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RESEARCH

Evaluation of Bio-Rational Insecticides for Controlling Hemipteran Sucking Pests and Their Impact on Natural Enemies in Tomato (*Lycopersicon esculentum* Mill.) Cultivation at Sylhet Region in Bangladesh

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ABSTRACT

Purpose: *The purpose of this study was to comprehensively evaluate bio-rational insecticides in controlling major hemipteran-sucking pests of tomatoes and to assess their impact on natural enemies during the winter season of 2023-2024.*

Research Method: *The experiment was conducted with six treatments applied at 10-days intervals: Spinosad 45 SC, Matrine 1EC, Abamectin 1.8 EC, Azadirachtin 0.03% EC, Cypermethrin 10 EC, and an untreated control. The insecticides' effectiveness in reducing pest populations (aphids, jassids, and whiteflies) and the number of marketable and infested fruits, yield, adjusted net return, and BCR were recorded to compare the treatments.*

Findings and Values: *Spinosad 45 SC significantly reduced pest populations, recording the lowest abundance of aphids (3.25-4.18), jassids (0.75-0.90), and whiteflies (1.02-1.18) per six leaves per plant. It produced 88.36% increase in marketable fruits than control. Increases in marketable fruits of other treatments over the control were 63.58%, 44.61%, 36.85%, and 31.25%. Untreated control plots had the highest number of predatory insects, while Spinosad 45 SC-treated plots supported the second highest count (2.85-3.22), followed by Abamectin 1.8 EC (2.42-3.17), Matrine 1EC (2.59-2.94), and Azadirachtin 0.03% EC (2.24-2.79). All bio-rational insecticides were relatively safe for natural enemies, with Cypermethrin 10 EC showing moderate toxicity. The highest yield (21.07 t ha-1), adjusted net return, and Benefit Cost Ratio (BCR) (7.94) were observed in the Spinosad 45 SC treatment, followed by Azadirachtin 0.03% EC (5.51), Abamectin 1.8 EC (4.56), and Cypermethrin 10 EC (3.49). Overall, Spinosad 45 SC proved effective and eco-friendly for managing hemipteran pests in tomato.*

Keywords: *BCR, Hemipteran insects, IPM, Naturally derived insecticides, Tomato yield.*

INTRODUCTION

Tomato (*Lycopersicon esculentum* Mill.) is a key vegetable crop within the Solanaceae family,

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recognized globally for its importance, ranking third in production after potato and sweet potato in terms of processing crops (Quinet *et al.* 2019). In Bangladesh, the tomato holds a prominent position among vegetable crops, cultivated over approximately 29616.01 hectares, yielding a total of 442 thousand MT, with an average yield of 6.65 t ha^{-1} (BBS, 2022). Similarly, in India, tomatoes are grown across diverse regions, with cultivation spanning about 879,000 hectares, yielding 20.09 million T, and an average productivity of 22.81 t ha^{-1} (Anamika *et al.* 2024).

Tomatoes are rich in essential nutrients, including vitamins C and E, beta-carotene, minerals, and secondary metabolites beneficial for human health (Staropoli *et al.* 2024). They are a valuable source of antioxidants such as lycopene, flavonoids, phenolics, and organic acids (Ali *et al.* 2020). Additionally, tomato seeds and skin contain important amino acids, and seeds are particularly rich in minerals like iron, manganese, zinc, and copper (Elbadrawy & Sello, 2016). Beyond their fresh consumption, tomatoes are processed into a variety of products, including curry, juice, paste, ketchup, puree, and soups.

Tomato cultivation in Bangladesh occurs predominantly during the winter season, although it is also grown in summer. Yield levels can vary significantly based on factors such as location, variety, season, planting schedules, soil conditions, and pest pressures. Among these factors, insect pests are a major constraint to tomato production. The primary insect pests affecting tomatoes include the tomato fruit borer (*Helicoverpa armigera*) and various sucking pests. Sucking pests, such as whitefly (*Bemisia tabaci*), aphid (*Aphis gossypii*), jassid (*Amrasca biguttula*), thrips (*Scirtothrips dorsalis*), and stink bug (*Hylomorpha halys*), have emerged as particularly devastating, causing significant damage by feeding on plant cell sap with their piercing-sucking and/or rasping-sucking type of mouth parts (Sajjad *et al.* 2014).

This feeding behavior results in changes to leaf morphology, premature leaf drop, and fruit drop, all of which negatively affect both yield and fruit quality, ultimately leading to lower market prices. Furthermore, these pests excrete honeydew, a sugary substance that can lead to the growth of sooty mold on leaves and fruits, further impairing plant health (Ergin *et al.* 2024).

Whitefly is a particularly notable pest, causing direct damage to tomatoes and acting as a vector for the spread of leaf curl virus (Zhao *et al.* 2022). The yield loss caused by whiteflies due to direct damage and disease transmission can range from 20 to 100 percent (Díaz-Pendón *et al.* 2019). Aphids, jassids, and thrips being polyphagous, contribute to the spread of viral diseases, with studies indicating significant yield losses of 23.7% from thrips and 54% from jassids (Ghosal *et al.* 2013, Depenbusch *et al.* 2023).

Farmers often seek quick solutions to pest problems, frequently relying on synthetic chemical insecticides. These insecticides, including organophosphates, carbamates, and pyrethroids, are commonly used but pose risks to human health, natural enemies, and pollinators. Conversely, biorational insecticides are less harmful and are considered safer alternatives. Therefore, the study aimed to assess the efficacy of selected bio-rational insecticides in managing sucking insect pests in tomato crops.

Specifically, the research aimed to evaluate their impact on the population of natural enemies in tomato fields, identify the most effective biorational insecticides for controlling these pests, and calculate the benefit-cost ratios (BCRs) on the use of bio-rational insecticides under investigation. This comprehensive evaluation provides valuable insights into both pest control and the ecological sustainability of using bio-rational insecticides in tomato farming.

MATERIALS AND METHODS

Experimental site

The experiment was conducted at the Agro Service Centre of the Bangladesh Agricultural Development Corporation (BADC) in Sylhet, Bangladesh, located approximately 11 km northwest of Sylhet City Centre at coordinates 24.91°N latitude and 91.84°E longitude, with an elevation of 19 meters above sea level.

Seed sowing and crop management

Hybrid tomato seeds (Brand name Raja) were sourced from the local market in Sylhet, Bangladesh. The seeds were soaked in water for 12 hours, dried with tissue paper, and then sown in nursery beds. Germination occurred within 10–14 days, and when the seedlings reached a height of 15.2 cm, they were transplanted to the main field. Any gaps in the plots were filled with marketable seedlings from the nursery. Standard agronomic practices, including mulching, irrigation, weeding, and other intercultural operations, were implemented as required to ensure optimal plant growth. Recommended doses of manure and fertilizers were applied according to standard practices (Khan *et al*. 2018).

Experimental design and treatments

The experiment was set up using a Randomized Complete Block Design (RCBD) with four replications during the winter season of 2023–2024. Each experimental plot measured 3 m × 3 m, with 61 cm row spacing and 30 cm plant spacing, totaling 18 plants per plot. The experimental field was divided into four blocks, each block containing six plots with a gap (1 m) between two blocks. Treatments were applied to plots after the initial establishment of a sufficient pest population with three spray applications at 10-days intervals. A knapsack sprayer was used for applying treatments, ensuring thorough coverage of both the upper and lower leaf surfaces and fruits. Each spraying event required 12 liters of spray solution to cover four plots, and all spraying was done in the afternoon to minimize the risk of sunburn. Steps were taken to prevent spray drift to neighboring plots.

Treatments

A total of six treatments were assigned to evaluate the efficacy of different insecticides against tomato pests under field conditions. Each treatment consisted of a specific active ingredient applied at a recommended dose and fixed spray interval. The treatments were as follows: Spinosad 45SC was applied at a concentration of 0.2 ml per liter of water at 10-day intervals (T1). Matrine 1EC was applied at 1.4 mL per liter of water following the same interval (T2). Abamectin 1.8EC was used at 1 mL per liter of water (T3). Azadirachtin 0.03% EC was applied at 1 mL per liter of water (T4), whereas Cypermethrin 10EC was sprayed at 2 mL per liter of water (T5). A control plot receiving no insecticidal and water application as the untreated check (T6). All treatments received three spray uniformly throughout the experiment, following standard agronomic practices.

Data collection

Sucking Pest and Predatory Insect Observations: To assess the pest populations, six randomly selected plants from each treatment plot were observed. For each selected plant, six leaves (two from the upper, middle, and lower parts of the plant) were inspected for the presence of adults and nymphs of aphids, jassids, and whiteflies both before and after spraying at 3, 7, and 10-days intervals. For accurate identification, a 10x magnification hand lens was used to distinguish nymphs and adults from sucking pests. The abundance of hemipteran predatory insects was also recorded on the whole six plants in each treatment plot.

Yield calculation

During each harvest, fruits from each treatment were carefully examined and categorized into marketable and infested fruits. Marketable fruits were those having no visible damage and meeting quality standards for size, color, and texture. Infested fruits were those showing clear signs of pest damage. The yield for each plot was calculated as tons per hectare (t ha^{-1}). The percentage increase or decrease in yield relative to the control treatment was determined using the following formula:

Economic analysis

The economic performance of each treatment was evaluated using the Benefit-Cost Ratio (BCR). Costs were calculated by summing the labor and input costs incurred for each

$$\%\text{Increase over Control (+)} = \frac{\text{No./Wt. of Tomato in treated plot - No./Wt. of Tomato in control plot}}{\text{No. or Wt. of Tomato in control plot}} \times 100$$

$$\%\text{ Decrease over Control (+)} = \frac{\text{No./Wt. of Totamo in Control Plot - No./Wt. of Totamo in Treated plot}}{\text{No./Wt. of Tomato in Control Plot}} \times 100$$

treatment, including the control plot, throughout the growing season. BCR was calculated for a hectare of land. Benefit-cost analysis was done through the following steps:

Treatment-wise cost of cultivation

This cost was calculated by adding all costs incurred for labor and inputs for each treatment including the control plot during the entire vegetative and fruiting period. The yield of each treatment was converted into tons per hectare.

Gross return and net return

The yield from each treatment was converted into monetary value by multiplying the total yield (in tons per hectare) by the local market price for tomatoes (Tk. 35 kg^{-1}). Net return was calculated by subtracting treatment-wise management cost from gross return. Gross return is the total value of the yield for each treatment, and net return is the gross return minus treatment-specific costs.

Adjusted Net Return

The difference between the net return of a given treatment and that of the control plot, calculated as:

Benefit cost ratio calculation

Finally, the benefit-cost ratio (BCR) was calculated by dividing the adjusted net return by the total cost of cultivation for each treatment following the formula:

$$\text{BCR} = \frac{\text{Adjusted Net Return}}{\text{Total Management Cost}}$$

Statistical data analysis

Data on pest infestation, recorded as the number of insects per plant, were collected from each treatment plot. These data, representing three replications per treatment were subjected to statistical analysis. Prior to analysis, the insect count data were checked for normality using the IBM SPSS Statistics version 25. Since the data were found to be approximately normally distributed, the mean values were analyzed using one-way Analysis of Variance (ANOVA) to determine significant differences among the treatment groups. For further validation, the analysis was crosschecked using R software.

Statistical significance was evaluated using F-tests at a significance level of $p \leq 0.05$. Post-hoc comparisons of treatment means were conducted using Duncan's Multiple Range Test (DMRT) to identify specific differences among the treatment groups. To ensure the robustness and reliability of the data, the results were cross-validated using R software. This comprehensive statistical approach was employed to assess the effectiveness of the various treatments on pest control and yield parameters.

RESULTS AND DISCUSSIONS

Impact of bio-rational insecticide treatments on sucking insect populations in tomato

The bio-rational insecticidal treatments demonstrated a statistically significant effect on the incidence of sucking pests in tomatoes at 3, 7, and 10 days post-application. Below is the analysis based on the average data from three separate spray applications.

Aphid populations

At 3 days post-spray, the lowest aphid population (3.25 aphids/6 leaves/plant) was observed in

$$\text{Adjusted Net Return} = \text{Net Return of Particular Treatment} - \text{Net Return of Control Plot}$$

Table 1. Effect of bio-rational insecticidal treatments against aphids in a tomato field after sprays.

Treatments	3 DAS	7 DAS	10 DAS
Spinosad 45SC	$3.25^d \pm 0.27$	$4.12^d \pm 0.21$	$4.18^d \pm 0.28$
Matrine 1EC	$5.50^b \pm 0.46$	$8.39^b \pm 0.43$	$7.54^b \pm 0.51$
Abamectin 1.8EC	$4.11^{cd} \pm 0.34$	$5.33^d \pm 0.27$	$4.77^d \pm 0.32$
Azadirachtin 0.03% EC	$5.42^b \pm 0.45$	$6.03^{cd} \pm 0.31$	$6.19^c \pm 0.42$
Cypermethrin 10 EC	$5.32^{bc} \pm 0.44$	$6.84^c \pm 0.35$	$6.97^{bc} \pm 0.47$
Control	$6.86^a \pm 0.57$	$9.68^a \pm 0.50$	$9.90^a \pm 0.67$
CV (%)	16.55	10.27	13.56
P value	**	***	**

Note: DAS = Days after spray. Means within the same letter(s) in a column are not significantly different at $p \leq 0.05$, as determined by DMRT. The mean comparison was done by LSD. * indicates 0.05 level, ** indicates 0.01 level, and *** indicates 0.001 level of significance.

plots treated with Spinosad 45 SC, making it the most effective treatment because this treatment consistently showed the lowest numerical aphid population compare to all other treatments. The Abamectin 1.8 EC treatment was followed with a population of 4.11 aphids, and the populations in plots treated with Cypermethrin 10 EC (5.32), Azadirachtin 0.03% EC (5.42), and Matrine 1EC (5.50) were statistically similar, significantly outperforming the untreated control (Table 1). At 7 days post-spray, Spinosad 45 SC continued to demonstrate the best performance with a population of 4.12 aphids/6 leaves/plant. All insecticide treatments resulted in significantly lower aphid populations than the untreated control, which recorded 9.68 aphids. In terms of population reduction, Spinosad always tended to have the lowest aphid numbers, even it was statistically at par with all treatments. At 10 days after spraying, Spinosad 45 SC again showed the lowest aphid population (4.18 aphids/6 leaves/plant), followed by Abamectin 1.8 EC (4.77). These findings are in line with those of Wagh et al. (2017), who also observed a reduction in aphid populations following Spinosad treatment.

Jassid populations

At 3 days post-spray, by number the lowest jassid population (0.90 jassids/6 leaves/plant) was observed in Spinosad 45 SC treated plots, followed by Abamectin 1.8 EC (1.00), Azadirachtin 0.03% EC (1.04), Matrine 1EC (1.06), and Cypermethrin 10 EC (1.11) with all treatments significantly outperforming the untreated control and except the treatment Cypermethrin 10 EC all treatments showed statistically similar effect (Table 2). This trend continued at 7 and 10 days after spraying, with Spinosad 45 SC continuing to maintain the lowest jassid population because this treatment consistently showed the lowest numerical jassid population. These results are consistent with findings from Ahmed *et al*. (2009), who also reported a significant reduction in jassid populations following Spinosad application, although with higher counts than those recorded in this study. On the other hand, Bambhaniya *et al*. (2018) stated that 2.77 jassids/plant were found in the Spinosad 45 SC treated plot which result was strongly supported by the current study.

Whitefly populations

The effect of bio-rational insecticides on whitefly populations was also evaluated at 3, 7, and 10 days post-spray. At 3 days post-spray, Spinosad 45 SC was the most effective treatment with the lowest whitefly population (1.15/6 leaves/plant), followed by Azadirachtin 0.03% EC (1.19), Cypermethrin 10 EC (1.31), Matrine 1EC (1.34), and Abamectin 1.8 EC (1.92),

Table 2. Effect of bio-rational insecticidal treatments against jassids in tomato field after sprays.

Treatments	3 DAS	7 DAS	10 DAS
Spinosad 45SC	$0.90^c \pm 0.04$	$0.75^d \pm 0.03$	$0.90^d \pm 0.04$
Matrine 1EC	$1.06^{bc} \pm 0.07$	$1.63^{bc} \pm 0.80$	$1.16^{cd} \pm 0.05$
Abamectin 1.8EC	$1.00^{bc} \pm 0.05$	$1.36^b \pm 0.71$	$1.05^{cd} \pm 0.05$
Azadirachtin 0.03% EC	$1.04^{bc} \pm 0.07$	$1.15^{bc} \pm 0.05$	$1.97^b \pm 0.09$
Cypermethrin 10 EC	$1.11^b \pm 0.09$	$1.04^c \pm 0.04$	$1.27^c \pm 0.07$
Control	$2.21^a \pm 0.18$	$2.74^a \pm 0.22$	$3.14^a \pm 0.24$
CV (%)	9.36	8.44	9.14
P value	*	**	***

Note: DAS = Days after spray. Means within the same letter(s) in a column are not significantly different at $p \leq 0.05$, as determined by DMRT. The mean comparison was done by LSD. * indicates 0.05 level, ** indicates 0.01 level, and *** indicates 0.001 level of significance.

Table 3. Effect of bio-rational insecticidal treatments against whiteflies in the tomato field after sprays.

Treatments	3 DAS	7 DAS	10 DAS
Spinosad 45SC	$1.15^d \pm 0.03$	$1.02^d \pm 0.02$	$1.18^b \pm 0.08$
Matrine 1EC	$1.34^b \pm 0.03$	$1.28^b \pm 0.03$	$1.26^b \pm 0.08$
Abamectin 1.8EC	$1.92^{bc} \pm 0.05$	$1.06^d \pm 0.03$	$1.35^b \pm 0.09$
Azadirachtin 0.03% EC	$1.19^{cd} \pm 0.03$	$1.17^c \pm 0.03$	$1.47^b \pm 0.10$
Cypermethrin 10 EC	$1.31^b \pm 0.03$	$1.21^{bc} \pm 0.03$	$1.48^b \pm 0.10$
Control	$2.61^a \pm 0.06$	$2.45^a \pm 0.06$	$3.16^a \pm 0.20$
CV (%)	4.88	4.74	12.89
P value	*	*	*

Note: DAS = Days after spray. Means within the same letter(s) in a column are not significantly different at $p \leq 0.05$, as determined by DMRT. The mean comparison was done by LSD. * indicates 0.05 level, ** indicates 0.01 level, and *** indicates 0.001 level of significance.

all of which were significantly more effective than the untreated control; and later on all treatments showed statistically similar number of whitefly population (Table 3). Similar trends were observed at 7 and 10 days after application, with the untreated control showing the highest whitefly populations (2.45 and 3.16), while Spinosad 45 SC maintained the lowest (1.02 and 1.18) whitefly populations. These results agreed with Wagh et al. (2017), Athivarman & Ashwani (2022) who found Spinosad to be highly effective against whiteflies.

Efficacy of insecticidal treatments against hemipteran predatory insects on tomato

The performance of bio-rational insecticides in terms of their effects on hemipteran predatory bug (Orius spp. and Geocoris spp.) insect populations was also assessed at 3, 7, and 10 days post-spray. The untreated control consistently exhibited the highest mean numbers of predatory insects at all-time points (4.71, 5.51, and 4.74 per 6 plants at 3, 7, and 10 days, respectively) (Table 4). Among the insecticide treatments, Spinosad 45 SC plots maintained a high population of beneficial hemipteran predators bug (Orius spp. and Geocoris spp.) (3.22/6 plants) at 3 days post-spray. This was followed by Abamectin 1.8 EC (2.85), Matrine 1EC (2.80), and Azadirachtin 0.03% EC (2.24), all of which were statistically similar. Cypermethrin 10 EC, however, showed the lowest hemipteran predatory bug population (Orius spp. and Geocoris spp.) (1.68/6 plants), and it indicating that Cypermethrin 10 EC comparatively more hazardous to beneficial species. This finding is consistent with previous studies by EFSA PPR Panel (2015), Wagh *et al.* (2017), who reported that Spinosad has a low toxicity to natural enemies. A similar pattern was observed in the incidence of hemipteran

Table 4. Effect of bio-rational insecticidal treatments against predatory insects in the tomato field after sprays.

Treatments	3 DAS	7 DAS	10 DAS
Spinosad 45SC	$3.22^{b} \pm 0.07$	$2.85^{b} \pm 0.09$	$3.14^{b} \pm 0.12$
Matrine 1EC	$2.80^{bc} \pm 0.06$	$2.59^{bc} \pm 0.08$	$2.94^{b} \pm 0.11$
Abamectin 1.8EC	$2.85^{bc} \pm 0.06$	$2.42^{bc} \pm 0.07$	$3.17^{b} \pm 0.12$
Azadirachtin 0.03% EC	$2.24^{cd} \pm 0.05$	$2.24^{c} \pm 0.07$	$2.79^{b} \pm 0.11$
Cypermethrin 10 EC	$1.68^{d} \pm 0.04$	$1.33^{d} \pm 0.04$	$1.76^{c} \pm 0.07$
Control	$4.71^{a} \pm 0.11$	$5.15^{a} \pm 0.15$	$4.74^{a} \pm 0.18$
CV (%)	4.49	5.97	7.56
P value	**	**	*

Note: DAS = Days after spray. Means within the same letter(s) in a column are not significantly different at $p \leq 0.05$, as determined by DMRT. The mean comparison was done by LSD. * indicates 0.05 level, ** indicates 0.01 level, and *** indicates 0.001 level of significance.

predatory insects at 7- and 10-days post-spraying. The highest numbers of predatory insects were recorded in the Spinosad 45 SC-treated plots, with averages of 2.85/6 plants and 3.14/6 plants, respectively. In contrast, the lowest numbers were found in the Cypermethrin 10 EC treated plots, with averages of 1.33/6 plants and 1.74/6 plants. These findings align with previous studies, such as those by Wagh *et al.* (2017), which reported that synthetic pyrethroids like Cypermethrin 10 EC tend to cause higher mortality in predatory insect populations.

Effect on fruit yield and quality of the tomato field

The effect of bio-rational insecticides on the number of marketable and infested fruits per plot was evaluated, and significant differences were found across treatments. Spinosad 45 SC was noted as the highest number of marketable fruits (218.50), followed by Azadirachtin 0.03% EC (189.75), Matrine 1EC (167.75), Abamectin 1.8 EC (158.75), and Cypermethrin 10 EC (152.25) treated plot (Table 5). The lowest number of marketable fruits was recorded in the untreated control plot (116.00).

Conversely, the untreated control plot had the highest number of infested fruits (35.75), followed by Cypermethrin 10 EC (33.25), Matrine 1EC and Abamectin 1.8EC (28.25), and Azadirachtin 0.03% EC (27.50). The lowest number of infested fruits was recorded in the Spinosad 45 SC (23.75) treated plot (Table 5). The present results agree with the previous research works reported by Choudhury *et al.* (2021), Habib *et al.* (2022).

Regarding infested fruits, Spinosad 45 SC (1.58 kg) resulted in the lowest weight of infested fruits, followed by Abamectin 1.8 EC (1.82 kg), Azadirachtin 0.03% EC (1.91 kg), Matrine 1EC (1.99 kg), and Cypermethrin 10 EC (1.20 kg) treated plots. According to Table 6, the weights of infested fruits differed among the treatments. All treatments were significantly different (P<0.05) from the untreated control which produced the highest weight of infested fruits (2.39 kg).

Percent increase in marketable fruits and reduction in infested fruits over control

The percent increase and reduction in the weight of marketable and infested fruits relative to the control treatment were significantly influenced by all treatments, as depicted in Fig. 2.

In terms of the percent increase in the weight of marketable fruits over the control, Spinosad 45 SC showed the highest increase (88.66%), followed by Azadirachtin 0.03% EC (61.69%), Matrine 1EC (44.78%), Abamectin 1.8 EC (37.01%), and Cypermethrin 10 EC (31.64%) treated plots. These results indicate a clear trend of increased fruit production due to the use of bio-rational insecticides, with Spinosad 45 SC showing the most significant improvement in yield.

For the reduction in the weight of infested

Table 5. Effect of bio-rational insecticidal treatments against sucking insect pests of tomatoes in terms of the number of marketable and infested fruits plot^{-1}.

Treatments	No. of marketable fruits plot^{-1}	No. infested fruits plot^{-1}
Spinosad 45SC	$218.50^{a} \pm 12.80$	$23.75^{c} \pm 1.10$
Matrine 1EC	$167.75^{bc} \pm 9.84$	$28.25^{bc} \pm 1.32$
Abamectin 1.8EC	$158.75^{c} \pm 9.30$	$28.25^{bc} \pm 1.35$
Azadirachtin 0.03% EC	$189.75^{ab} \pm 11.12$	$27.50^{bc} \pm 1.29$
Cypermethrin 10 EC	$152.25^{c} \pm 8.92$	$33.25^{ab} \pm 1.55$
Control	$116.00^{d} \pm 6.80$	$35.75^{a} \pm 1.66$
CV (%)	11.73	9.31
P value	**	**

Table 6. Effect of bio-rational insecticidal treatments against sucking insect pests of tomatoes in terms of weight of marketable and infested fruits plot^{-1}.

Treatments	Weight of marketable fruits (kg plot^{-1})	Weight of infested fruits (kg plot^{-1})
Spinosad 45SC	$18.96^{a} \pm 0.08$	$1.58^{c} \pm 0.20$
Matrine 1EC	$14.55^{bc} \pm 0.60$	$1.99^{abc} \pm 0.25$
Abamectin 1.8EC	$13.77^{bc} \pm 0.55$	$1.82^{bc} \pm 0.23$
Azadirachtin 0.03% EC	$16.25^{b} \pm 0.65$	$1.91^{bc} \pm 0.24$
Cypermethrin 10 EC	$13.23^{c} \pm 0.60$	$2.25^{ab} \pm 0.28$
Control	$10.05^{d} \pm 0.50$	$2.39^{a} \pm 0.30$
CV (%)	7.05	5.86
P value	*	***

fruits over control, Spinosad 45 SC recorded the highest reduction (33.89%), followed by Abamectin 1.8 EC (23.85%), Azadirachtin 0.03% EC (20.08%), and Matrine 1EC (16.74%) treated plots. Cypermethrin 10 EC demonstrated the lowest reduction in infested fruit weight (5.86%) in treated plots (Fig. 2). In a study by Gajanana *et al*. (2006), the Integrated Pest Management (IPM) methods demonstrated relatively lower effectiveness, with mortality rates of 48.5% and 62.64%, respectively. The implementation of IPM technology has proven to be economically beneficial, as farms using IPM reported a 46% higher yield, a 21% reduction in cultivation costs, and a 119% increase in net returns.

Yield performance (t ha^{-1}) of tomato

The effects of different bio-rational insecticidal treatments on tomato yield (t ha^{-1}), including total fruit yield, marketable yield, and infested fruit yield obtained throughout the cropping season (Table 7). Spinosad 45 SC treatment resulted in the highest marketable yield (22.07 t ha^{-1}), significantly outperforming the other treatments. Azadirachtin 0.03% EC (18.06 t ha^{-1}), Matrine 1EC (16.17 t ha^{-1}), Abamectin 1.8 EC (15.30 t ha^{-1}), and Cypermethrin 10 EC (14.69 t ha^{-1}) followed in descending order, with all these treatments being statistically comparable but significantly higher than the untreated control (11.10 t ha^{-1}) plot.

For infested yield, the lowest quantity weight was recorded in the Spinosad 45 SC treated plots (1.75 t ha^{-1}), while the untreated control plots showed the highest infested yield (2.65 t ha^{-1}). However, the lowest infested yield was noted in Spinosad 45 SC treated plots and it was significantly at similar with other treatments, but different from untreated control plot. The total yield was also highest in

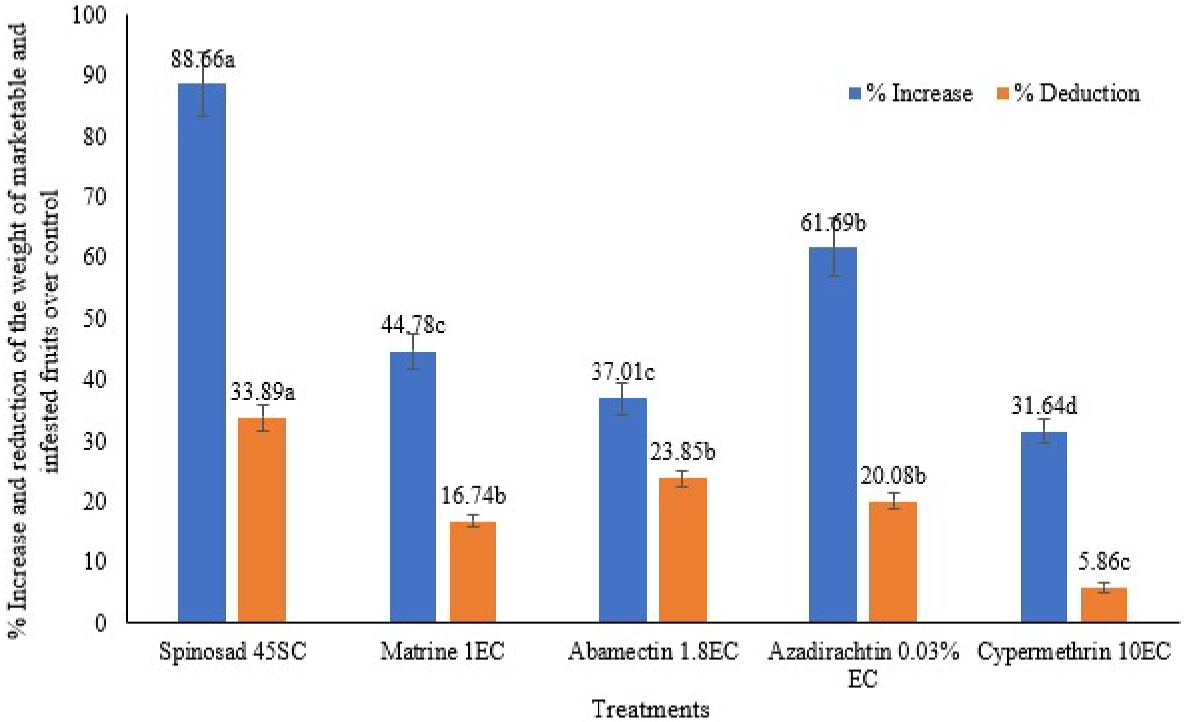

Figure 2. The percent increase and reduction in the weight of marketable and infested fruits over control.

Table 7. Effect of bio-rational insecticidal treatments against sucking insect pests of tomatoes on fruit yield (t ha^{-1}).

Treatments	**Marketable fruit yield (t ha^{-1})**	**Infested fruit yield (t ha^{-1})**	**Total fruit yield (t ha^{-1})**	**% increase over control (+)**
Spinosad 45SC	21.07^{a} ±0.90	1.75^{c} ±0.20	22.82^{a} ±0.95	65.96
Matrine 1EC	16.17^{bc} ±0.80	2.21^{abc} ±0.25	18.38^{bc} ±0.85	33.67
Abamectin 1.8EC	15.30^{bc} ±0.75	2.02^{bc} ±0.23	17.32^{bc} ±0.80	25.96
Azadirachtin 0.03% EC	18.06^{bc} ±0.85	2.12^{bc} ±0.24	20.18^{ab} ±0.90	46.76
Cypermethrin 10 EC	14.69^{c} ±0.70	2.50^{ab} ±0.28	17.19^{c} ±0.85	25.02
Control	11.10^{d} ±0.60	2.65^{a} ±0.30	13.75^{d} ±0.70	–
CV (%)	8.05	5.87	9.53	–
P value	*	***	**	–

Table 8. Economic analysis of different treatments applied against the major sucking pests of tomatoes during the winter season.

Treatment	**Cost of control (BDT)**	**Marketable yield (t ha^{-1})**	**Gross return (Taka)**	**Net return (Taka)**	**Adjusted net return (Taka)**	**BCR (taka/taka)**
Spinosad 45 SC	39020.00	21.07	737450.00	698430.00	309930.00	7.94
Matrine 1EC	55420.05	16.17	565950.00	510529.95	122029.95	2.20
Abamectin 1.8 EC	26420.04	15.30	535500.00	509079.96	120579.96	4.56
Azadirachtin 0.03% EC	37420.07	18.06	632100.00	595679.93	207179.93	5.51
Cypermethrin 10 EC	28000.03	14.69	514150.00	490149.97	101649.97	3.49
Control	0.00	11.10	388500.00	388500.00	0.00	–

Spinosad 45 SC treated plots (22.82 t ha^{-1}) and lowest in the untreated control plots (13.75 t ha^{-1}). These findings suggest that bio-rational insecticides significantly reduce the infestation of sucking insect pests in tomato fields while enhancing overall yield. The current study aligns with previous research (Wagh *et al*. 2017, Choudhury *et al*., 2021, Habib *et al*. 2022) that reported Spinosad 45 SC as an effective agent for boosting tomato yield, supporting the potential of this insecticide for sustainable pest management in tomato cultivation.

Economic analysis of different treatments and benefit-cost rsatio (BCR)

An economic analysis was conducted to assess the cost-effectiveness of the treatments based on gross return, net return, and the benefit-cost ratio (BCR) (Table 8). Spinosad 45 SC provided the highest adjusted net return (Tk. 309,930.00) and BCR (7.94), significantly outperforming other treatments. Azadirachtin 0.03% EC, Abamectin 1.8 EC, and Cypermethrin 10 EC showed BCR values of 5.51, 4.56, and 3.49, respectively. Matrine 1EC exhibited the lowest BCR of 2.20. These results align with findings from Ahmed et al. (2020), who also reported a favorable BCR for Spinosad 45 SC, although slightly lower than the current study's findings (BCR of 7.94). Furthermore, the current study corroborates the results of Habib *et al*. (2022), who observed a higher BCR (8.74) for Spinosad 45 SC.

CONCLUSION

Among the five bio-rational insecticide treatments evaluated, Spinosad 45 SC (0.2 mL L^{-1} of water, applied at 10-day intervals) was identified as the most effective treatment for controlling sucking insect pests in tomato fields. It not only significantly reduced pest populations but also resulted in the highest marketable yield of tomatoes. Moreover, Spinosad 45 SC proved to be relatively safe for natural predatory insects, making it a valuable tool for integrated pest management (IPM) in tomato cultivation.

Azadirachtin 0.03% EC (1 mL L^{-1} of water, applied at 10-day intervals) was found to be the second most effective treatment, offering a viable alternative with slightly lower efficacy compared to Spinosad 45 SC. Furthermore, Abamectin 1.8 EC (1 g L^{-1} of water, applied at 10-day intervals) also demonstrated significant pest control and can serve as a third effective alternative intervention for managing sucking pests in tomato fields.

Based on the findings of this study, it is recommended that Spinosad 45 SC be utilized as the preferred bio-rational insecticide for sustainable pest management in tomato farming. Azadirachtin 0.03% EC and Abamectin 1.8 EC can be considered as supplementary options, particularly in integrated pest management strategies aimed at ensuring both pest control and the conservation of beneficial insect populations in tomato fields across Bangladesh.

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REFERENCES

Ahmed T, Miah MRU, Nasrin M, Amin MR (2020) Biorational management of sucking pests of tomato. *Bangladesh Journal of Ecology*, 2(2), 69–73.

Ali MY, Ibn Sina AA, Khandker SS, Neesa L, Tanvir EM, Kabir A, Khalil MI, Gan SH (2020) Nutritional composition and bioactive compounds in tomatoes and their impact on human health and disease: A review. *Foods*, 10(1), 45–60. https://doi.org/10.3390/foods10010045.

Anamika, Ghalawat S, Goyal M, Mehla S, Malik JS, Yadav E (2024) Growth trend in area, production, and productivity of tomato in India and Haryana. *Indian Journal of Extension Education*, 60(3), 72–76. https://doi.org/10.48165/IJEE.2024.60314.

Athivarman R, Ashwani K (2022) Field efficacy of selected insecticides against aphids infesting tomato (*Lycopersicon esculentum* Mill.). *International Journal of Entomology Research*, 7(10), 67–70.

Bambhaniya V, Khanpara A, Patel H (2018) Bio-efficacy of insecticides against sucking pests. *Journal of Pharmacognosy and Phytochemistry*, 7(3), 1471–1479.

BBS (Bangladesh Bureau of Statistics) (2022) Year Book of Agricultural Statistics. Bangladesh Bureau of Statistics, Ministry of Agriculture, Government of the People's Republic of Bangladesh.

Choudhury MAR, Mondal MF, Khan AU, Hossain MS, Azad MOK, Prodhan MDH, Uddain J, Rahman MS, Ahmed N, Choi KY, Naznin MT (2021) Evaluation of biological approaches for controlling shoot and fruit borer (*Earias vitella* F.) of okra grown in peri-urban area in Bangladesh. *Horticulturae*, 7, 7–18. https://doi.org/10.3390/horticulturae7010007.

Depenbusch L, Sequeros T, Schreinemachers P, Sharif M, Mannamparambath K, Uddin N, Hanson P (2023) Tomato pests and diseases in Bangladesh and India: Farmers' management and potential economic gains from insect resistant varieties and integrated pest management. *International Journal of Pest Management*, 69, 1–15. https://doi.org/10.1080/09670874.2023.2252760.

Díaz-Pendón JA, Sánchez-Campos S, Fortes IM, Moriones E (2019) Tomato yellow leaf curl Sardinia virus, a begomovirus species evolving by mutation and recombination: A challenge for virus control. *Viruses*, 11(1), 45. https://doi.org/10.3390/v11010045.

EFSA PPR Panel (2015) Scientific Opinion addressing the state of the science on risk assessment of plant protection products for non-target arthropods. *EFSA Journal*, 13(2), 3996, 1–212. https://doi.org/10.2903/j.efsa.2015.3996.

Elbadrawy E, Sello A (2016) Evaluation of nutritional value and antioxidant activity of tomato peel extracts. *Arabian Journal of Chemistry*, 9(S2), S1010–S1018. https://doi.org/10.1016/j.arabjc.2011.11.011.

Ergin GO, Bozkurt YE, Başer G, Canpolat E, Görür G, Öztürk A (2024) Effect of honeydew secreted by *Aphis gossypii* Glover (Hemiptera: Aphididae) on fungal growth. *Turkish Journal of Agriculture: Food Science and Technology*, 12(s4), 2817–2822. https://doi.org/10.24925/turjaf.v12is4.2817-2822.7301.

Gajanana TM, Krishna MPN, Anupama HL, Raghunatha R, Prasanna KGT (2006) Integrated pest and disease management in tomato: An economic analysis. *Agricultural Economics Research Review*, 19(2), 269–280.

Ghosal A, Chatterjee ML, Bhattacharyya A (2013) Bio-efficacy of neonicotinoids against *Aphis gossypii* Glover of okra. *Journal of Crop and Weed*, 9, 181–184.

Habib MJ, Choudhury MAR, Maleque MA, Das B, Khan AU (2022) Efficacy of bio-rational and microbial insecticides against fruit borer (*Helicoverpa armigera* Hub.) attacking tomato. *Bangladesh Journal of Entomology*, 30(1 & 2), 79–87.

Khan AU, Choudhury MAR, Islam MS, Maleque MA (2018) Abundance and fluctuation patterns of insect pests in country bean. *Journal of Sylhet Agricultural University*, 5(2), 167–172.

Quinet M, Angosto T, Yuste-Lisbona FJ, Blanchard-Gros R, Bigot S, Martinez JP, Lutt S (2019) Tomato fruit development and metabolism. *Frontiers in Plant Science*, 10, 1554. https://doi.org/10.3389/fpls.2019.01554.

Sajjad AK, Abdul WS, Abdul GL (2014) Surveillance on the sucking insect pests and their natural enemies on tomato crop. *Advances in Life Science and Technology*, 20, 24–28.

Staropoli A, Di Mola I, Ottaiano L, Cozzolino E, Pironti A, Lombardi N, Nanni B, Mori M, Vinale F, Woo SL, Marra R (2024) Biodegradable mulch films and bioformulations based on *Trichoderma* sp. and seaweed extract differentially affect the metabolome of industrial tomato plants. *Journal of Fungi*, 10(2), 97. https://doi.org/10.3390/jof10020097.

Wagh BM, Pagire KS, Thakare DP, Birangal AB (2017) Management of sucking pests by using newer insecticides and their effect on natural enemies in tomato (*Lycopersicon esculentum* Mill.). *International Journal of Current Microbiology and Applied Sciences*, 6(4), 615–622.

Zhao K, Liu S, Wang W, Yang G, Pan L (2022) Manipulation of whitefly behavior by plant viruses. *Microorganisms*, 10(12), 2410. https://doi.org/10.3390/microorganisms10122410.