Original Research Article

Development of IPM packages based on effective insecticides and bio-pesticides for controlling tomato fruit borer

Abstract

The experiment was conducted in the experimental field of Sher-e-Bangla Agricultural University, Sher-e-Bangla Nagar, Dhaka during the period from October, 2015 to March, 2016 for the development of IPM packages based on effective insecticides and bio-pesticides against tomato fruit borer. Tomato variety BARI tomato-14 was used as planting material. The experiment was consisted of six treatments as- T_1: Mechanical control, T_2: Voliam Flexi 300 SC @ 0.5 ml/l of water at 7 days interval + Pheromone trap at 10 m^2 distance, T_3: Voliam Flexi 300 SC @ 0.5 ml/l of water + Bioneem plus 1EC (Azadiractin) @1 ml/l of water at 7 days interval, T_4: Bioneem plus 1EC (Azadiractin) @1 ml/l of water + Spinosad 45 SC @ 4 ml/10l of water (bio-pesticides) + Pheromone trap at 10 m^2 distance, T_5: Mechanical control + Voliam Flexi 300 SC @ 0.5 ml/l of water + Bioneem plus 1EC (Azadiractin) @1 ml/l + Pheromone trap at 10 m^2 distance and T_6: Untreated control. The experiment was laid out in Randomized Complete Block Design (RCBD) with three replications. At the total fruiting and ripening stage, the minimum number of fruit borer larvae per plant (0.73 and 1.00, respectively) was recorded from T_5, while the maximum number of fruit borer larvae per plant (9.47 and 13.07, respectively) was found from T_6. At entire ripening stage of tomato in number basis, the lowest percentage of infested fruits per plant in number basis (2.11%) was found in T_5, while the highest percentage of infested fruits in number basis (11.55%) was found in T_6 treatment. At entire ripening stage of tomato in weight basis, the lowest percentage of infested fruits per plant in weight basis (1.97%) was found in T_5, while the highest percentage of infested fruits in weight basis (10.20%) was observed in T_6. The highest fruit yield (59.82 t/ha) was found in T_5, whereas the lowest fruit yield (50.36 t/ha) was recorded in T_6 treatment. The highest benefit cost ratio (2.11) was estimated for T_5 treatment and the lowest (0.15) for T_1 treatment under the trial. It is observed that Mechanical control + Voliam Flexi 300 SC @ 0.5 ml/l of water + Bioneem plus 1EC (Azadiractin) @1 ml/l + Pheromone trap at 10 m^2 distance was more effective against the fruit borer of yield attributes and yield of tomato.

Keywords: Biopesticides, insecticides, pheromone trap, fruit borer and tomato

1. Introduction

Tomato (*Solanum lycopersicum* L.) belongs to the family Solanaceae is the centre of origin of the genus Solanum is the Andean zone particularly Peru-Ecuador-Bolivian areas but cultivated tomato originated in Mexico [1] is one of the most popular and nutritious vegetables of Bangladesh [2].

Tomato ranks top of the list of canned vegetables and next to potato and sweet potato in the world produced vegetables [3]. Food value of tomato is very rich due to the higher contents of vitamins A, B and C including calcium, carotene and other nutrients [4]. The present leading tomato producing countries of the world are China, United States of America (USA), Turkey, India, Egypt, Italy, Iran, Spain, Brazil Mexico, and Russia [3]. In Bangladesh, the yield of tomato is not satisfactory in comparison with other tomato growing countries of the World [5]. The low yield of tomato in Bangladesh however is not an indication of low yielding potentially of this crop but the fact that the low yield may be attributed to a number of reasons, among them insect pests is the important one. In order to increase tomato production in Bangladesh, it is essential to identify cultivars capable of year-round production with higher yield and resistance to pests [6]. According to Alam *et al.* [7] the key constraint of tomato production are the related to the infestation of fruit borer (*H. armigera*) and all plant parts including leaves, stems, flowers, and fruits are subjected to attack by these insect pests in different growing stages. Generally the farmers of Bangladesh control the tomato fruit borer by the application of chemical insecticides but the management of this pest through non chemical tactics such as cultural, mechanical, biological and host plant resistance etc. throughout the world is limited. A huge quantity of pesticide is used in controlling tomato fruit borer and the application of chemical insecticides for controlling tomato fruit borer has got many limitation and undesirable side effects [8]. Indiscriminate use of insecticide created several adverse effects such as pest resistance, outbreak of secondary pests, health hazards and environmental pollution. The sole application of different insecticides in tomato field has shown many side effects and limitations [9, 10 and 11]. The fruits of tomato are harvested at the short intervals, are likely to retain unavoidably high level of pesticide residues which may be highly hazardous causing serious problems including pest resistance, pest outbreak, pest resurgence and environmental pollution [12]. As a result, these harmful insecticides dissolved into our water system and ultimately enter into the system of human, fishes and many other animals and cause severe damage to their health. Moreover, the farmers of Bangladesh are very poor and they have very limited access to buy insecticides and the spraying equipments [13]. Further, the excessive reliance on chemicals has led to the problem of resistance, resurgence, environmental pollution decimation of useful fauna and flora. Facing these problems, Scientists all over the world are being motivated to adopt the technique of integrated pest management (IPM). In Bangladesh, efforts are underway to popularize among the farmers the IPM practices involving bio-control agents, pheromone traps, botanicals etc. in managing tomato fruit borer. But their exact level of acceptance, farmers' including their impact have not been reported in details through any independent study. IPM approach advocates an integration of all possible or at least some of the known natural means of control (i.e. cultural, physical, biological, mechanical control etc.) with or without insecticides for best insect management in terms of economics within threshold level of tomato fruit borer. IPM also gives importance on botanicals and it is becoming popular day by day [14]. These are not hazardous for environment, human health and beneficial insects although a few works has been conducted to determine the efficacy of botanicals to control tomato fruit borer. Considering the above all perspective, the present study was undertaken to determine the effectiveness of different IPM packages based on effective insecticides and bio-pesticides against tomato fruit borer; to assess the level of infestation caused by tomato fruit borer for different IPM packages based on effective insecticides and bio-pesticides; and to analyze the BCR (Benefit Cost Ratio) of effective IPM packages for the management of tomato fruit borer.

2. Materials and methods

2. Methodology

2.1 Experimental site

The field research was conducted in the central farm of Sher-e-Bangla Agricultural University (SAU), Sher-e-Bangla Nagar, Dhaka during the period from October, 2015 to March, 2016. The location of the site is $23^0 74^/$N latitude and $90^0 35^/$E longitude with an elevation of 8.2 meter from sea level. The soil of the field experimental area belongs to the Modhupur Tract under AEZ No. 28 and is dark grey terrace soil. Experimental area is situated in the sub-tropical climate zone, which is characterized by heavy rainfall during the months of April to September and scanty rainfall during the rest period of the year.

2.2 Planting materials

Tomato variety BARI tomato-14 was used as planting material. The seeds of tomato were collected from Bangladesh Agricultural Research Institute (BARI), Gazipur and grown at the nursery of experimental field of Sher-e-Bangla Agricultural University, Sher-e-Bangla Nagar, Dhaka.

2.3 Detail of experimental treatments and designing

The experiment was consisted of six treatments. These were as follows-T_1: Mechanical control, T_2: Voliam Flexi 300 SC @ 0.5 ml/l of water at 7 days interval + Pheromone trap at 10 m^2 distance, T_3: Voliam Flexi 300 SC @ 0.5 ml/l of water + Bioneem plus 1EC (Azadiractin) @1 ml/l of water at 7 days interval, T_4: Bioneem plus 1EC (Azadiractin) @1 ml/l of water + Spinosad 45 SC @ 4 ml/10l of water (bio-pesticides) + Pheromone trap at 10 m^2 distance, T_5: Mechanical control + Voliam Flexi 300 SC @ 0.5 ml/l of water + Bioneem plus 1EC (Azadiractin) @1 ml/l + Pheromone trap at 10 m^2 distance and T_6: Untreated control. The experiment was laid out in Randomized Complete Block Design (RCBD) with three replications. The layout of the experiment was prepared for distributing all of the treatments. Each experiment consists of total 18 plots of size 3.5 m × 2.0 m.

2.4 Crop husbandry

The seedlings were raised in 3 m × 1 m size seed bed under special care at SAU nursery shed, Dhaka. Well ploughed and well prepared seedbed was dried in the sun to destroy the soil insect and protect the young seedlings from the attack of damping off disease. In controlling damping off disease Cupravit fungicide was applied. Ten (10) grams of seeds were sown in seedbed on October 28, 2015 for producing 30 days old seedlings. After sowing of seeds all the necessary measures have been taken as per when needed. The selected experimental field was opened in the 1st week of November 2015 with a power tiller and was exposed to the sun for a week for sun drying. After one week the land was harrowed, ploughed and cross-ploughed several times followed by laddering to obtain a good condition for the growth of tomato seedlings. As a source of N, P_2O_5, K_2O and H_3BO_3; urea, TSP, MoP and borax were applied in the final land, respectively. The entire amounts of TSP, MoP and borax were applied during the final land preparation. Urea was applied in three equal installments at 15, 30 and 45 days after seedling transplanting. Well-decomposed cowdung 20 t/ha also applied during final land preparation. Healthy and uniform tomato seedlings of 30 days old were transplanted in the experimental plots on 27 November, 2015. Seedlings were transplanted in the plot with maintaining distance between row to row 60 cm and plant to plant 40 cm.

After transplanting of seedlings, various intercultural operations such as irrigation, weeding and top dressing etc. were accomplished for better growth and development of the tomato seedlings.

2.5 Data recorded

The data were recorded on the incidence of fruit borer, infested and healthy fruit and the data on yield and yield contributing traits such as plant height, number of branches plant^{-1}, number of flower bunches plant^{-1}, number of flowers bunch^{-1}, single fruit weight and yield hectare^{-1} have also been collected.

The percentage of fruit borer infested fruits was calculated using the following formula:

$$\text{\% fruit borer infestation (by number)} = \frac{\text{Number of infested fruits}}{\text{Total number of fruits inspected}} \times 100$$

Weight of infested fruits

% fruit borer infestation (by weight) = $$\frac{\qquad}{\text{Total weight of fruits inspected}} \times 100$$

2.6 Statistical package used

The data obtained from insect incidence and different growth and yield characters were statistically analyzed to find out the significance for different tomato varieties. The analysis of variance was performed by using MSTAT Program. The significance of the difference among the treatment combinations means was estimated by LSD (Least Significant Difference) at 5% level of [15].

3. Results and discussion

The experiment was conducted for the development of IPM packages based on effective insecticides and bio-pesticides against tomato fruit borer and the observed findings have been presented with possible interpretations as below:-

3.1 Number of fruit borer larvae plant^{-1} at fruiting stage

Statistically significant differences was observed in terms of number of fruit borer larvae plant^{-1} in tomato plants at early, mid, late and total fruiting and ripening stage for IPM packages based on effective insecticides and bio-pesticides. At early fruiting stage, minimum number of fruit borer larvae plant^{-1} (0.13) was observed from T_5 (Mechanical control + Voliam Flexi 300 SC @ 0.5 ml/l of water + Bioneem plus 1EC-Azadiractin @1 ml/l + Pheromone trap at 10 m^2 distance) which was statistically similar (0.27) to T_4 (Bioneem plus 1EC-Azadiractin @1 ml/l of water + Spinosad 45 SC @ 4 ml/10l of water-bio-pesticides + Pheromone trap at 10 m^2 distance) and followed (0.53 and 0.87, respectively) by T_3 (Voliam Flexi 300 SC @ 0.5 ml/l of water + Bioneem plus 1EC-Azadiractin @1 ml/l of water at 7 days interval) and T_2 (Voliam Flexi 300 SC @ 0.5 ml/l of water at 7 days interval + Pheromone trap at 10 m^2 distance) treatment, whereas the maximum number of fruit borer larvae plant^{-1} (2.87) was recorded from T_6 (Untreated control) which was followed (2.13) by T_1 (Mechanical control) treatment (Table 1). At mid fruiting stage the minimum number of fruit borer larvae plant^{-1} (0.27) was found from T_5 which was statistically similar (0.40) to T_4 and followed (0.73) by T_3 treatment, while the maximum number of fruit borer larvae plant^{-1} (3.13) was recorded from T_6 which was followed (2.33) by T_1 treatment (Table 1).

Data revealed that at late fruiting stage, the minimum number of fruit borer larvae plant^{-1} (0.33) was observed from T_5 which was statistically similar (0.47) to T_4 and followed (1.07 and 1.20, respectively) by T_3 and T_2 treatment and they were statistically similar, whereas the maximum number (3.47) was recorded from T_6 which was followed (2.53) by T_1 treatment (Table 1). At the total fruiting stage, the minimum number of fruit borer larvae plant^{-1} (0.73) was recorded from T_5 which was statistically similar (1.13) to T_4 and followed (2.33) by T_3 treatment, while the maximum number of fruit borer larvae plant^{-1} (9.47) was found from T_6 which was followed (7.00) by T_1 treatment (Table 1).

Table 1. Effect of different IPM packages on number of fruit borer larvae plant^{-1} at different fruiting stages of tomato

Treatments	Number of fruit borer larvae plant^{-1} at fruiting stage			
	Early	Mid	Late	Total
T_1	2.13 b	2.33 b	2.53 b	7.00 b
T_2	0.87 c	1.07 c	1.20 c	3.13 c
T_3	0.53 d	0.73 d	1.07 c	2.33 d

T_4	0.27 e	0.40 e	0.47 d	1.13 e
T_5	0.13 e	0.27 e	0.33 d	0.73 e
T_6	2.87 a	3.13 a	3.47 a	9.47 a
$LSD_{(0.05)}$	0.257	0.199	0.244	0.492
Level of significance	0.01	0.01	0.01	0.01
CV(%)	12.48	8.13	8.93	6.83

In a column means having similar letter(s) are statistically identical and those having dissimilar letter(s) differ significantly as per 0.05 level of probability by DMRT.
T_1: Mechanical control, **T_2**: Voliam Flexi 300 SC @ 0.5 ml/l of water at 7 days interval + Pheromone trap at 10 m^2 distance, **T_3**: Voliam Flexi 300 SC @ 0.5 ml/l of water + Bioneem plus 1EC (Azadiractin) @1 ml/l of water at 7 days interval, **T_4**: Bioneem plus 1EC (Azadiractin) @1 ml/l of water + Spinosad 45 SC @ 4 ml/10l of water (bio-pesticides) + Pheromone trap at 10 m^2 distance, **T_5**: Mechanical control + Voliam Flexi 300 SC @ 0.5 ml/l of water + Bioneem plus 1EC (Azadiractin) @1 ml/l + Pheromone trap at 10 m^2 distance, **T_6**: Untreated control

At early ripening stage, the minimum number of fruit borer larvae plant^{-1} (0.27) was found from T_5 which was statistically similar (0.33) to T_4 treatment and followed (0.67) by T_3, while the maximum number of fruit borer larvae plant^{-1} (3.80) was recorded from T_6 which was followed (2.53) by T_1 treatment (Figure 1). Data revealed that at mid ripening stage, the minimum number of fruit borer larvae plant^{-1} (0.33) was found from T_5 which was statistically similar (0.47) to T_4 treatment, while the maximum number of fruit borer larvae plant^{-1} (4.40) was recorded from T_6 which was followed (2.80) by T_1 treatment (Figure 1). The minimum number of fruit borer larvae plant^{-1} (0.40) was found from T_5 which was statistically similar (0.53) to T_4 and closely followed (0.93) by T_3 treatment, while the maximum number of fruit borer larvae plant^{-1}(4.87) was observed from T_6 which was followed (3.33) by T_1 treatment at late ripening stage (Figure 1). At total ripening stage, the minimum number of fruit borer larvae plant^{-1} (1.00) was recorded from T_5 which was statistically similar (1.33) to T_4 treatment, whereas the maximum number of fruit borer larvae plant^{-1} (13.07) was found from T_6 which was followed (8.67) by T_1 treatment at late ripening stage (Figure 1).

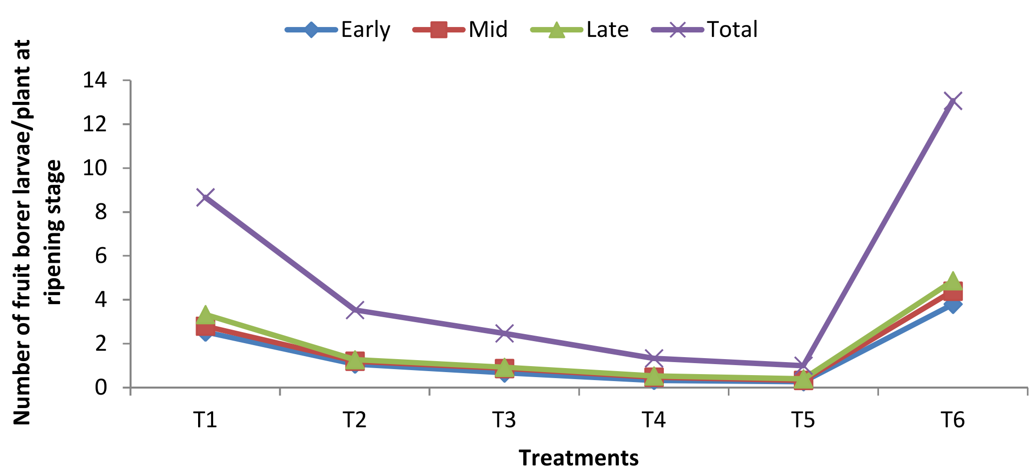

Figure 1. Effect of different IPM packages on number of fruit borer larvae per plant at ripening stages of tomato

T_1: Mechanical control, **T_2**: Voliam Flexi 300 SC @ 0.5 ml/l of water at 7 days interval + Pheromone trap at 10 m^2 distance, **T_3**: Voliam Flexi 300 SC @ 0.5 ml/l of water + Bioneem plus 1EC (Azadiractin) @1 ml/l of water at 7 days interval, **T_4**: Bioneem plus 1EC (Azadiractin) @1 ml/l of water + Spinosad 45 SC @ 4 ml/10l of water (bio-pesticides) + Pheromone trap at 10 m^2 distance, **T_5**: Mechanical control + Voliam Flexi 300 SC @ 0.5 ml/l of water + Bioneem plus 1EC (Azadiractin) @1 ml/l + Pheromone trap at 10 m^2 distance, **T_6**: Untreated control

From the above findings, it is revealed that Mechanical control + Voliam Flexi 300 SC @ 0.5 ml/l of water + Bioneem plus 1EC (Azadiractin) @1 ml/l + Pheromone trap at 10 m^2 distance was more effective against the fruit borer of tomato which was similar to Bioneem plus 1EC (Azadiractin) @1 ml/l of water + Spinosad 45 SC @ 4 ml/10l of water (bio-pesticides) + Pheromone trap at 10 m^2 distance and followed by Voliam Flexi 300 SC @ 0.5 ml/l of water + Bioneem plus 1EC (Azadiractin) @1 ml/l of water at 7 days interval. Different previous experiments revealed that IPM practice is an effective tools for controlling insect pests of tomato. Gajanana *et al*. [16] reported that IPM technology was more effective in controlling insect pests of tomato. Chavan *et al.* [17] evaluated the efficacy of various pest management module against tomato fruit borer, and the results revealed that IPM module was found most promising in reducing larval population (1.04/plant). Chavan *et al.* [18] reported that integrated pest management practices showed maximum efficacy against *H. armigera* and Chloropyrifos 20 EC @ 1 liter/ha was most effective against fruit borer. Mandal [19] reported that IPM technology was very effective in reducing the incidence of pests and minimizing the yield losses.

3.2 Effect of different IPM packages on fruit bearing status and infestation of tomato

Different IPM packages based on effective insecticides and bio-pesticides varied significantly in terms of healthy, infested fruits and fruit infestation percentage at early, mid, late and total ripening period in number and weight basis.

3.2.1 Early ripening stage

At early ripening stage of tomato in number basis, the highest number of healthy fruits $plant^{-1}$ (10.13) was found in T_5 which was statistically similar (9.93, 9.67 and 9.40, respectively) to T_4, T_3 and T_2 treatment, whereas the lowest number (8.73) was found in T_6 which was statistically similar (8.93) to T_1 treatment (Figure 2). The lowest number of infested fruits $plant^{-1}$ (0.20) was recorded in T_5 which was statistically similar (0.27 and 0.33, respectively) to T_4 and T_3 treatment, whereas the highest number of infested fruits (0.93) were observed in T_6 which was statistically similar (0.87) to T_1 (Figure 2). The lowest percentage of infested fruits $plant^{-1}$ in number basis (1.94%) was found in T_5 which was statistically similar (2.60%, 3.33% and 3.38%, respectively) to T_4, T_3 and T_2 treatment, whereas the highest percentage of infested fruits in number basis (9.64%) was found in T_6 which was statistically similar (8.84%) to T_1 treatment (Figure 2). In consideration of fruit infestation decrease over control in number basis, the highest value (79.88%) was observed in T_5, whereas the lowest value (8.30%) was recorded in T_1 treatment (Figure 2).

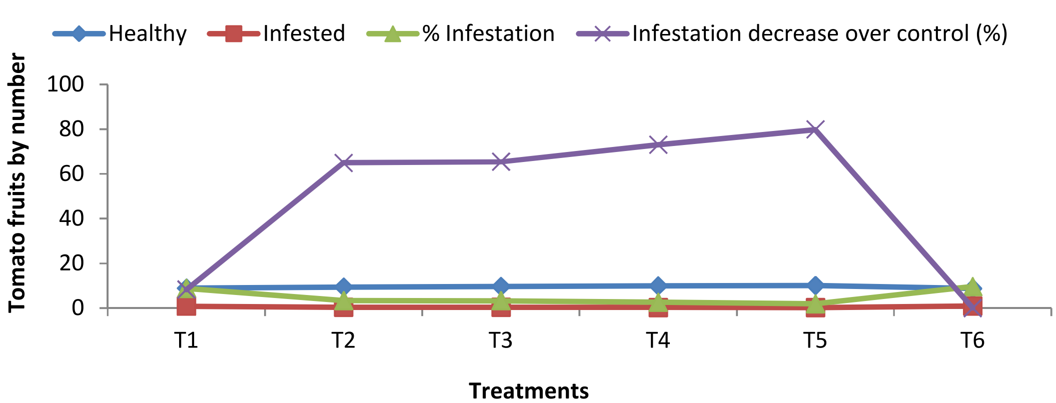

Figure 2. Effect of different IPM packages on fruit bearing status and fruit infestation at early ripening stages in number basis

T_1: Mechanical control, **T_2**: Voliam Flexi 300 SC @ 0.5 ml/l of water at 7 days interval + Pheromone trap at 10 m^2 distance, **T_3**: Voliam Flexi 300 SC @ 0.5 ml/l of water + Bioneem plus 1EC (Azadiractin) @1 ml/l of water at 7 days interval, **T_4**: Bioneem plus 1EC (Azadiractin) @1 ml/l of water + Spinosad 45 SC @ 4 ml/10l of water (bio-pesticides) + Pheromone trap at 10 m^2 distance, **T_5**: Mechanical control + Voliam Flexi 300 SC @ 0.5 ml/l of water + Bioneem plus 1EC (Azadiractin) @1 ml/l + Pheromone trap at 10 m^2 distance, **T_6**: Untreated control

At early ripening stage of tomato in weight basis, the highest weight of healthy fruits plant^{-1} (911.55 g) was observed in T_5 which was statistically similar (901.26 g, 885.45 g and 880.19 g, respectively) to T_4, T_3 and T_2 treatment, whereas the lowest weight (783.61 g) was found in T_6 treatment (Table 2). The lowest weight of infested fruits plant^{-1} (17.03 g) was found in T_5 which was similar (23.61 g) to T_4 treatment, whereas the highest weight of infested fruits (76.20 g) was recorded in T_6 which was similar (71.77 g) to T_1 treatment (Table 2). The lowest percentage of infested fruits plant^{-1} in weight basis (1.83%) was recorded in T_5 which was statistically similar (2.56%) by T_4 treatment, while the highest percentage of infested fruits in weight basis (8.86%) was found in T_6 which was closely followed (7.98%) by T_1 treatment (Table 2). In consideration of fruit infestation decrease over control in weight basis, the highest value (79.35%) was recorded in T_5, whereas the lowest value (9.93%) was observed in T_1 treatment (Table 2).

Table 2. Effect of different IPM packages on fruit bearing status and fruit infestation at early ripening stages by number and weight

Treatments	Tomato fruits by weight			
	Healthy	Infested	% Infestation	Infestation decrease over control (%)
T_1	829.54 bc	71.77 a	7.98 b	9.93
T_2	880.19 ab	29.93 b	3.29 c	62.87
T_3	885.45 ab	29.62 b	3.24 c	63.43
T_4	901.26 ab	23.61 bc	2.56 cd	71.11
T_5	911.55 a	17.03 c	1.83 d	79.35
T_6	783.61 c	76.20 a	8.86 a	--
$LSD_{(0.05)}$	75.04	7.371	0.799	--
Level of significance	0.05	0.01	0.01	--
CV(%)	4.77	9.80	9.51	--

In a column means having similar letter(s) are statistically identical and those having dissimilar letter(s) differ significantly as per 0.05 level of probability by DMRT.

T_1: Mechanical control, **T_2**: Voliam Flexi 300 SC @ 0.5 ml/l of water at 7 days interval + Pheromone trap at 10 m^2 distance, **T_3**: Voliam Flexi 300 SC @ 0.5 ml/l of water + Bioneem plus 1EC (Azadiractin) @1 ml/l of water at 7 days interval, **T_4**: Bioneem plus 1EC (Azadiractin) @1 ml/l of water + Spinosad 45 SC @ 4 ml/10l of water (bio-pesticides) + Pheromone trap at 10 m^2 distance, **T_5**: Mechanical control + Voliam Flexi 300 SC @ 0.5 ml/l of water + Bioneem plus 1EC (Azadiractin) @1 ml/l + Pheromone trap at 10 m^2 distance, **T_6**: Untreated control

3.2.2 Mid ripening stage

At mid ripening stage of tomato in number basis, the highest number of healthy fruits plant^{-1} (16.07) was observed in T_5 which was statistically similar (15.73, 15.07 and 14.53, respectively) to T_4, T_3 and T_2 treatment, whereas the lowest number (12.47) was found in T_6 which was statistically similar (13.67) to T_1 treatment (Figure 3). The lowest number of infested fruits plant^{-1} (0.33) was observed in T_5 which was statistically similar (0.47 and 0.53, respectively) to T_4 and T_3 treatment, while the highest number of infested fruits (1.60) was recorded in T_6 which was closely followed (1.33) by T_1

treatment (Figure 3). The lowest percentage of infested fruits plant^{-1} in number basis (2.03%) was found in T_5 which was statistically similar (2.88% and 3.42%, respectively) by T_4 and T_3 treatment, while the highest percentage of infested fruits in number basis (11.37%) was found in T_6 which was followed (8.90%) by T_1 treatment (Figure 3). In consideration of fruit infestation decrease over control in number basis, the highest value (82.15%) was recorded in T_6, while the lowest value (21.72%) was found in T_1 treatment (Figure 3).

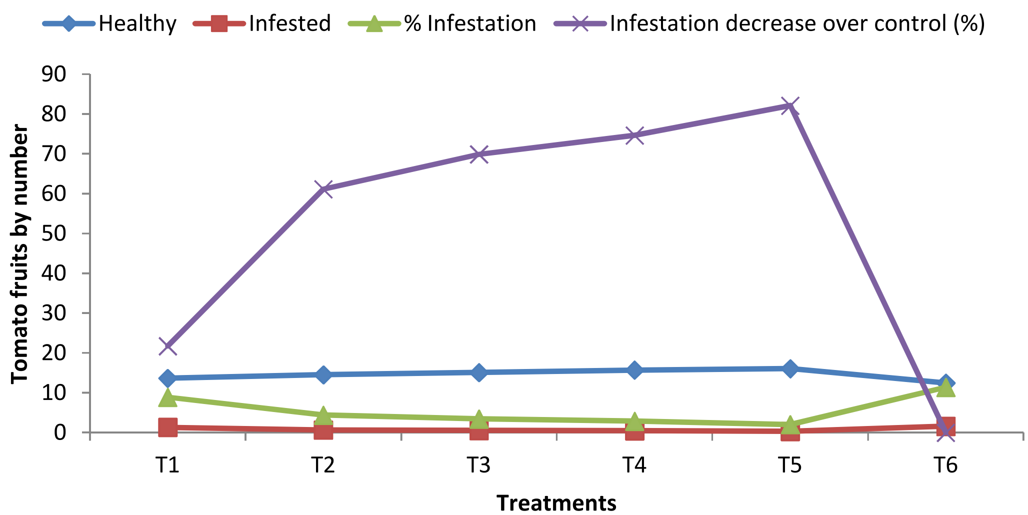

Figure 3. Effect of different IPM packages on fruit bearing status and fruit infestation at mid ripening stages in number basis

T_1: Mechanical control, **T_2**: Voliam Flexi 300 SC @ 0.5 ml/l of water at 7 days interval + Pheromone trap at 10 m^2 distance, **T_3**: Voliam Flexi 300 SC @ 0.5 ml/l of water + Bioneem plus 1EC (Azadiractin) @1 ml/l of water at 7 days interval, **T_4**: Bioneem plus 1EC (Azadiractin) @1 ml/l of water + Spinosad 45 SC @ 4 ml/10l of water (bio-pesticides) + Pheromone trap at 10 m^2 distance, **T_5**: Mechanical control + Voliam Flexi 300 SC @ 0.5 ml/l of water + Bioneem plus 1EC (Azadiractin) @1 ml/l + Pheromone trap at 10 m^2 distance, **T_6**: Untreated control

At mid ripening stage of tomato in weight basis, the highest weight of healthy fruits plant^{-1} (993.77 g) was found in T_5 which was statistically similar (978.37 g, 971.52 g and 951.96 g, respectively) to T_4, T_3 and T_1 treatment, whereas the lowest weight (871.02 g) was recorded in T_6 treatment which was statistically similar (898.35 g) to T_1 treatment (Table 3). The lowest weight of infested fruits plant^{-1} (19.96 g) was recorded in T_5 which was statistically similar (26.05 g) to T_4 and closely followed (31.63 g) by T_3 treatment, whereas the highest weight of infested fruits (98.50 g) was observed in T_6 which was followed (84.37 g) by T_1 treatment (Table 3). The lowest percentage of infested fruits plant^{-1} in weight basis (1.97%) was found in T_5 which was statistically similar (2.59%) to T_4 and closely followed (3.16%) by T_3 treatment, whereas the highest percentage of infested fruits in weight basis (10.16%) was observed in T_6 which was closely followed (8.64%) by T_1 treatment (Table 3). In consideration of fruit infestation decrease over control in weight basis, the highest value (80.61%) was recorded in T_5, while the lowest value (14.96%) was recorded in T_1 treatment (Table 3).

Table 3. Effect of different IPM packages on fruit bearing status and fruit infestation at mid ripening stages by weight

Treatments	Tomato fruits by weight			
	Healthy	Infested	% Infestation	Infestation decrease over control (%)
T_1	898.35 bc	84.37 b	8.64 b	14.96
T_2	951.96 abc	38.09 c	3.84 c	62.20
T_3	971.52 ab	31.63 cd	3.16 cd	68.90
T_4	978.37 ab	26.05 de	2.59 de	74.51
T_5	993.77 a	19.96 e	1.97 e	80.61
T_6	871.02 c	98.50 a	10.16 a	--
$LSD_{(0.05)}$	79.03	7.269	1.032	--
Level of significance	0.01	0.05	0.01	--
CV(%)		4.60	8.03	--

In a column means having similar letter(s) are statistically identical and those having dissimilar letter(s) differ significantly as per 0.05 level of probability by DMRT.

T_1: Mechanical control, **T_2**: Voliam Flexi 300 SC @ 0.5 ml/l of water at 7 days interval + Pheromone trap at 10 m^2 distance, **T_3**: Voliam Flexi 300 SC @ 0.5 ml/l of water + Bioneem plus 1EC (Azadiractin) @1 ml/l of water at 7 days interval, **T_4**: Bioneem plus 1EC (Azadiractin) @1 ml/l of water + Spinosad 45 SC @ 4 ml/10l of water (bio-pesticides) + Pheromone trap at 10 m^2 distance, **T_5**: Mechanical control + Voliam Flexi 300 SC @ 0.5 ml/l of water + Bioneem plus 1EC (Azadiractin) @1 ml/l + Pheromone trap at 10 m^2 distance, **T_6**: Untreated control

3.2.3 Late ripening stage

At late ripening stage of tomato in number basis, the highest number of healthy fruits plant^{-1} (14.13) was recorded in T_5 which was statistically similar (13.80, 13.13 and 12.67, respectively) to T_4, T_3 and T_2 treatment, whereas the lowest number (10.93) was found in T_6 treatment which was statistically similar (11.93) to T_1 treatment (Figure 4). The lowest number of infested fruits plant^{-1} (0.33) was observed in T_5 which was statistically similar (0.47) to T_4, while the highest number of infested fruits (1.67) was recorded in T_6 which was statistically similar (1.53) to T_1 treatment and followed (0.73 and 0.67) by T_2 and T_3 treatment and they were statistically similar (Figure 4). The lowest percentage of infested fruits plant^{-1} in number basis (2.35%) was observed in T_5 which was statistically similar (3.28%) by T_4 treatment, whereas the highest percentage of infested fruits in number basis (13.20%) was recorded in T_6 which was statistically similar (11.46%) to T_1 and followed (5.50% and 4.82%) by T_2 and T_3 treatment, respectively and they were statistically similar (Figure 4). In consideration of fruit infestation decrease over control in number basis, the highest value (82.20%) was observed in T_5, whereas the lowest value (13.18%) was recorded in T_1 treatment (Figure 4).

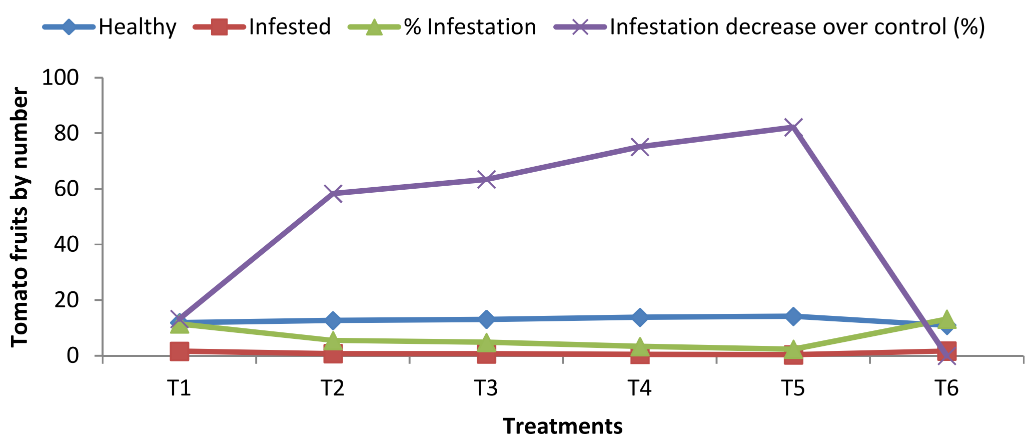

Figure 4. Effect of different IPM packages on fruit bearing status and fruit infestation at late ripening stage by number

T_1: Mechanical control, **T_2**: Voliam Flexi 300 SC @ 0.5 ml/l of water at 7 days interval + Pheromone trap at 10 m^2 distance, **T_3**: Voliam Flexi 300 SC @ 0.5 ml/l of water + Bioneem plus 1EC (Azadiractin) @1 ml/l of water at 7 days interval, **T_4**: Bioneem plus 1EC (Azadiractin) @1 ml/l of water + Spinosad 45 SC @ 4 ml/10l of water (bio-pesticides) + Pheromone trap at 10 m^2 distance, **T_5**: Mechanical control + Voliam Flexi 300 SC @ 0.5 ml/l of water + Bioneem plus 1EC (Azadiractin) @1 ml/l + Pheromone trap at 10 m^2 distance, **T_6**: Untreated control

At late ripening stage of tomato in weight basis, the highest weight of healthy fruits plant^{-1} (856.07 g) was observed in T_5 which was statistically similar (840.99 g, 831.48 g and 812.70 g, respectively) to T_4, T_3 and T_2 treatment, whereas the lowest weight (736.93 g) was found in T_6 which was statistically similar (755.02 g) to T_1 treatment (Table 4). The lowest weight of infested fruits plant^{-1} (18.45 g) was observed in T_5 which was closely followed (23.82 g) by T_4 treatment, while the highest weight of infested fruits (96.85 g) was observed in T_6 which was followed (84.64 g) by T_1 treatment (Table 4). The lowest percentage of infested fruits plant^{-1} in weight basis (2.11%) was found in T_5 which was closely followed (2.76%) by T_4 treatment, while the highest percentage of infested fruits in weight basis (11.63%) was recorded in T_6 which was closely followed (10.09%) by T_1 treatment (Table 4). In consideration of fruit infestation decrease over control in weight basis, the highest value (81.86%) was found in T_5, whereas the lowest value (13.24%) was recorded in T_1 treatment (Table 4).

Table 4. Effect of different IPM packages on fruit bearing status and fruit infestation at late ripening stage by weight

Treatments	Tomato fruits by weight			
	Healthy	Infested	% Infestation	Infestation decrease over control (%)
T_1	755.02 bc	84.64 b	10.09 b	13.24
T_2	812.70 abc	38.93 c	4.58 c	60.62
T_3	831.48 ab	33.75 d	3.90 d	66.47
T_4	840.99 a	23.82 e	2.76 e	76.27
T_5	856.07 a	18.45 f	2.11 f	81.86
T_6	736.93 c	96.85 a	11.63 a	--

$LSD_{(0.05)}$	76.84	4.126	0.438	--
Level of significance	0.05	0.01	0.01	--
CV(%)	5.24	4.59	4.12	--

In a column means having similar letter(s) are statistically identical and those having dissimilar letter(s) differ significantly as per 0.05 level of probability by DMRT.

T_1: Mechanical control, **T_2**: Voliam Flexi 300 SC @ 0.5 ml/l of water at 7 days interval + Pheromone trap at 10 m^2 distance, **T_3**: Voliam Flexi 300 SC @ 0.5 ml/l of water + Bioneem plus 1EC (Azadiractin) @1 ml/l of water at 7 days interval, **T_4**: Bioneem plus 1EC (Azadiractin) @1 ml/l of water + Spinosad 45 SC @ 4 ml/10l of water (bio-pesticides) + Pheromone trap at 10 m^2 distance, **T_5**: Mechanical control + Voliam Flexi 300 SC @ 0.5 ml/l of water + Bioneem plus 1EC (Azadiractin) @1 ml/l + Pheromone trap at 10 m^2 distance, **T_6**: Untreated control

3.2.4 Entire ripening stage

At entire ripening stage of tomato in number basis, the highest number of healthy fruits plant^{-1} (40.33) was observed in T_5 which was statistically similar (39.47 and 37.87, respectively) to T_4 and T_3 treatment and closely followed (36.60) by T_2, while the lowest number (32.13) was found in T_6 treatment which was statistically similar (34.53) to T_1 (Figure 5). The lowest number of infested fruits plant^{-1} (0.87) was observed in T_5 which was statistically similar (1.20) to T_4 and closely followed (1.53) by T_3, whereas the highest number of infested fruits (4.20) was recorded in T_6 which was closely followed (3.73) by T_1 treatment (Figure 5). The lowest percentage of infested fruits plant^{-1} in number basis (2.11%) was found in T_5 which was statistically similar (2.96%) by T_4 and closely followed (3.88%) by T_3 treatment, while the highest percentage of infested fruits in number basis (11.55%) was found in T_6 which was followed (9.77%) by T_1 treatment (Figure 5). In consideration of fruit infestation decrease over control in number basis, the highest value (81.73%) was found in T_5, whereas the lowest value (15.41%) was observed in T_1 treatment (Figure 5).

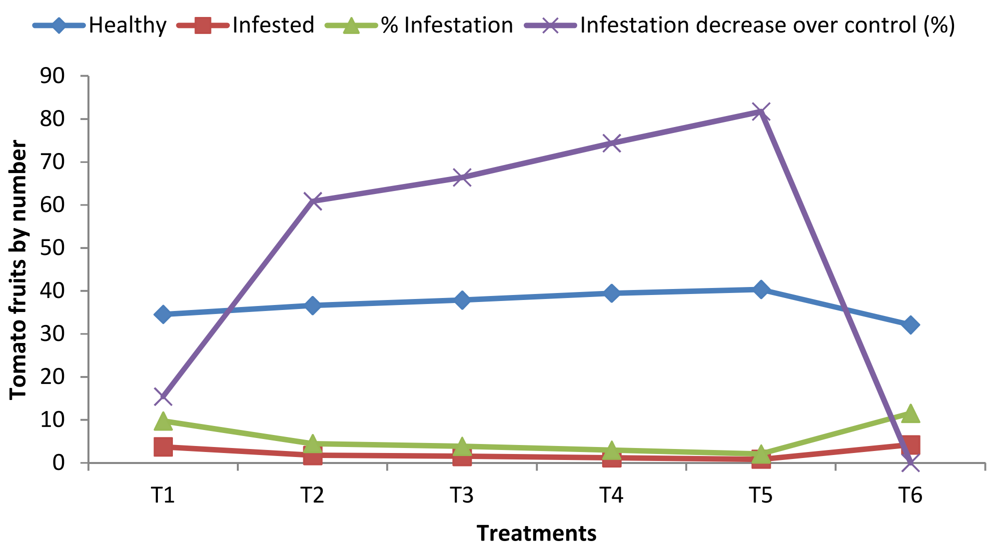

Figure 5. Effect of different IPM packages on fruit bearing status and fruit infestation at entire ripening stage by number

T_1: Mechanical control, **T_2**: Voliam Flexi 300 SC @ 0.5 ml/l of water at 7 days interval + Pheromone trap at 10 m^2 distance, **T_3**: Voliam Flexi 300 SC @ 0.5 ml/l of water + Bioneem plus 1EC (Azadiractin) @1 ml/l of water at 7 days interval, **T_4**: Bioneem plus 1EC (Azadiractin) @1 ml/l of water + Spinosad 45 SC @ 4 ml/10l of water (bio-pesticides) + Pheromone trap at 10 m^2 distance, **T_5**: Mechanical control + Voliam Flexi 300 SC @ 0.5 ml/l of water + Bioneem plus 1EC (Azadiractin) @1 ml/l + Pheromone trap at 10 m^2 distance, **T_6**: Untreated control

At entire ripening stage of tomato in weight basis, the highest weight of healthy fruits plant^{-1} (2761.39 g) was recorded in T_5 which was statistically similar (2720.61 g, 2688.46 g and 2644.85 g, respectively) to T_4, T_3 and T_2 treatment, whereas the lowest weight (2391.57 g) was found in T_6 which was statistically similar (2482.91 g) to T_1 treatment (Table 5). The lowest weight of infested fruits plant^{-1} (55.44 g) was recorded in T_5 which was closely followed (73.48 g) by T_4 treatment, whereas the highest weight of infested fruits (271.56 g) was found in T_6 which was followed (240.78 g) by T_1 treatment (Table 5). The lowest percentage of infested fruits plant^{-1} in weight basis (1.97%) was found in T_5 which was closely followed (2.63%) by T_4 treatment, while the highest percentage of infested fruits in weight basis (10.20%) was observed in T_6 which was closely followed (8.86%) by T_1 treatment (Table 5). In consideration of fruit infestation decrease over control in weight basis, the highest value (80.69%) was observed in T_5, while the lowest value (13.14%) was observed in T_1 treatment (Table 5). The present findings are agreed with the findings of [20] who reported that integration of *B. thuringiensis* + tracer + *B. hebetor* + neemosol and *C. carnea*, resulted in minimum infestation of marketable tomato fruits caused by the pest. Similarly, Gajanana *et al*. [16] who reported that IPM technology was more effective in reducing fruit infestation.

Table 5. Effect of different IPM packages on fruit bearing status and fruit infestation at entire ripening stage in weight basis

Treatments	Tomato fruits by weight			
	Healthy	Infested	% Infestation	Infestation decrease over control (%)
T_1	2482.91 bc	240.78 b	8.86 b	13.14
T_2	2644.85 ab	106.95 c	3.89 c	61.86
T_3	2688.46 a	95.01 c	3.41 c	66.57
T_4	2720.61 a	73.48 d	2.63 d	74.22
T_5	2761.39 a	55.44 e	1.97 e	80.69
T_6	2391.57 c	271.56 a	10.20 a	--
$LSD_{(0.05)}$	186.60	13.34	0.555	--
Level of significance	0.01	0.01	0.01	--
CV(%)	3.92	5.22	5.91	--

In a column means having similar letter(s) are statistically identical and those having dissimilar letter(s) differ significantly as per 0.05 level of probability

T_1: Mechanical control, **T_2**: Voliam Flexi 300 SC @ 0.5 ml/l of water at 7 days interval + Pheromone trap at 10 m^2 distance, **T_3**: Voliam Flexi 300 SC @ 0.5 ml/l of water + Bioneem plus 1EC (Azadiractin) @1 ml/l of water at 7 days interval, **T_4**: Bioneem plus 1EC (Azadiractin) @1 ml/l of water + Spinosad 45 SC @ 4 ml/10l of water (bio-pesticides) + Pheromone trap at 10 m^2 distance, **T_5**: Mechanical control + Voliam Flexi 300 SC @ 0.5 ml/l of water + Bioneem plus 1EC (Azadiractin) @1 ml/l + Pheromone trap at 10 m^2 distance, **T_6**: Untreated control.

3.3 Effect of different IPM packages on yield attributes and yield of tomato

Statistically significant variation was observed in terms of yield attributes and yield of tomato due to different IPM packages based on effective insecticides and bio-pesticides.

3.3.1 Plant height

Data revealed that the longest plant (99.54 cm) was recorded in T_5 which was statistically similar (98.69 g, 97.80 g and 95.26 g, respectively) to T_4, T_3 and T_2 treatment, while the shortest plant (92.15 cm) was found in T_6 which was statistically similar (93.49 cm) to T_1 treatment (Figure 6). Chavan *et* *al.* [17] evaluated the efficacy of various pest management module against tomato fruit borer, and the results revealed that IPM module was found most promising for producing tallest plant.

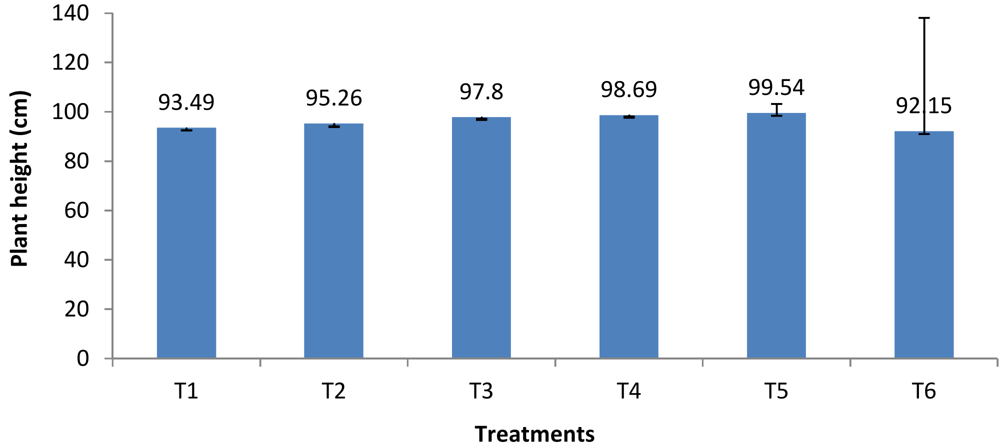

Figure 6. Effect of different IPM packages on plant height (cm) of tomato.

T_1: Mechanical control, **T_2**: Voliam Flexi 300 SC @ 0.5 ml/l of water at 7 days interval + Pheromone trap at 10 m^2 distance, **T_3**: Voliam Flexi 300 SC @ 0.5 ml/l of water + Bioneem plus 1EC (Azadiractin) @1 ml/l of water at 7 days interval, **T_4**: Bioneem plus 1EC (Azadiractin) @1 ml/l of water + Spinosad 45 SC @ 4 ml/10l of water (bio-pesticides) + Pheromone trap at 10 m^2 distance, **T_5**: Mechanical control + Voliam Flexi 300 SC @ 0.5 ml/l of water + Bioneem plus 1EC (Azadiractin) @1 ml/l + Pheromone trap at 10 m^2 distance, **T_6**: Untreated control

3.3.2 Number of branches plant^{-1}

The maximum number of branches plant^{-1} (19.40) was recorded in T_5 which was statistically similar (19.07, 18.40 and 18.20, respectively) to T_4, T_3 and T_2 treatment, whereas the minimum number (16.60) was observed in T_6 which was statistically similar (17.27) to T_1 treatment (Table 6).

Table 6. Effect of different IPM packages on different yield attributes and yield of tomato

Treatments	Number of branches plant^{-1}	Number of flower bunches plant^{-1}	Number of flowers bunch^{-1}	Fruit yield (t ha^{-1})
T_1	17.27 bc	13.60 ab	7.47 bc	51.37 bc
T_2	18.20 abc	14.27 a	7.87 abc	57.07 ab
T_3	18.40 ab	14.80 a	7.80 abc	58.74 a
T_4	19.07 a	14.93 a	8.07 ab	59.19 a
T_5	19.40 a	15.13 a	8.47 a	59.82 a
T_6	16.60 c	12.47 b	7.07 c	50.36 c
$LSD_{(0.05)}$	1.605	1.700	0.757	6.340
Level of significance	0.05	0.05	0.05	0.05
CV(%)	4.86	6.58	5.34	6.21

In a column means having similar letter(s) are statistically identical and those having dissimilar letter(s) differ significantly as per 0.05 level of probability by DMRT.

$\mathbf{T_1}$: Mechanical control, $\mathbf{T_2}$: Voliam Flexi 300 SC @ 0.5 ml/l of water at 7 days interval + Pheromone trap at 10 m^2 distance, $\mathbf{T_3}$: Voliam Flexi 300 SC @ 0.5 ml/l of water + Bioneem plus 1EC (Azadiractin) @1 ml/l of water at 7 days interval, $\mathbf{T_4}$: Bioneem plus 1EC (Azadiractin) @1 ml/l of water + Spinosad 45 SC @ 4 ml/10l of water (bio-pesticides) + Pheromone trap at 10 m^2 distance, $\mathbf{T_5}$: Mechanical control + Voliam Flexi 300 SC @ 0.5 ml/l of water + Bioneem plus 1EC (Azadiractin) @1 ml/l + Pheromone trap at 10 m^2 distance, $\mathbf{T_6}$: Untreated control

3.3.3 Number of flower bunches plant^{-1}

Data revealed that the maximum number of flower brunches plant^{-1} (15.13) was found in T_5 which was statistically similar (14.93, 14.80, 14.27 and 13.60, respectively) to T_4, T_3, T_2 and T_1 treatment, while the minimum number (12.47) was recorded in T_6 treatment (Table 6).

3.3.4 Number of flowers bunch^{-1}

The maximum number of flowers brunch^{-1} (8.47) was recorded in T_5 which was statistically similar (8.07, 7.80 and 7.87, respectively) to T_4, T_3 and T_2 treatment, whereas the minimum number (7.07) was found in T_6 treatment which was statistically similar (7.47) to T_1 (Table 6). This result is agreed with [19] who reported that IPM technology was very effective in reducing the incidence of pests and producing highest number of flower per bunch in tomato.

3.3.5 Single fruit weight

It was observed that the highest weight of single fruit (98.45 g) was recorded in T_5 which was statistically similar (97.96 g, 96.74 g, 95.42 g and 91.06 g, respectively) to T_4, T_3, T_2 and T_1 treatment, while the lowest weight of single fruit (87.73 g) was found in T_6 treatment (Figure 7). This result is similar with [21] who reported that integration of bioagents and Neem Seed Kernel Extract increased single fruit weight.

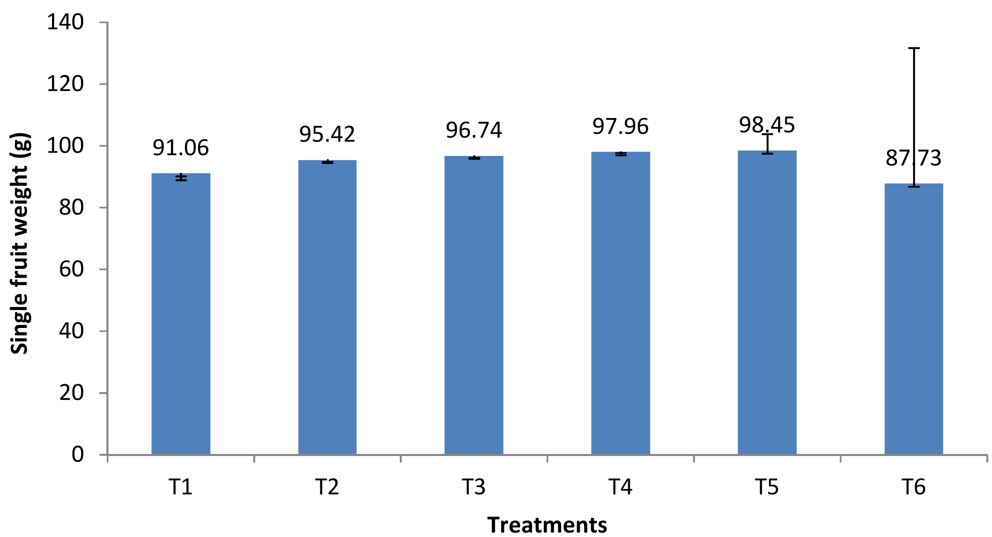

Figure 7. Effect of different IPM packages on single fruit weight (g) of tomato

$\mathbf{T_1}$: Mechanical control, $\mathbf{T_2}$: Voliam Flexi 300 SC @ 0.5 ml/l of water at 7 days interval + Pheromone trap at 10 m^2 distance, $\mathbf{T_3}$: Voliam Flexi 300 SC @ 0.5 ml/l of water + Bioneem plus 1EC (Azadiractin) @1 ml/l of water at 7 days interval, $\mathbf{T_4}$: Bioneem plus 1EC (Azadiractin) @1 ml/l of water + Spinosad 45 SC @ 4 ml/10l of water (bio-pesticides) + Pheromone trap at 10 m^2 distance, $\mathbf{T_5}$: Mechanical control + Voliam Flexi 300 SC @ 0.5 ml/l of water + Bioneem plus 1EC (Azadiractin) @1 ml/l + Pheromone trap at 10 m^2 distance, $\mathbf{T_6}$: Untreated control

3.3.6 Fruit yield hectare^{-1}

The highest fruit yield (59.82 t ha^{-1}) was found in T_5 which was statistically similar (59.19 t ha^{-1}, 58.74 t ha^{-1} and 57.07 t ha^{-1}, respectively) to T_4, T_3 and T_2 treatment, whereas the lowest fruit yield (50.36 t ha^{-1}) was recorded in T_6 treatment which was statistically similar (51.37 t ha^{-1}) to T_1 treatment (Table 6). These findings also agreed with that of [20] who reported that integration of *B. thuringiensis* + tracer + *B. hebetor* + neemosol and *C. carnea*, resulted in minimum infestation of marketable tomato fruits caused by the pest, as such it, proved to be the best. [17] evaluated the efficacy of various pest management module against tomato fruit borer, and the results revealed that IPM module was found most promising in increasing yield (36445 kg ha^{-1}). Chavan *et al.* [17] evaluated the efficacy of various pest management module against tomato fruit borer, and the results revealed that IPM module was found most promising in reducing fruit infestation (15.35%). Sardana *et al.* [22] reported that IPM technology resulted in reducing the number of chemical sprays with higher CBR of 1:3.85 in IPM.

3.3.7 Benefit Cost analysis

The analysis was done in order to find out the most profitable IPM packages based on effective insecticides and bio-pesticides on cost and benefit of various components. The results of cost benefit analysis of tomato cultivation showed that the highest net benefit of Tk. 76,960 ha^{-1} was obtained in T_5 treatment and the second highest was found Tk. 70,460 ha^{-1} in T_4 (Table 7). The highest benefit cost ratio (2.11) was estimated for T_5 treatment and the lowest (0.15) for T_1 treatment under the trial. The highest BCR was found in the treatment T_5 may be due to the minimum pest infestation to the other treatment components and the highest yield of this treatment. Sardana *et al.* (2013) reported that IPM technology resulted in reducing the number of chemical sprays with higher CBR of 1:3.85 in IPM.

Table 7. Cost of tomato production of different IPM packages

Treatments	Cost of pest management (Tk.)	Fruit yield (t/ha)	Gross return (Tk.)	Net return (Tk.)	Adjusted net return (Tk.)	Benefit cost ratio
T_1	10500	51.37	616440	605940	1620	0.15
T_2	32650	57.07	684840	652190	47870	1.47
T_3	34580	58.74	704880	670300	65980	1.91
T_4	35500	59.19	710280	674780	70460	1.98
T_5	36560	59.82	717840	681280	76960	2.11
T_6	0	50.36	604320	604320	0	--

T_1: Mechanical control, **T_2**: Voliam Flexi 300 SC @ 0.5 ml/l of water at 7 days interval + Pheromone trap at 10 m^2 distance, **T_3**: Voliam Flexi 300 SC @ 0.5 ml/l of water + Bioneem plus 1EC (Azadiractin) @1 ml/l of water at 7 days interval, **T_4**: Bioneem plus 1EC (Azadiractin) @1 ml/l of water + Spinosad 45 SC @ 4 ml/10l of water (bio-pesticides) + Pheromone trap at 10 m^2 distance, **T_5**: Mechanical control + Voliam Flexi 300 SC @ 0.5 ml/l of water + Bioneem plus 1EC (Azadiractin) @1 ml/l + Pheromone trap at 10 m^2 distance, **T_6**: Untreated control

Concluding remarks

From the present study it was concluded that, different tomato varieties and cultivars showed significantly different performance on tomato fruit borer infestation, yield and yield contributing characters. As in combination Mechanical control + Voliam Flexi 300 SC @ 0.5 ml/l of water + Bioneem plus 1EC (Azadiractin) @1 ml/l + Pheromone trap at 10 m^2 distance was more effective against the fruit borer of tomato which was statistically similar to Bioneem plus 1EC (Azadiractin) @1 ml/l of water + Spinosad 45 SC @ 4 ml/10l of water (bio-pesticides) + Pheromone trap.

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