, where it severely impacts production [18-21]. Managing ESFB is particularly challenging because its larvae burrow into the fruit and block the entry with frass, protecting them from insecticides and natural predators [22]. This internal feeding behavior leads to a significant loss of vitamin C (up to 80%) and market value, with potential yield losses reaching up to 90% [23, 24]. The heavy reliance on chemical insecticides to control ESFB contributes to issues such as pesticide resistance, environmental degradation, and the mortality of beneficial insects like ladybird beetles and stink bugs [25-27].
Microbial insecticides offer a promising alternative to synthetic chemicals, presenting a less hazardous option for pest management in eggplant cultivation [28]. These biocontrol agents are believed to exert their effects through immune suppression [29, 30], toxemia [31], or inducing apoptosis in pest cells [32]. This study aims to evaluate the effectiveness of microbial insecticides as viable replacements for synthetic chemicals in controlling the fruit borer and eggplant shoot.

Materials and Methods

Study location and soil properties

The trial was conducted in Gazipur, Bangladesh, using the 'Singnath' variety of eggplant during the Kharif season to measure the efficacy of microbial insecticides in controlling the eggplant shoot and fruit borer (*L. orbonalis*) and their effects on crop yield. The site is located at 24.09° N latitude and 90.26° E longitude. This region is part of the Agro-Ecological Zone of Madhupur Tract (AEZ-28), with silty clay loam soil exhibiting a pH range of 5.8–6.5 and a cation exchange capacity (CEC) of 25.58 [33].

Experimental design and treatment application

A randomized complete block design was implemented, consisting of three replications. Each plot measured 10.0 x 2.0 meters, with a 0.7-meter spacing between plants and rows. Two rows of 13 plants each were planted per plot. Standard crop management practices were followed, including intercultural operations and fertilization as required [25].
The treatments tested:

- Spinosad 45 SC at a rate of 0.2 mL/L (T1)
- *Bacillus thuringiensis* var. *kurstaki* 5% WP at 1.5 g/L (T2)
- Carbosulfan 20 EC at 3 mL/L (T3)
- Abamectin 1.2% + emamectin benzoate 1% at 2.0 mL/L (T4)
- Water as a control (T5)

The synthetic insecticide was purchased from a local supplier, while the microbial insecticides were sourced from Russell IPM, UK. Treatment details are listed in **Table 1**. Water was added to the insecticide mixtures to achieve the correct concentrations for effective spraying. The application was done with a knapsack sprayer, delivering 500 to 750 liters of spray mixture per hectare, depending on the plant growth stage. Spraying commenced during the vegetative stage and continued every 7 days until harvest.

Table 1. List of insecticides used in this study with their information

Trade name	Common name	Trading Company	Dose
Tracer 45 SC	Spinosad 45 SC	Auto Crop Care Ltd.	0.2 mL/L
Antario 32 KAB	*Bacillus thuringiensis* var. *kurstaki* 5% WP	Russell IPM, UK	1.5 g/L
Marshal 20 EC	Carbosulfan 20 EC	Auto Crop Care Ltd.	3 mL/L
Biotin M	Abamectin 1.2% + emamectin benzoate 1%	Russell IPM, UK	2.5 mL/L

Data collection and evaluation

Shoot infestation levels were recorded every third day across all plots. The number of healthy shoots was noted, and the number of infestations was calculated in percentages. Fruits were harvested every five days from all the plants within each plot, and the fruits were categorized into healthy and infested groups. The total count and weight of infested fruits were saved separately at each harvest, and the percentage of fruit damage was calculated. The overall yield was determined by adding the weights of healthy and infested fruits across all harvests and then converted to tons per hectare. The weight of individual fruits was also measured. A total of eight observations for both shoot and fruit infestations were made. The percentage of shoot and fruit damage was calculated using the following formula:

$$Percent\ (\%)\ shoot/fruit\ infestation = \frac{Number\ of\ infested\ shoot/fruits}{Total\ number\ of\ shoot/fruits} \times 100 \quad (1)$$

$$\text{Percent (\%) increase/reduction over control} = \frac{\text{Mean value of the control} - \text{Mean value of the treatment}}{Mean\ value\ of\ the\ control} \times 100 \quad (2)$$

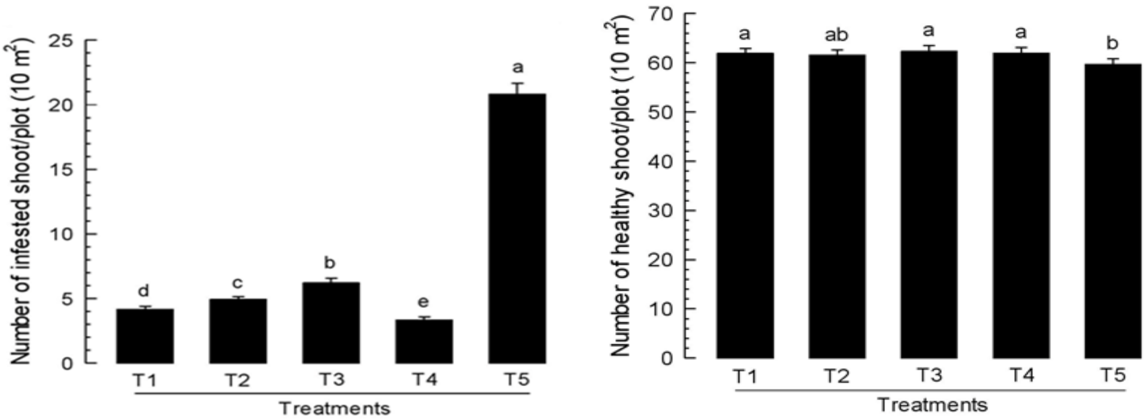
Statistical analysis

Data were organized and analyzed using Microsoft Excel. All continuous variables underwent a one-way analysis of variance (ANOVA) using the PROG GLM procedure in SAS software [34]. Means were compared using the least significant difference (LSD) test at a 0.05 significance level. The data were presented in graphical form using SigmaPlot 12.5. Each treatment was repeated three times with eight observations per treatment. Significant differences among treatments were indicated by different letters above the error bars ($P < 0.05$, LSD Test).

Results and Discussion

Impact of microbial insecticides on shoot damage and plant health

The eggplant shoot and fruit borer (*L. orbonalis*) significantly affects eggplant plants during both the vegetative and reproductive phases, causing shoot wilting and eventual death. In this study, we evaluated the effectiveness of several microbial insecticides in reducing shoot infestation caused by this pest **(Figure 1)**. All treatments demonstrated a significant reduction in shoot infestation compared to the untreated control ($P < 0.05$). Among the insecticides tested, abamectin 1.2% + emamectin benzoate 1% and spinosad 45 SC were the most effective in controlling infestation **(Figure 1a)**. These treatments also enhanced the overall health of the shoots, with spinosad 45 SC and Carbosulfan 20 EC promoting better shoot development **(Figure 1b)**. The infestation levels varied across treatments, with abamectin 1.2% + emamectin benzoate 1% and spinosad 45 SC showing the lowest rates of damage, while Carbosulfan 20 EC showed the highest infestation levels **(Figure 1c)**. When compared to the untreated control, abamectin 1.2% + emamectin benzoate 1% and spinosad 45 SC reduced infestation by 75.76% and 71.43%, respectively. These findings suggest that abamectin 1.2% + emamectin benzoate 1% and spinosad 45 SC are highly effective in mitigating shoot damage caused by the fruit borer and eggplant shoot.



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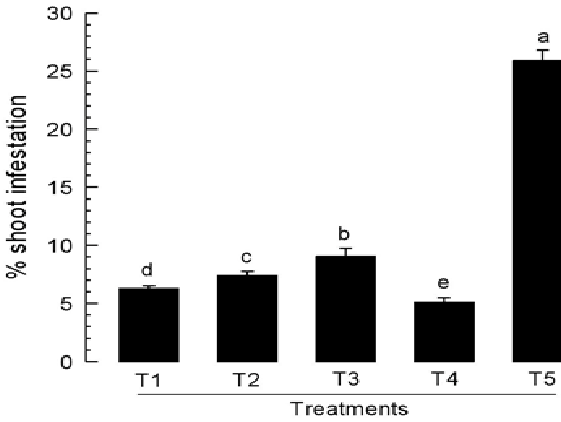

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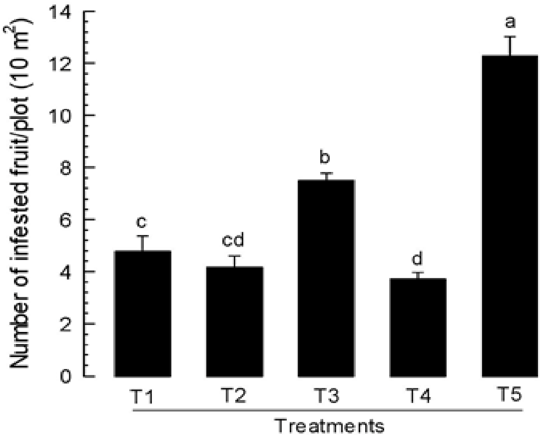
Figure 1. Impact of insecticides on shoot damage caused by the eggplant shoot and fruit borer; a) count of infested shoots per plot, b) count of healthy shoots per plot, and c) percentage reduction in shoot infestation due to insecticide treatments.

Effect of insecticides on fruit damage

The eggplant shoot and fruit borer invade the inner flesh of the fruit, leading to considerable harm. In this study, the use of microbial insecticides significantly ($P < 0.05$) reduced the level of fruit infestation **(Figure 2)**. The degree of infestation varied depending on the insecticide applied **(Figure 2a)**. Among the treatments, abamectin 1.2% + emamectin benzoate 1% and *Bacillus thuringiensis* var. *kurstaki* 5% WP was notably more effective than carbosulfan 20 EC and spinosad 45 SC in reducing fruit damage. Additionally, these insecticides had a positive impact on the production of healthy fruits **(Figure 2b)**, with abamectin 1.2% + emamectin benzoate 1% and spinosad 45 SC contributing to a higher number of healthy fruits in comparison to the other treatments. Furthermore, microbial insecticides proved effective in controlling the infestation rate in fruits **(Figure 2c)**. When compared to the control group, abamectin 1.2% + emamectin benzoate 1% and spinosad 45 SC showed lower infestation rates than *Bacillus thuringiensis* var. *kurstaki* 5% WP and Carbosulfan 20 EC. The percentage of damage reduction in fruits when compared to the control was used to assess the insecticides' efficacy. In this case, abamectin 1.2% + emamectin benzoate 1% achieved the highest reduction of 70.88%, followed by spinosad 45 SC (66.39%), *Bacillus thuringiensis* var. *kurstaki* 5% WP (63.69%), and Carbosulfan 20 EC (46.09%).



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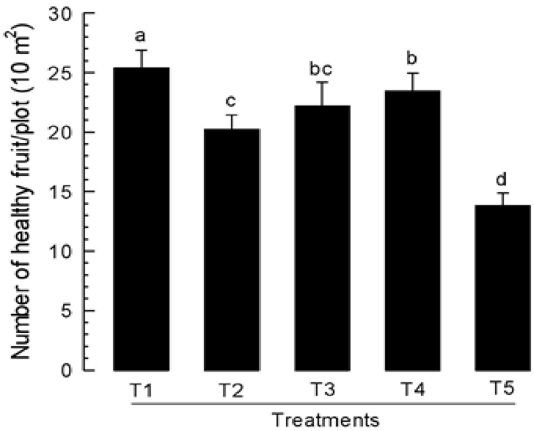

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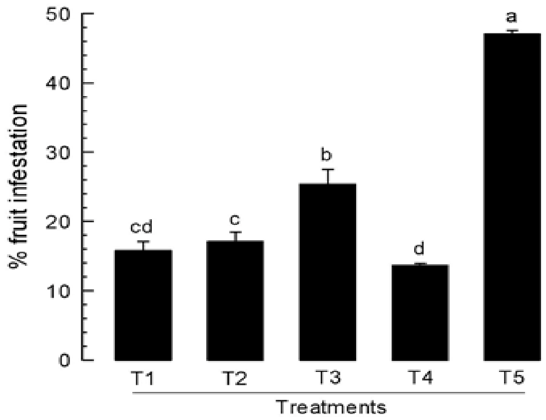

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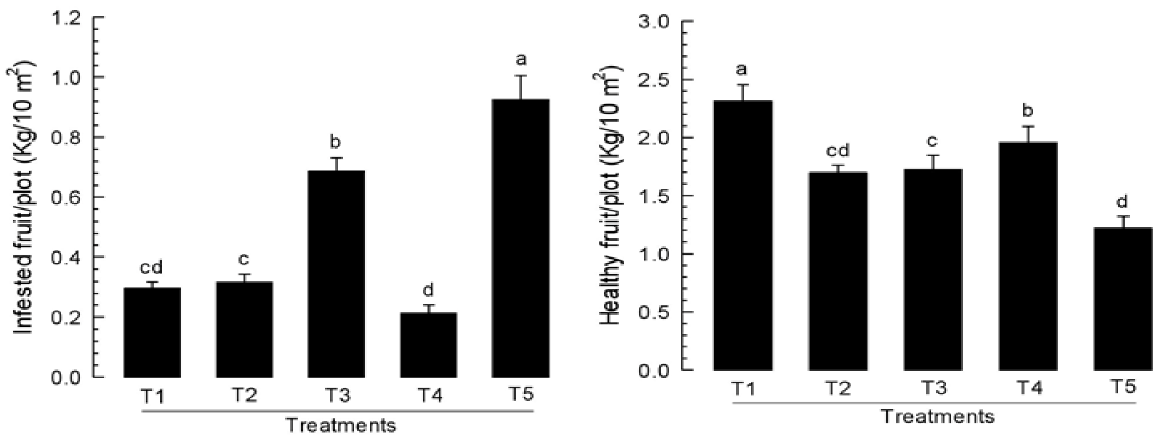
Figure 2. Impact of microbial insecticides on fruit infestation (on a per-fruit basis) caused by the eggplant shoot and fruit borer; a) total number of infested fruits in each plot, b) total number of healthy fruits in each plot, and c) percentage of fruit infestation (on a per-fruit basis).

Microbial insecticides demonstrated a notable ($P < 0.05$) influence in reducing fruit infestation based on weight **(Figure 3)**. Among the treatments applied, abamectin 1.2% + emamectin benzoate 1% and spinosad 45 SC showed a significant reduction in infested fruit compared to Carbosulfan 20 EC and *Bacillus thuringiensis* var. *kurstaki* 5% WP, as well as the control group **(Figure 3a)**. In terms of healthy fruit production, higher quantities were observed from spinosad 45 SC and abamectin 1.2% + emamectin benzoate 1% compared to Carbosulfan 20 EC and *Bacillus thuringiensis* var. *kurstaki* 5% WP **(Figure 3b)**. Consequently, the lowest fruit infestation percentage by weight was seen with abamectin 1.2% + emamectin benzoate 1%, followed by spinosad 45 SC, *Bacillus thuringiensis* var. *kurstaki* 5% WP, and Carbosulfan 20 EC, with the highest infestation in the control group (43.24%) **(Figure 3c)**. The reduction in fruit infestation across treatments can be explained by the percentage decrease in infestation relative to the control. Abamectin 1.2% + emamectin benzoate 1% showed the greatest efficacy with a 77.41% reduction, followed by spinosad 45 SC (73.68%), *Bacillus thuringiensis* var. *kurstaki* 5% WP (63.62%), and Carbosulfan 20 EC (34.07%). These findings suggest that microbial insecticides, particularly abamectin 1.2% + emamectin benzoate 1% and spinosad 45 SC, are highly effective in controlling the fruit borer and eggplant shoot.



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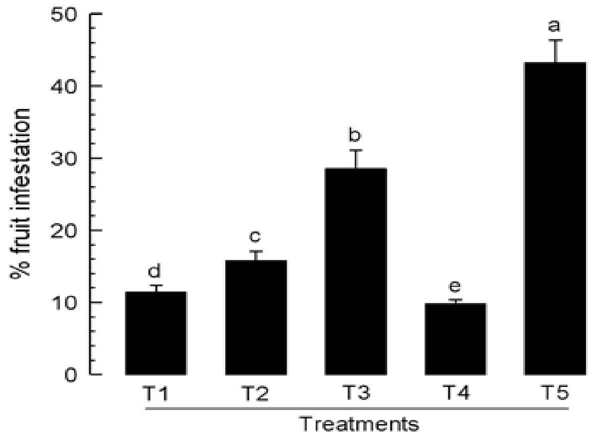

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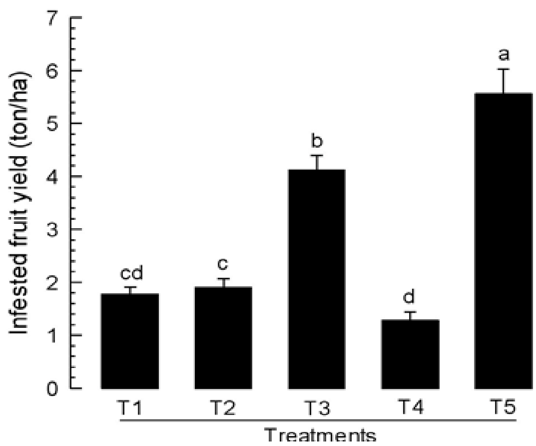
Figure 3. Impact of insecticides on fruit infestation (based on weight) caused by the eggplant shoot and fruit borer; a) quantity of infested fruits per plot, b) quantity of healthy fruits per plot, and c) percentage of fruit infestation (weight-based).

Effect of insecticides on eggplant yield

Eggplant yield is largely influenced by how effectively eggplant shoot and fruit borer (ESFB) infestations are managed. In this study, microbial insecticides demonstrated significant ($P < 0.05$) effectiveness in reducing ESFB infestations and enhancing yield **(Figure 4)**. The fruit yield from infested plants was lower in the treatments of abamectin 1.2% + emamectin benzoate 1% and spinosad 45 SC compared to *Bacillus thuringiensis* var. *kurstaki* 5% WP and Carbosulfan 20 EC when compared to the control group **(Figure 4a)**. Additionally, the application of microbial insecticides resulted in a notable ($P < 0.05$) increase in the yield of marketable or healthy fruits **(Figure 4b)**. The highest marketable yield was observed with spinosad 45 SC, followed by abamectin 1.2% + emamectin benzoate 1%, Carbosulfan 20 EC, and *Bacillus thuringiensis* var. *kurstaki* 5% WP, with the control group yielding the least. In terms of gross yield, the insecticides also showed varying effects **(Figure 4c)**. Spinosad 45 SC provided the highest gross yield, comparable to Carbosulfan 20 EC, while *Bacillus thuringiensis* var. *kurstaki* 5% WP had a lower yield, similar to the control and abamectin 1.2% + emamectin benzoate 1%. Yield changes compared to control are further detailed in **Figure 4d**. The largest increase in marketable yield was seen with spinosad 45 SC (90.00%), followed by abamectin 1.2% + emamectin benzoate 1% (60.68%), Carbosulfan 20 EC (41.78%), and *Bacillus thuringiensis* var. *kurstaki* 5% WP (39.32%). However, gross yield showed a modest increase: spinosad 45 SC had a 21.71% increase, Carbosulfan 20 EC increased by 12.61%, Abamectin 1.2% + emamectin benzoate 1% showed a 1.25% increase, and *Bacillus thuringiensis* var. *kurstaki* 5% WP resulted in a 6.18% decrease. The findings suggest that spinosad 45 SC and abamectin 1.2% + emamectin benzoate 1% are highly effective in improving marketable fruit yield by controlling ESFB infestations.



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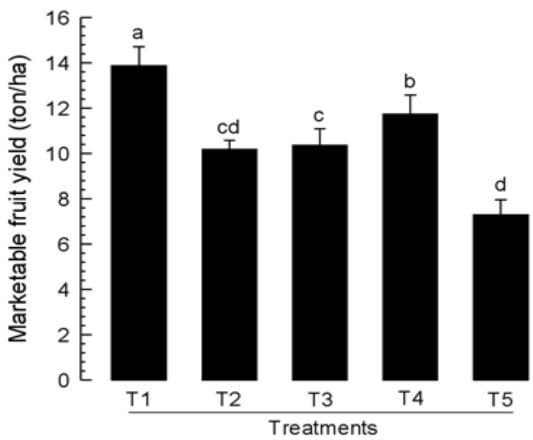

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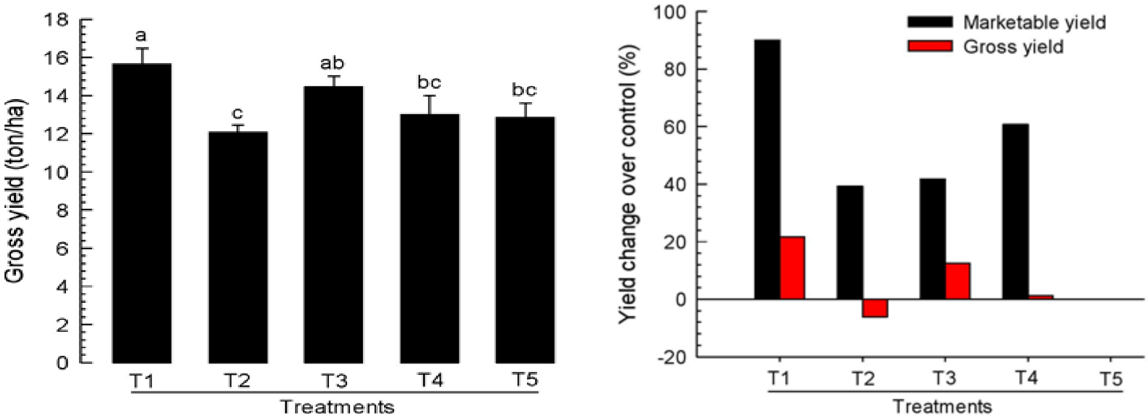
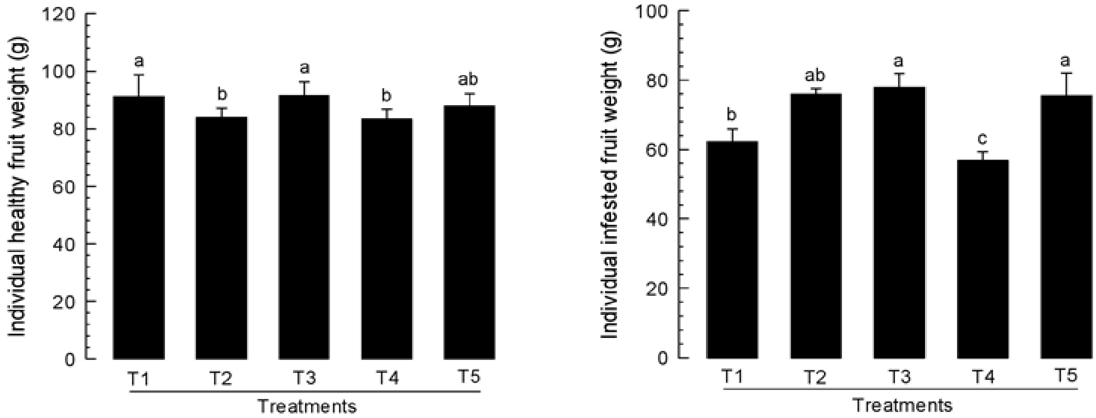


c) d)

Figure 4. Effect of insecticide on fruit yield by controlling eggplant shoot and fruit borer; a) infested fruit yield, b) marketable fruit yield, c) Gross yield, and d) Yield change over control.

Effect of insecticides on individual fruit weight

The larvae of the fruit borer and eggplant shoot damage the internal part of the fruit by feeding on it, which hampers the growth and development of the fruit, ultimately leading to reduced fruit weight. The application of insecticides showed significant ($P < 0.05$) results in mitigating weight loss, though their effects varied **(Figure 5)**. Among the insecticides, Carbosulfan 20 EC and spinosad 45 SC led to an increase in the weight of healthy fruits, with weight gains of 4.03% and 3.75%, respectively, over the control. On the other hand, *Bacillus thuringiensis* var. *kurstaki* 5% WP and abamectin 1.2% + emamectin benzoate 1% resulted in weight losses of 4.59% and 5.11%, respectively **(Figure 5a)**. Regarding infested fruits, Carbosulfan 20 EC and *Bacillus thuringiensis* var. *kurstaki* 5% WP showed weight gains of 3.29% and 0.62% over the control, while spinosad 45 SC and abamectin 1.2% + emamectin benzoate 1% experienced significant weight losses of 17.47% and 24.68%, respectively **(Figure 5b)**. When comparing the weight of healthy and infested fruits, spinosad 45 SC (28.93 g), abamectin 1.2% + emamectin benzoate 1% (26.58 g), and Carbosulfan 20 EC (13.50 g) all resulted in heavier fruits than the control (12.44 g). *Bacillus thuringiensis* var. *kurstaki* 5% WP, however, produced a lower weight (7.93 g) than the control **(Figure 5c)**. These findings indicate that spinosad 45 SC and abamectin 1.2% + emamectin benzoate 1% show promising potential in enhancing marketable fruit yield.



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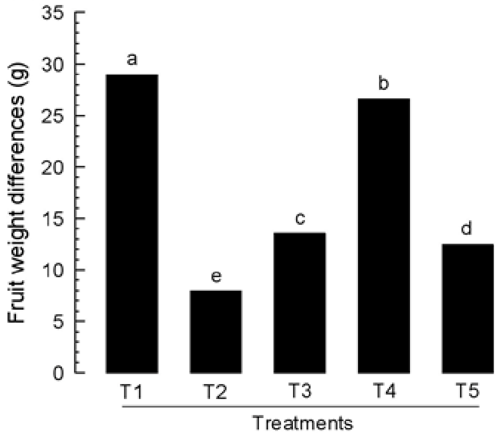

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Figure 5. Impact of insecticide on the weight of individual fruits; a) weight of individual healthy fruits, b) weight of individual infested fruits, and c) weight difference between healthy and infested fruits.

Microbial insecticides have shown considerable promise in controlling significant pests of eggplant, resulting in enhanced yields. In this study, treatments with spinosad 45 SG, *Bacillus thuringiensis* var. *kurstaki* 5% WP, Carbosulfan 20 EC, and abamectin 1.2% + emamectin benzoate 1% were all effective in managing infestations caused by the eggplant shoot and fruit borer larvae, particularly when compared to the untreated control. Among these treatments, the most effective results were observed with abamectin 1.2% + emamectin benzoate 1%, spinosad 45 SG, and *Bacillus thuringiensis* var. *kurstaki*. These findings align with previous research, such as Awal *et al*. [35], which demonstrated that spinosad 45 SC and emamectin benzoate 5 SG were highly effective in controlling shoot damage, achieving 88.22% and 84.41% control, respectively. Another study by Mane and Kumar [36] reported that emamectin benzoate 25 WG at 0.4 g/L and spinosad 45 SC at 0.5 ml/L resulted in minimal fruit damage, with values of 6.95% and 8.06%, respectively. In Yin [37], the application of Bt emulsion effectively controlled shoot and fruit borers with a control range of 78.8% to 100%. Similarly, Singh *et al*. [38] found that spinosad 45 SC and emamectin Benzoate 5 EC effectively reduced fruit borer infestations.

Microbial insecticides such as spinosad and abamectin + emamectin benzoate were also found to produce the highest yields of marketable, healthy fruit. This result is consistent with Mane and Kumar [36], where emamectin benzoate 25 WG at 0.4 g/L and spinosad 45 SC at 0.5 ml/L achieved marketable yields of 351.46 qt/ha and 341.75 qt/ha, respectively. Additionally, Singh *et al*. [38] found that both emamectin benzoate 5 EC and spinosad 45 SC produced the highest marketable fruit yields. Dipel 8L at 0.2% also resulted in notable marketable yields of 196.96 q/ha [39]. The microbial insecticides outperformed Carbosulfan 20 EC in their ability to control ESFB larvae. This success is likely due to the diverse mechanisms of action of microbial insecticides, including immune suppression, toxicity, and apoptosis [30-32]. Entomopathogenic bacteria, for example, release PLA2 inhibitors that reduce insect immunity [29, 30, 40]. Furthermore, certain microbial metabolites have an affinity for insect immune proteins, such as dorsal switch protein 1, which disrupts immune responses in insects like *Spodoptera exigua* [41]. Dorsal switch protein 1 also plays a role in immune function in other insects, including Tenebrio molitor [42]. While the mode of action of *Bacillus thuringiensis* is well understood, further research is needed to clarify how these microbial insecticides specifically target and eliminate *L. orbonalis* larvae.

Conclusion

The study evaluated various non-toxic microbial insecticides for their ability to control *L. orbonalis* (Eggplant Shoot and Fruit Borer, ESFB) and enhance eggplant yield. All the tested microbial insecticides demonstrated effectiveness in reducing ESFB infestations in both shoots and fruits. Among the treatments, abamectin 1.2% + emamectin benzoate 1% and spinosad 45 SC were identified as the most potent, also significantly increasing the marketable fruit yield.

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Conflict of Interest: None

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Ethics Statement: None

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