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COMPARATIVE ANALYSIS OF ECO-FRIENDLY MODULES FOR MANAGEMENT OF TOMATO PESTS

K.D. Marwade, S.L. Borkar, A.N. Humane* and D.B. Undirwade

Department of Agricultural Entomology, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola - 444 104, Maharashtra, India.

*Corresponding author E-mail : akankshahumane5@gmail.com

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ABSTRACT

The study titled “Comparative Analysis of Eco-Friendly Modules for Management of Tomato pests” was conducted on Pusa Ruby variety of tomato crop at the Department of Entomology, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola during the *Kharif* season of 2018-19. The aim was to test different botanicals and bio-pesticides against pest of tomato. Seven treatment modules were set up in a randomized block design, including various botanicals such as Neem seed Extract (NSE) 5%, Azadirachtin 10,000 ppm, Azadirachtin 300 ppm and bio-pesticides like *HaNPV* 250 LE/ha, *Beauveria bassiana* 1×10^8 CFU, *Metarhizium anisopliae* 1×10^8 CFU, *Bacillus thuringiensis* 1000 g/ha and *Trichogramma chilonis* @ 1.5 lakh/ha, alongside an untreated control. These modules were applied at different intervals after planting to manage tomato leaf miner. Observations on tomato leaf miner infestation were recorded at 3, 5 and 10 days after each treatment application. The cumulative percentage of leaf infestation by tomato leaf miner was calculated for each treatment module. Additionally, the yield and cost-effectiveness were evaluated. The treatment module M4, which included the application of Azadirachtin 300 ppm @ 5 ml/lit at 35 and 45 DAP, *Metarhizium anisopliae* at 55 Days after planting (DAP) and the release of *T. chilonis* @ 1.5 lakh/ha at 65, 75 and 85 DAP, demonstrated the most effectiveness against tomato leaf miner. Meanwhile, treatment module M3, with the application of Azadirachtin 300 ppm @ 5 ml/lit at 35 and 45 DAP, application of *B. bassiana* at 55 DAP, and the release of *T. chilonis* @ 1.5 lakh/ha at 65, 75 and 85 DAP, showed promise in reducing leaf infestation by tomato leaf miner. The treatment module M5, involving the application of Azadirachtin 10,000 ppm @ 3 ml/lit at 35 and 45 DAP, the application of *HaNPV* 250 LE at 55 DAP and the release of *T. chilonis* @ 1.5 lakh/ha at 65, 75 and 85 DAP, demonstrated a positive impact against the tomato fruit borer. Additionally, treatment modules M4 and M3 showed promise in reducing the percentage of fruit infestation by the tomato fruit borer. Likewise, the treatment modules M5 and M4 were found to be the most effective and economically viable, with a calculated Income Cost Benefit Ratio (ICBR) of 1:15.62 and 1:10.95, respectively. These findings underscore the potential of eco-friendly treatment modules like M4 and M3, encouraging environmentally sustainable practices for tomato pest management.

Key words : Eco-Friendly, *HaNPV*, Modules, *Trichogramma chilonis*, Tomato Leaf Miner.

Introduction

Tomato (*Lycopersicon esculentum* Mill) is recognized as the world’s second most significant vegetable, valued for its commercial appeal and rich nutritional content, trailing only behind potatoes. Although, commonly regarded as a vegetable, botanically it is classified as a fruit (berry) due to its development from an ovary, propagated through sexual or asexual means. Originating from South America, particularly Peru, it was introduced to India from Europe during the 17th century (Kale and Kale, 1984). Its widespread cultivation globally attests to its immense popularity and economic importance.

Tomatoes are widely recognized as a “Protective Food”, serving as a vital source of income for small and marginal farmers while also contributing essential nutrients to consumers (Sharma and Singh, 2020). Their versatility extends to various processed forms including soups, juices, jams, ketchup, purees, powders, and pickles. The consumption of lycopene, responsible for the vibrant red colour of tomatoes, is associated with preventing serious diseases such as cancer and heart conditions. Additionally, tomato soup is considered a beneficial remedy for individuals suffering from constipation (Thamburaj and Singh, 2018).

Tomatoes, being vital crops, face significant challenges primarily from pests and diseases, leading to reduced production and quality. Various parts of the tomato plant, including roots, stems, foliage and fruits, are susceptible to attack by numerous insect pests and diseases (Lange and Bronson, 1981). Cohic (1958) identified 13 insect pests of tomatoes, predominantly Lepidopterans, Coleopterans and Hemipterans, among which the notable ones include the tomato fruit borer (*Helicoverpa armigera*), whitefly (*Bemisia tabaci*), jassids (*Amrasca devastans*), leaf miner (*Liriomyza trifolii*), tomato pinworm (*Tuta absulata*), potato aphid (*Myzus persicae*) and hadda beetle (*Henosepilachna vigintioctopunctata*).

In India, the tomato fruit borer, *H. armigera*, presents a significant challenge, profoundly impacting the production and market value of tomato crops. Known by various names such as gram pod borer, American bollworm and tomato fruit borer, it stands out as one of the most destructive pests affecting tomatoes in the country. Adult moths primarily lay eggs on the upper and lower surfaces of the top four leaves within the canopy. The larvae, in their early stages, extensively feed on foliage, flower buds and flowers, while later instars bore into the fruit, rendering them unmarketable and unfit for human consumption. This infestation results in substantial crop losses, with yield reductions of up to 55% reported (Selvanarayanan, 2000). Studies by Dhandapani *et al*. (2003) indicate yield losses ranging from 22% to 38% due to tomato fruit borer infestations alone, reaching over 80% in cases of severe infestation (Dhaliwal and Srivastava, 2014). Similarly, avoidable losses during different seasons have been reported, such as 36.36%, 37.39% and 22.39% during January-February, March-April and October-November, respectively (Tiwari and Krishnamurty, 1984).

The leaf miner, *Liriomyza trifolii*, a member of the Liriomyza genus, encompasses more than 300 species, with 23 species being economically significant. The damage caused by *L. trifolii* involves small yellow maggots feeding inside leaf tissue, leaving distinctive long, slender, widening, white tunnels or mines throughout the leaf (Trumble, 1981). The oviposition wounds created by female *L. trifolii* on the leaf's upper surface provide habitats for pathogenic bacteria and fungi. Upon hatching, the larvae proceed to mine through leaf tissue, feeding on mesophyll and forming serpentine mines and blotches on the leaf's upper surface. This damages the photosynthesis rate of affected leaves, and in severe infestations, plants can undergo complete defoliation due to the combined damage of leaf miner larvae and plant pathogens. These results in plant stress, moisture loss, or sun scalding of fruits due to leaf shedding (Gore, 2007; Chavan *et al*., 2006). Such damage negatively impacts the plant's photosynthetic activity, growth of young shoots, and ultimately, fruit formation (Parella, 1987). In tomatoes, the extent of damage caused by this pest has been reported to range from 30 to 40% (Anonymous, 1995).

The indiscriminate use of pesticides poses significant threats to both the environment and human health, while also contributing to the development of pesticide-resistant insect populations. Consequently, there is a pressing need for alternative pest management strategies to minimize reliance on chemical pesticides, particularly in vegetable crops. Botanicals and bio-pesticides offer promising eco-friendly alternatives to synthetic insecticides (Schmutterer, 1995; Elshafie and Basedow, 2003).

Entomopathogenic fungi, such as *Beauveria bassiana* and *Metarhizium anisopliae*, play a crucial role in managing insect pests, particularly in humid tropical regions, with these two species constituting a significant portion of microbial pesticides (Faria and Wright, 2007). Botanical pesticides, particularly neem (Azadirachta *indica*), is also widely utilized and available commercially in various formulations containing the active component azadirachtin (Rijal *et al*., 2008).

Given these considerations, the present investigation aims to evaluate and recommend safer and environmentally compatible alternative methods of pest control utilizing botanicals and bio-pesticides. These include Neem Seed Extract (NSE), Azadirachtin at concentrations of 10,000 and 300 ppm, *Bacillus thuringiensis*, *Beauveria bassiana*, *Metarhizium anisopliae*, *Trichogramma chilonis* and *HaNPV* 250 LE (Larval equivalent). Such integrated approaches are essential to safeguard crops from devastating pests while ensuring eco-safety and sustainability in agricultural practices, particularly in the management of major insect pests affecting tomato crops.

Materials and Methods

An experiment was conducted on tomato crop (Variety Pusa Ruby) in the field conditions at the

Department of Entomology, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola during the *Kharif* season of 2018-19. The objective was to assess the efficacy of various botanicals and bio-pesticide module in managing the major insect pests of tomato. The experiment was designed with seven treatments, each replicated three times.

Details of botanicals and bio-pesticides used for this work such as common name, formulation, concentration, chemical name, trade name and source of supply are given in Table 1.

Even distinct treatment combinations were employed, incorporating botanical extracts such as Neem Seed Extract (NSE) at a concentration of 5%, Azadirachtin at 10,000 ppm and 300 ppm, and bio-pesticides including *HaNPV* at 250 LE/ha, *Beauveria bassiana* at 1×10^8 CFU, *Metarhizium anisopliae* at 1×10^8 CFU, Bacillus thuringiensis at 1000 gm or ml/ha and *Trichogramma chilonis* at 1.5 lakh/ha. These treatments, along with an untreated control, were assessed at various intervals after planting (DAP) in each module to manage major insect pests affecting tomato crops. Detailed specifications of each treatment module are provided in the corresponding Table 2.

The initial application of each treatment module for controlling tomato leaf miner occurred at 35 DAP, while for tomato fruit borer, it was conducted at 55 DAP. Subsequent applications were made at 10-day intervals after each initial application, total four sprays per treatment module.

Preparation of neem seeds extract (NSE)

The process involved taking the required quantity of dried crushed neem seeds at a rate of 5%, equating to 5 kg for every 100 liters of water as needed. These weighed seeds were finely ground and placed in a vessel with sufficient water for soaking overnight, one day prior to spraying. The following morning, the extract was carefully decanted through a muslin cloth and the process was repeated with water washing until complete extraction was achieved. The resulting suspension was then adjusted to the desired volume by adding the remaining quantity of water. Additionally, soap powder was incorporated into the extract at a rate of 0.2% (200 gm/100 liters of water) to facilitate better coverage of the material on the crop.

Preparation of bio-pesticide suspension

The amount of *HaNPV*(Dr. PDKV), Btk, *B. bassiana* and *M. anisopliae* needed for treatment was determined according to the size of the plot to be treated,

Table 1 : Details of botanicals and bio-pesticides used in the experiments.

S. no.	Common Name	Chemical name/ Scientific name	Formu-lation	Trade name	Conc. (%) used	Source of supply
1	Neem Seed Extract (NSE)	In crude form (*Azadirachta indica* A. Juss)		NSE	5%	Laboratory prepared
2	Azadirachtin	*Azadirachtin*	10,000 ppm	Margo Econeem Plus	1%	Margo Biocontrols Private Limited, No. 344/8, 4th Main, Sadashivanagar, Bengaluru - 560 080, Karnataka.
3	Azadirachtin	Azadirachtin	300 ppm	Margo Tricure	0.03%	Margo Biocontrols Private Limited, No. 344/8, 4th Main, Sadashivanagar, Bengaluru - 560 080, Karnataka.
4	HaNPV	*Helicoverpa . armigera Nuclear Polyhedrosis Virus*	250 LE	HaNPV	250 LE/ha	Biocontrol Laboratory, Deptt. of Entomology, Dr.P.D.K.V.,Akola
5	Bt	*Bacillus thuringiensis* var. Kurustaki	1000 mg	BT-k		Ruchi Oyster Muschroom, Suman House, Tirora Road, Kudwa, Gondia- 441614
6	*Beauveria bssiana*	*Beauveria bssiana*	1×10^8 CFU	Attack		Ruchi Oyster Muschroom, Suman House, Tirora Road, Kudwa, Gondia - 441 614
7	*Metarhizium anisopliae*	*Metarhizium anisopliae*	1×10^8 CFU	Khodkid-anashak		Ruchi Oyster Muschroom, Suman House, Tirora Road, Kudwa, Gondia- 441614
8	Trichocard	*Trichogramma chilonis*				Biocontrol Laboratory, Deptt. of Entomology, Dr. P.D.K.V., Akola

Table 2 : Details of treatment Modules.

Module-1	a. Application of NSE 5% at 35 and 45 DAP b. Release of *Trichogramma chilonis* @ 1.5 lakh/ha. at 55, 65, 75, 85 DAP
Module-2	a. Application of Azadirachtin 10,000 ppm @ 3ml/lit. at 35 and 45 DAP b. Release of *Trichogramma chilonis* @ 1.5 lakh/ ha. at 55, 65, 75 and 85 DAP
Module-3	a. Application of Azadirachtin 300 ppm @ 5 ml per lit at 35 and 45 DAP b. Application of *Beauveria bassiana* at 55 DAP c. Release of *Trichogramma chilonis* @1.5 lakh/ha at 65, 75 and 85 DAP
Module-4	a. Application of Azadirachtin 300 ppm @ 5 ml/lit at 35 and 45 DAP b. Application of *Metarhizium anisopliae* at 55 DAP c. Release of *Trichogramma chilonis* @1.5 lakh/ha at 65, 75, 85 DAP
Module-5	a. Application of Azadirachtin 10,000 ppm @ 3 ml/lit at 35 and 45 DAP b. Application of *HaNPV* 250 LE/ha at 55 DAP c. Release of *Trichogramma chilonis* @1.5 lakh/ha at 65, 75 and 85 DAP
Module-6	a. Application of Azadirachtin 10,000 ppm @ 3 ml/lit at 35 and 45 DAP b. Application of *Bt*. 1000 gm or ml/ha at 55 DAP c. Release of *Trichogramma chilonis* @1.5 lakh/ha at 65, 75 and 85 DAP
Module-7	Control Plot

DAP = Days after planting.

following the specified doses provided in Table 2. During the application of *HaNPV*, a commonly used UV protectant called Ranipal 10% aqueous solution was added at a rate of 1 ml per liter of the spray mixture containing the nuclear polyhedrosis virus.

Method of recording observations

The observations were recorded on the following aspects in the field after transplanting.

Observations on the tomato leaf miner were conducted following the onset of leaf damage and after the application of each treatment module at intervals of 3, 5 and 10 days. Similarly, observations on the tomato fruit borer were made after the initiation of fruit formation on the plants and following the application of each treatment module at the same intervals.

To assess the impact of the treatments, the number of total and affected leaves was tallied from five randomly selected plants in each plot. Subsequently, the percentage of infested leaves due to leaf miner was calculated based on these observations.

Similarly, the number of total healthy and affected fruits of the plants was recorded from five randomly selected plants in each plot. This allowed for the calculation of the percentage of infested fruits attributable to the tomato fruit borer.

The percent leaf miner and fruit borer infestation were calculated by using the following formula.

$$\text{\% leaf miner infestation} = \frac{\text{No of mined leaves}}{\text{Total no. of leaves}} \times 100$$

The fruit borer infestation was carried out by using following formula.

$$\text{\% fruit borer infestation} = \frac{\text{No of infested fruits}}{\text{Total no. of fruits to be plucked}} \times 100$$

Statistical analysis

Following the methodology outlined by Gomez and Gomez (1984), data collected from field experiments throughout the season were transformed appropriately and subjected to statistical analysis to assess their significance. Additionally, yield data underwent statistical analysis to compare the effects of different treatment modules. The pest and yield data gathered during the experimentation period were statistically analysed after undergoing suitable transformations, enabling the interpretation of results across various parameters.

Results

Efficacy of different treatment modules against major insect pests of tomato

Efficacy of treatment modules on percent leaves infestation of tomato leaf miner (*Liriomyza trifolii*) 3, 5 and 10 days after spray at 35 DAP

At 3 DAS, the statistical analysis of the data presented in Table 3 revealed significant findings. Notably, treatment module M4 exhibited the lowest leaf infestation at 7.21%, followed by M3 at 10.21%, both significantly better than other modules. Subsequently, treatment modules M1, M2, and M5 displayed relatively higher leaf infestation rates at 13.96%, 16.40% and 17.63%, respectively, with no significant difference among them.

Table 3 : Efficacy of treatment modules on percent leaves infestation of tomato leaf miner (*L. trifolii*) 3, 5 and 10 days after spray at 35, 45, 55 and 65 DAT.

Mo.No.	Treatment Modules	Percent leaves infestation of *L. trifolii* / plant at 35 DAP			Percent leaves infestation of *L. trifolii* / plant at 45 DAP			Percent leaves infestation of *L. trifolii* / plant at 55 DAP			Percent leaves infestation of *L. trifolii* / plant at 65 DAP		
		3 DAS	**5 DAS**	**10 DAS**	**3 DAS**	**5 DAS**	**10 DAS**	**3 DAS**	**5 DAS**	**10 DAS**	**3 DAS**	**5 DAS**	**10 DAS**
M1	a. Application of NSE 5% at 35 and 45 DAP b. Release of *Trichogramma chilonis* @ 1.5 lakh/ha at 55, 65, 75, 85 DAP	11.32(3.36)	10.16(3.15)	11.25(3.34)	12.24(3.50)	10.91(3.30)	12.64(3.55)	13.96(3.74)	9.72(3.12)	11.14(3.33)	10.26(3.19)	7.20(2.67)	9.91(3.15)
M2	a. Application of Azadirachtin 10,000 ppm@3ml/lit at 35 and 45 DAP b. Release of *Trichogramma chilonis* @ 1.5 lakh/ha at 55, 65, 75 and 85 DAP	15.83(3.96)	14.68(3.82)	15.23(3.90)	16.65(4.08)	14.21(3.77)	16.34(4.04)	16.40(4.05)	13.78(3.71)	15.62(3.95)	13.86(3.72)	10.84(3.29)	13.84(3.70)
M3	a. Application of Azadirachtin 300 ppm @ 5 ml per lit at 35 and 45 DAP b. Application of *Beauveria bassiana* @ 55 DAP c. Release of *Trichogramma chilonis*@ 1.5 lakh/ha at 65, 75 and 85 DAP	10.43(3.21)	8.91(2.98)	10.25(3.18)	11.85(3.43)	9.14(3.02)	11.65(3.41)	10.21(3.19)	8.13(2.83)	10.92(3.29)	7.32(2.70)	6.14(2.53)	7.82(2.79)
M4	a. Application of Azadirachtin 300 ppm @ 5 ml/lit at 35 and 45 DAP b. Application of *Metarhizium anisopliae* @ 55 DAPc. Release of *Trichogramma chilonis*@ 1.5 lakh/ha at 65, 75, 85DAP	6.71(2.57)	5.11(2.23)	7.12(2.63)	8.34(2.87)	6.65(2.54)	8.24(2.84)	7.21(2.66)	5.32(2.30)	7.30(2.66)	4.21(2.04)	3.21(1.78)	5.23(2.32)
M5	a. Application of Azadirachtin 10,000 ppm @ 3 ml/lit at 35 and 45 DAP b. Application of *HaNPV* 250 LE @ 55 DAPc. Release of *Trichogramma chilonis* @ 1.5 lakh/ha at 65, 75 and 85 DAP	16.34(3.83)	15.20(3.90)	15.94(3.99)	18.26(4.31)	15.42(3.91)	17.62(4.19)	17.63(4.19)	14.71(3.83)	16.63(4.08)	14.61(3.82)	11.71(3.42)	14.61(3.81)
M6	a. Application of Azadirachtin 10,000 ppm @ 3 ml/lit at 35 and 45 DAP b. Application of *Bt*. (k.) 1000 gm/ha @ 55 DAPc. Release of *Trichogramma chilonis* @ 1.5 lakh/ha at 65, 75 and 85 DAP	18.38(4.27)	17.23(4.15)	19.31(4.39)	19.15(4.36)	18.25(4.27)	20.72(4.55)	18.53(4.30)	17.42(4.17)	18.78(4.33)	18.26(4.27)	14.82(3.84)	18.42(4.29)
M7	Control Plot	25.76(5.07)	23.61(4.85)	26.52(5.15)	26.74(5.18)	24.61(4.95)	26.92(5.19)	27.56(5.25)	23.56(4.85)	26.74(5.17)	23.65(4.85)	21.53(4.60)	23.94(4.89)
	F 'test'	Sig	Sig	Sig	Sig	Sig	Sig	Sig	Sig	Sig	Sig	Sig	Sig
	SE (m) ±	0.19	0.19	0.17	0.17	0.15	0.15	0.16	0.14	0.17	0.14	0.20	0.15
	CD at 5%	0.58	0.59	0.53	0.53	0.46	0.46	0.51	0.44	0.54	0.44	0.61	0.46
	CV (%)	9.29	9.38	7.84	7.64	7.05	6.54	7.44	7.07	7.98	7.13	10.97	7.30

Figures in parenthesis are corresponding square root transformation values. DAT = Days after transplanting.

However, treatment module M6 recorded a slightly higher infestation rate at 18.53%. Conversely, the untreated control demonstrated the highest leaf infestation rate at 27.56%.

At 5 DAS, statistical analysis revealed significant superiority of all treatment modules over the untreated control. Treatment module M4 displayed the lowest infestation rate at 5.32%, followed by M3 and M1 at 8.13% and 9.72%, respectively, with no significant difference between them. Furthermore, treatment modules M2 and M5 exhibited moderate effectiveness with infestation rates of 13.78% and 14.71%, respectively, showing no significant difference between them. However, treatment module M6 recorded a slightly higher infestation rate at 17.42%. In contrast, the untreated control showed the highest infestation rate at 23.56%.

At 10 DAS, statistical analysis indicated significant findings. Treatment module M4 demonstrated the lowest infestation rate at 7.30%, followed by M3 at 10.92% and M1 at 11.14%, both significantly better than other modules. Moreover, treatment modules M2, M5 and M6 exhibited similar lower infestation rates at 15.62%, 16.63% and 18.78%, respectively, with no significant difference among them. However, the untreated control recorded the highest infestation rate at 26.74%.

Efficacy of treatment modules on percent leaves infestation of tomato leaf miner (*L. trifolii*) 3, 5 and 10 days after spray at 45 DAP

At 3 DAS, the results from Table 3 indicate that all treatments significantly outperformed the control. Notably, treatment M4 exhibited the most effective control of leaf infestation, with only 8.34% of leaves affected. Following closely were M3 and M1, with 11.85% and 12.24% leaf infestation, respectively. Treatment modules M2, M5 and M6 showed comparable efficacy, with leaf infestation rates of 16.65%, 18.26% and 19.15%, respectively. Conversely, the untreated control exhibited the highest leaf miner infestation at 26.74%.

At 5 DAS, statistical analysis revealed significant superiority of all treatment modules over the untreated control. Treatment M4 displayed the lowest infestation rate at 6.65%, followed by M3 (9.14%) and M1 (10.91%), both significantly better than other modules. Treatment modules M2 and M5 exhibited moderate effectiveness with infestation rates of 14.21% and 15.42%, respectively, while M6 recorded 18.25% infestation. However, there was no significant difference between M2 and M5. In contrast, the untreated control demonstrated a higher infestation rate of 24.61%.

At 10 DAS, all treatment modules continued to show significant superiority over the control. M4 displayed the lowest infestation rate at 8.24%, followed by M3 (11.65%) and M1 (12.64%), exhibiting similar effectiveness. M2 and M5 recorded infestation rates of 16.34% and 17.62%, respectively, with no significant difference between them. However, M6 exhibited a higher infestation rate of 20.72%. Conversely, the untreated control showed the highest infestation rate at 26.92%.

Efficacy of treatment modules on percent leaves infestation of tomato leaf miner (*L. trifolii*) 3, 5 and 10 days after spray at 55 DAP

At 3 DAS, the statistical analysis of the data presented in Table 3 revealed significant findings. Notably, treatment module M4 exhibited the lowest leaf infestation at 7.21%, followed by M3 at 10.21%, both significantly better than other modules. Subsequently, treatment modules M1, M2 and M5 displayed relatively higher leaf infestation rates at 13.96%, 16.40% and 17.63%, respectively, with no significant difference among them. However, treatment module M6 recorded a slightly higher infestation rate at 18.53%. Conversely, the untreated control demonstrated the highest leaf infestation rate at 27.56%.

At 5 DAS, statistical analysis revealed significant superiority of all treatment modules over the untreated control. Treatment module M4 displayed the lowest infestation rate at 5.32%, followed by M3 and M1 at 8.13% and 9.72%, respectively, with no significant difference between them. Furthermore, treatment modules M2 and M5 exhibited moderate effectiveness with infestation rates of 13.78% and 14.71%, respectively, showing no significant difference between them. However, treatment module M6 recorded a slightly higher infestation rate at 17.42%. In contrast, the untreated control showed the highest infestation rate at 23.56%.

At 10 DAS, statistical analysis indicated significant findings. Treatment module M4 demonstrated the lowest infestation rate at 7.30%, followed by M3 at 10.92% and M1 at 11.14%, both significantly better than other modules. Moreover, treatment modules M2, M5 and M6 exhibited similar lower infestation rates at 15.62%, 16.63% and 18.78%, respectively, with no significant difference among them. However, the untreated control recorded the highest infestation rate at 26.74%.

Cumulative efficacy of treatment modules on percent leaves infestation of tomato leaf miner (*L. trifolii*) at 3, 5 and 10 DATS

At 3 Days after Treatment (DATs), the data presented in Table 5 demonstrate statistically significant findings. It is apparent that all treatment modules exhibit

Table 4 : Cumulative efficacy of treatment modules on percent leaves infestation of tomato leaf miner (*L. trifolii*) at 3, 5 and 10 DATS.

Mo. No.	Treatment Modules	Cumulative Percent leaves infestation of *L. trifolii* / plant			Mean
		3 DATS	5 DATS	10 DATS	
M1	a. Application of NSE 5% at 35 and 45 DAP b. Release of *Trichogramma chilonis* @1.5 lakh/ha at 55, 65, 75, 85 DAP	11.94(3.45)	9.49(3.08)	11.23(3.35)	10.88(3.29)
M2	a. Application of Azadirachtin 10,000 ppm @ 3ml/lit at 35 and 45 DAP b. Release of *Trichogramma chilonis* @1.5 lakh/ha at 55, 65, 75 and 85 DAP	15.66(3.96)	13.37(3.65)	15.25(3.90)	14.76(11.51)
M3	a. Application of Azadirachtin 300 ppm @ 5 ml per lit at 35 and 45 DAP b. Application of *Beauveria bassiana* @ 55 DAP c. Release of *Trichogramma chilonis*@1.5 lakh/ha at 65, 75 and 85 DAP	9.95(3.14)	8.14(2.85)	10.15(3.18)	9.41(3.05)
M4	a. Application of Azadirachtin 300 ppm @ 5 ml/lit at 35 and 45 DAP b. Application of *Metarhizium anisopliae* @ 55 DAP c. Release of *Trichogramma chilonis*@ 1.5 lakh/ha at 65, 75, 85 DAP	6.61(2.56)	5.07(2.24)	7.00(2.63)	6.22(2.47)
M5	a. Application of Azadirachtin 10,000 ppm @ 3 ml/lit at 35 and 45 DAP b. Application of *HaNPV* 250 LE @ 55 DAP c. Release of *Trichogramma chilonis* @ 1.5 lakh/ha at 65, 75 and 85 DAP	16.42(4.05)	14.25(3.77)	16.19(4.02)	15.62(3.94)
M6	a. Application of Azadirachtin 10,000 ppm @ 3 ml/lit at 35 and 45 DAP b. Application of *Bt*. (k.) 1000 gm/ha @55 DAP c. Release of *Trichogramma chilonis* @ 1.5 lakh/ha at 65, 75 and 85 DAP	18.51(4.30)	16.92(4.11)	19.30(4.39)	18.24(4.26)
M7	Control Plot	25.95(5.09)	23.24(4.82)	26.02(5.10)	25.07(5.00)
	F 'test'	Sig	Sig	Sig	Sig
	SE (m) ±	0.12	0.11	0.13	0.12
	CD at 5 %	0.37	0.35	0.42	0.38
	CV (%)	5.60	5.62	6.23	5.81

Figures in parenthesis are corresponding square root transformation values. DAT= Days after transplanting.

a significant superiority over the untreated control group in terms of cumulative leaves infestation caused by the tomato leaf miner. Notably, Treatment Module 4 (M4) displayed the lowest cumulative leaves infestation rate at 6.61 percent. Following closely behind are Treatment Modules 3 (M3) and 1 (M1) with rates of 9.95 and 11.94 percent, respectively, both of which are statistically comparable.

Subsequent treatment modules, namely M2, M5 and M6, exhibited similar effectiveness, with leaves infestation rates of 15.66, 16.42, and 18.51 percent, respectively. Conversely, the untreated control group displayed the highest leaves infestation rate at 25.95 percent.

At 5 DATs, the cumulative outcomes depicted in Table 6 remain statistically significant. Treatment Module 4 (M4) demonstrated the minimum leaves infestation by *L. trifolii* at 5.07 percent, significantly outperforming the other treatment modules. Following M4, Treatment Modules 3 (M3) and 1 (M1) displayed leaves infestation rates of 8.14 and 9.49 percent, respectively, both statistically comparable.

The subsequent effective treatment modules, M2 and M5, exhibited similar effectiveness with leaves infestation rates of 13.37 and 14.25 percent, respectively. Meanwhile, Treatment Module 6 (M6) recorded a leaves infestation rate of 16.92 percent. However, the untreated control group registered the highest leaves infestation rate at 23.24 percent by *L. trifolii* after 5 days of treatment.

At 10 DATs, the cumulative data from Table 6 and Fig. 1 remain statistically significant. All treatment modules displayed a significant superiority over the untreated control group. Treatment Module 4 (M4) demonstrated the best performance by recording the minimum leaves infestation at 7.00 percent, followed by Treatment Modules 3 (M3) and 1 (M1) with rates of 10.15 and 11.23 percent, respectively. However, both M3 and M1 were statistically comparable.

Following suit, Treatment Modules 2 (M2) and 5 (M5) displayed statistically equal responses with leaves infestation rates of 15.23 and 16.19 percent, respectively. Meanwhile, Treatment Module 6 (M6) recorded a leaves infestation rate of 19.30 percent, still outperforming the untreated control group which registered the highest leaves infestation rate at 26.02 percent caused by tomato leaf miner, *L. trifolii*.

Efficacy of treatment modules on percent fruit infestation of tomato fruit borer (*H. armigera*) 3, 5 and 10 days after spray at 65 DAP

At 3DAS, analysis of the data presented in Table 5 demonstrated that all treatments were significantly more effective than the control. Notably, treatment M5 exhibited the lowest fruit infestation at 8.78%, followed by M4 and M3 at 12.03% and 12.65%, respectively. Following, treatments M6, M1, and M2 showed similar efficacy with fruit infestation rates of 16.78%, 18.29%, and 20.65%, respectively, all statistically comparable. In contrast, the untreated control displayed the highest fruit borer infestation at 26.42%.

At 5 DAS, all treatment modules were significantly superior to the untreated control. Treatment M5 demonstrated the lowest fruit infestation at 8.61%, followed by M4 and M3 at 10.79% and 11.45%, respectively, both significantly better than other modules. Subsequently, treatments M6, M1, and M2 showed effectiveness with fruit infestation rates of 14.67%, 17.75%, and 19.43%, respectively. However, they were statistically similar. In contrast, the untreated control showed the highest fruit infestation at 24.54%.

At 10 DAS, each treatment module was significantly more effective than the untreated control. Treatment M5 exhibited the lowest fruit infestation at 9.12%, followed by M4, M3, and M6 at 12.89%, 13.21%, and 16.72%, respectively, with similar effectiveness. Furthermore, treatments M1 and M2 recorded fruit infestation rates of 18.81% and 20.93%, respectively, with no statistical difference between them. The untreated control showed the highest fruit infestation at 26.91%.

Efficacy of treatment modules on percent fruit infestation of tomato fruit borer (*H. armigera*) 3, 5 and 10 days after spray at 75 DAP

At 3 DAS, analysis of the data presented in Table 5 indicated statistically significant findings. Treatment module M5 displayed the lowest fruit infestation at 7.42%, followed closely by M4 at 9.34%, both significantly better than other modules and comparable to each other. Subsequently, treatments M3, M6 and M1 showed similar efficacy with fruit infestation rates of 11.28%, 13.61%, and 15.27%, respectively, all statistically comparable. However, treatment module M2 recorded a higher fruit infestation rate at 18.35%. In contrast, the untreated control exhibited the highest fruit infestation at 24.32%.

At 5 DAS, treatment module M5 continued to exhibit the most effective control, with the lowest fruit infestation at 4.23%. This was followed by M4 and M3 at 9.45% and 9.76%, respectively, both statistically comparable. Moreover, treatments M1, M6 and M2 showed similar efficacy with fruit infestation rates of 14.42%, 14.67%, and 17.21%, respectively. However, there was no statistical difference among them. The untreated control displayed a higher fruit infestation at 21.29%.

At 10 DAS, treatment module M5 maintained its effectiveness, with the lowest fruit infestation at 6.12%, followed by M4 and M3 at 9.78% and 10.25%, respectively, both significantly superior to other modules. Additionally, treatments M6, M1, and M2 showed similar efficacy with fruit infestation rates of 15.72%, 15.61%, and 18.72%, respectively, all statistically comparable. However, the untreated control exhibited the highest fruit infestation at 25.16%.

Efficacy of treatment modules on percent fruit infestation of tomato fruit borer (*H. armigera*) 3, 5 and 10 days after spray at 85 DAP

At 3 DAS, analysis of the data in Table 5 revealed statistically significant results regarding fruit infestation. Treatment module M5 exhibited the lowest fruit infestation at 5.14%, followed by M4 at 8.13% and M3 at 9.22%, both significantly better than other modules and comparable to each other. Subsequently, treatments M6, M1, and M2 showed similar efficacy with fruit infestation rates of 12.89%, 13.42%, and 16.74%, respectively, all

Table 5 : Efficacy of treatment modules on Percent fruit infestation of tomato fruit borer (*H. armigera*) 3, 5 and 10 days after spray at 55, 65, 75 and 8 5DAP.

Mo.No.	Treatment Modules	Percent fruit infestation of *H. armigeral* plant at 55 DAP			Percent fruit infestation of *H. armigera* / plant at 65 DAP			Percent fruit infestation of *H. armigera* / plant at 75 DAP			Percent fruit infestation of *H. armigera* / plant at 85 DAP		
		3 DAS	5 DAS	10 DAS	3 DAS	5 DAS	10 DAS	3 DAS	5 DAS	10 DAS	3 DAS	5 DAS	10 DAS
M1	c. Application of NSE 5% at 35 and 45 DAP d. Release of Trichogramma chilonis @ 1.5 lakh/ha at 55, 65, 75, 85 DAP	17.25(4.15)	16.54(4.07)	17.94(4.22)	18.29(4.27)	17.75(4.21)	18.81(4.31)	15.27(3.90)	14.42(3.77)	15.61(3.94)	13.42(3.65)	12.67(3.55)	13.78(3.68)
M2	c. Application of Azadirachtin 10,000 ppm@3ml/lit at 35 and 45 DAP d. Release of *Trichogramma chilonis* @ 1.5 lakh/ha at 55, 65, 75 and 85 DAP	19.32(4.39)	18.71(4.31)	19.73(4.44)	20.65(4.54)	19.43(4.40)	20.93(4.57)	18.35(4.26)	17.21(4.13)	18.72(4.33)	16.74(4.08)	14.35(3.78)	17.65(4.20)
M3	a. Application of Azadirachtin 300 ppm @ 5 ml per lit at 35 and 45 DAP b. Application of *Beauveria bassiana* @ 55 DAP c. Release of *Trichogramma chilonis* @1.5 lakh/ha at 65, 75 and 85 DAP	11.98(3.44)	11.28(3.35)	12.49(3.52)	12.65(3.54)	11.45(3.35)	13.21(3.62)	11.28(3.35)	9.76(3.11)	10.25(3.18)	9.22(3.03)	6.73(2.59)	9.67(3.09)
M4	a. Application of Azadirachtin 300 ppm @ 5 ml/lit at 35 and 45 DAP b. Application of *Metarhizium anisopliae* @ 55 DAP c. Release of *Trichogramma chilonis* @ 1.5 lakh/ha at 65, 75, 85 DAP	11.78(3.43)	10.75(3.28)	10.91(3.30)	12.03(3.46)	10.79(3.28)	12.89(3.58)	9.34(3.05)	9.45(3.07)	9.78(3.12)	8.13(2.84)	5.46(2.32)	8.23(2.84)
M5	a. Application of Azadirachtin 10,000 ppm @ 3 ml/lit at 35 and 45 DAP b. Application of *HaNPV* 250 LE @ 55 DAP c. Release of *Trichogramma chilonis* @ 1.5 lakh/ha at 65, 75 and 85 DAP	7.78(2.74)	7.31(2.69)	9.27(3.04)	8.78(2.95)	8.61(2.93)	9.12(2.99)	7.42(2.71)	4.23(2.02)	6.12(2.36)	5.14(2.26)	3.42(1.84)	4.98(2.22)
M6	a. Application of Azadirachtin 10,000 ppm @ 3 ml/lit at 35 and 45 DAP b. Application of *Bt.* (k.) 1000 gm/ha @ 55 DAP c. Release of *Trichogramma chilonis* @ 1.5 lakh/ha at 65, 75 and 85 DAP	16.95(4.11)	15.23(3.89)	15.27(3.90)	16.78(4.09)	14.67(3.82)	16.72(4.09)	13.61(3.68)	14.67(3.82)	15.72(3.96)	12.89(3.59)	9.82(3.13)	13.65(3.68)
M7	Control Plot	24.68(4.95)	23.85(4.87)	25.61(5.05)	26.42(5.13)	24.54(4.93)	26.91(5.19)	24.32(4.90)	21.29(4.56)	25.16(5.00)	23.72(4.86)	20.47(4.51)	24.71(4.96)
	F 'test'	Sig	Sig	Sig	Sig	Sig	Sig	Sig	Sig	Sig	Sig	Sig	Sig
	SE (m) ±	0.21	0.17	0.16	0.16	0.20	0.19	0.19	0.23	0.24	0.16	0.15	0.19
	CD at 5%	0.65	0.53	0.50	0.50	0.64	0.58	0.58	0.71	0.75	0.50	0.46	0.58
	CV (%)	9.39	8.00	7.19	7.06	9.40	8.06	8.91	11.51	11.42	8.19	8.44	9.33

Figures in parenthesis are corresponding square root transformation values. DAT= Days after transplanting.

Table 6 : Cumulative efficacy of treatment modules percent fruit infestation of tomato fruit borer (*H. armigera*) at 3, 5 and 10 DAT.

Mo. No.	Treatment Modules	Cummulative % fruit infestation of *H. armigera*			Mean
		3 DAS	5 DAS	10 DAS	
M1	a. Application of NSE 5% at 35 and 45 DAP b. Release of *Trichogramma chilonis*@1.5 lakh/ha at 55, 65, 75, 85 DAP	16.05(4.00)	15.34(3.91)	16.54(4.05)	15.97(3.98)
M2	a. Application of Azadirachtin 10,000 ppm @ 3ml/lit at 35 and 45 DAP b. Release of *Trichogramma chilonis* @1.5 lakh/ha at 55, 65, 75 and 85 DAP	18.74(4.33)	17.41(4.17)	19.26(4.39)	18.47(4.29)
M3	a. Application of Azadirachtin 300 ppm @ 5 ml per lit at 35 and 45 DAP b. Application of *Beauveria bassiana*@ 55 DAP c. Release of *Trichogramma chilonis*@1.5 lakh/ha at 65, 75 and 85 DAP	11.21(3.34)	9.80(3.12)	11.41(3.37)	10.80(3.27)
M4	a. Application of Azadirachtin 300 ppm @ 5 ml/lit at 35 and 45 DAP b. Application of *Metarhizium anisopliae*@ 55 DAP c. Release of *Trichogramma chilonis*@ 1.5 lakh/ha at 65, 75, 85 DAP	10.44(3.23)	9.11(3.01)	10.60(3.25)	10.05(3.16)
M5	a. Application of Azadirachtin 10,000 ppm @ 3 ml/lit at 35 and 45 DAP b. Application of *HaNPV* 250 LE at 55 DAP c. Release of *Trichogramma chilonis* @ 1.5 lakh/ha at 65, 75 and 85 DAP	7.03(2.64)	5.89(2.42)	7.08(2.63)	6.66(2.56)
M6	a. Application of Azadirachtin 10,000 ppm @ 3 ml/lit at 35 and 45 DAP b. Application of *Bt*. (k.) 1000 gm/ha @55 DAP c. Release of *Trichogramma chilonis* @ 1.5 lakh/ha at 65, 75 and 85 DAP	15.45(3.93)	13.60(3.68)	15.72(3.96)	14.92(3.85)
M7	Control Plot	24.78(4.96)	22.53(4.74)	25.60(5.05)	24.30(4.91)
	F 'test'	Sig	Sig	Sig	Sig
	SE (m)±	0.15	0.12	0.16	0.14
	CD at 5 %	0.48	0.38	0.49	0.45
	CV (%)	7.27	5.97	7.36	6.86

Figures in parenthesis are corresponding square root transformation values. DAT= Days after transplanting.

statistically comparable. However, the untreated control displayed the highest fruit infestation at 23.72% caused by *H. armigera*.

At 5 DAS, all treatment modules were significantly superior to the untreated control. Treatment module M5 demonstrated the lowest fruit infestation at 3.42%, followed by M4 at 5.46% and M3 at 6.73%, both significantly better than other modules. Moreover, treatments M6 and M1 showed similar efficacy with fruit infestation rates of 9.82% and 12.67%, respectively, statistically comparable. However, treatment module M2 exhibited individually significant effectiveness with 14.35% fruit infestation. The untreated control showed the highest fruit infestation at 20.47%.

At 10 DAS, treatment module M5 continued to exhibit the most effective control, with the lowest fruit infestation at 4.98%, followed by M4 at 8.23% and M3 at 9.67%, statistically comparable. Furthermore, treatments M6, M1 and M2 showed similar efficacy with fruit infestation rates of 13.65%, 13.78% and 17.65%, respectively, all

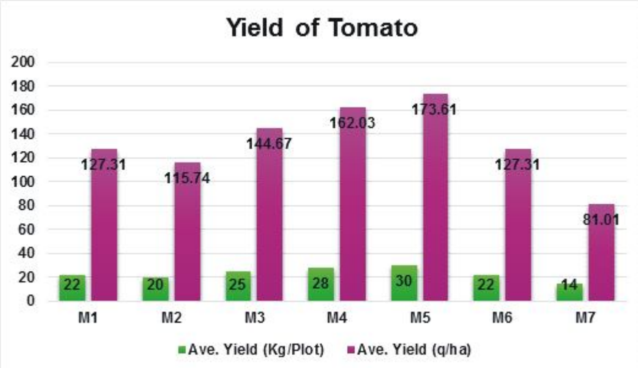

Fig. 1 : Effects of treatment modules on the yield of tomato.

statistically comparable. However, the untreated control exhibited the highest fruit infestation at 24.71%.

Cumulative efficacy of treatment modules on percent fruit infestation of tomato fruit borer (*H. armigera*) at 3, 5 and 10 DATS.

At 3 Days After Treatment (DATs), the cumulative data presented in Table 6 reveal statistically significant findings. All treatment modules demonstrate a significant superiority over the untreated control group in terms of cumulative fruit infestation caused by the tomato fruit borer. Notably, Treatment Module 5 (M5) exhibited the lowest cumulative fruit infestation rate at 7.03 percent. Following M5, Treatment Modules 4 (M4) and 3 (M3) recorded fruit infestation rates of 10.44 and 11.21 percent, respectively, with both treatment modules statistically comparable.

The subsequent effective treatment modules, namely M6, M1 and M2, exhibited statistically equal effectiveness, with fruit infestation rates of 15.45, 16.05, and 18.74 percent, respectively. Conversely, the untreated control group displayed the highest fruit infestation rate at 24.78 percent.

At 5 DATs, the cumulative results presented in Table 12 remains statistically significant. Treatment Module 5 (M5) demonstrated the minimum fruit infestation by *H. armigera*at 5.89 percent, significantly outperforming the other treatment modules. Following M5, Treatment Modules 4 (M4) and 3 (M3) displayed fruit infestation rates of 9.11 and 9.80 percent, respectively, both statistically comparable.

The subsequent effective treatment modules, M6 and M1, exhibited similar effectiveness with fruit infestation rates of 13.60 and 15.34 percent, respectively. Meanwhile, Treatment Module 2 (M2) recorded a fruit infestation rate of 17.41 percent. However, the untreated control group registered the highest fruit infestation rate at 22.53 percent by *H. armigera* after 5 days of treatment.

At 10 DATs, the cumulative data from Table 12 remain statistically significant. All treatment modules displayed a significant superiority over the untreated control group. Treatment Module 5 (M5) demonstrated the best performance by recording the minimum fruit infestation at 7.08 percent, followed by Treatment Modules 4 (M4) and 3 (M3) with rates of 10.60 and 11.41 percent, respectively. However, both M4 and M3 were statistically comparable.

The subsequent effective treatment modules, M6, M1 and M2, exhibited statistically equal responses with fruit infestation rates of 15.72, 16.54 and 19.26 percent, respectively. However, the untreated control group recorded the highest fruit infestation rate at 25.60 percent due to tomato fruit borer, *H. armigera*.

Effects of treatment modules on the yield of tomato fruit

The data depicted in Fig. 1 reveal statistically significant results.

The highest yield of tomato fruit was observed in Treatment Module 5 (M5), with a yield of 173.61 q/ha, followed closely by Treatment Module 4 (M4), which recorded 162.03 q/ha. Both M5 and M4 were statistically comparable in terms of yield.

Treatment Modules 3 (M3), 6 (M6) and 1 (M1) displayed yields of 144.67, 127.31 and 127.31 q/ha, respectively. These three treatment modules were statistically comparable in their effectiveness.

In contrast, Treatment Module 2 (M2) recorded a yield of 115.74 q/ha. However, the lowest yield of 81.01 q/ha was recorded in the untreated control group. Both M2 and the untreated control were statistically equal in their effectiveness.

These findings indicate that Treatment Modules 5 and 4 exhibit the highest efficacy in promoting tomato fruit yield, while Treatment Modules 3, 6 and 1 also contribute positively to yield improvement, albeit to a lesser extent. Treatment Module 2 and the untreated control group displayed comparatively lower yields.

Incremental cost benefit ratio (ICBR) of various treatment modules

The data pertaining to the Incremental Cost Benefit Ratio (ICBR) are presented in Table 7. The treatment module yielding the maximum ICBR of 1:15.62 was observed in M5.

Following M5, the next best treatment modules in terms of incremental cost benefit ratio were M4 (1:10.95) and M1 (1:9.44). Additionally, treatment modules M3, M6 and M2 were also economically favourable, recording ICBRs of 1:8.92, 1:6.76 and 1:5.24, respectively.

Table 7 : Incremental cost benefit ratio (ICBR) of various treatment modules in tomato.

S. no.	Treatment Module	No. of sprays	Qty. per ha.	Rate per kg or lit.	Cost of treatments: Cost of insecticides (Rs./ha)	Cost of treatments: Labour cost and machinery charges (Rs./ha)	Cost of treatments: Total cost (Rs./ha) A	Yield (q/ha)	Yield increased over control (q/ha)	Value ofB increased yield (Rs.)	Incremental benefit (Rs.) B-A	ICBR (B-A)/A	Rank
1.	NSE 5 % *T. chilonis*	2 4	50 kg 6 lakh	25 375/ 1.5 lakh egg	1330 1500 } 2830	4260	7090	127.31	46.30	74080	66990	1: 9.44	3
2.	Azadi. 10,000 ppm *T. chilonis*	2 4	3 lit 6 lakh	1050 375/ 1.5 lakh egg	3150 1500 } 4650	4260	8910	115.74	34.73	55568	46658	1: 5.24	6
3	Azadi. 300 ppm *B. bassiana* *T. chilonis*	2 1 3	5 lit 2 kg 4.5 lakh	800 440 375/1.5 lakh egg	4000 880 1125 } 6005	4260	10265	144.67	63.66	101856	91591	1: 8.92	4
4	Azadi. 300 ppm *M. anisopliae* *T. chilonis*	2 1 3	5 lit 2 kg 4.5 lakh	800 730 375/1.5 lakh egg	4000 1460 1125 } 6585	4260	10845	162.03	81.02	129632	118787	1: 10.95	2
5	Azadi. 10,000 ppm *HaNPV* 250 LE *T. chilonis*	2 1 3	3 lit 250 LE 4.5 lakh	1050 1500 375/1.5 lakh egg	3150 375 1125 } 4650	4260	8910	173.61	92.60	148160	139250	1: 15.62	1
6	Aadi. 10,000 ppm *Bt.*(k.) *T. chilonis*	2 1 3	3 lit 1 kg 4.5 lakh	1050 1000 375/1.5 lakh egg	3150 1000 1125 } 5275	4260	9535	127.31	46.30	74080	64545	1: 6.76	5
7	Untreated control	-	-	-	-	-	-	81.01	-	-	-	-	-

Note:
1) Neem Seeds : Rs 25/ kg
2) Azadirachtin 10,000 ppm : Rs 1050/ lit
3) Azadirachtin 300 ppm : Rs 800/ lit
4) Beauveria bassiana : Rs 400/kg
5) Metarhizium anisopliae : Rs 730/ kg
6) Ha.NPV 1000 LE : Rs 1500/lit
7) Bacillus thuringiensis (k.): Rs 1000/ Kg.
8) Trichogramma chilonis : Rs 50/ Card
9) Detergent powder : Rs 40/ kg.
10) Spray pump charges : Rs 50 / day.
11) Labour charges : Rs. 220 / day
12) Sale price tomato fruit : Rs 1600/q

These findings suggest that M5 offers the highest economic benefit relative to its cost, followed by M4 and M1. Meanwhile, M3, M6 and M2 also provide favourable economic returns, albeit to a slightly lesser extent.

Discussion

The current study aimed to assess the efficacy of various treatment modules, incorporating botanicals, bio-pesticides and microbial agents, against two significant pests affecting tomato crops: the tomato leaf miner and the tomato fruit borer. Additionally, the study evaluated the Incremental Cost Benefit Ratio (ICBR) of each treatment module to gauge their economic viability. The results indicate that Treatment Module 4, which included botanicals and bio-pesticides such as Azadirachtin 300 ppm, exhibited notable efficacy in reducing leaf infestation by the tomato leaf miner. This finding is consistent with previous studies conducted by Patnaik (1997) and Salas and Mendoza (2001), validating the effectiveness of Azadirachtin formulations in pest management. While the efficacy of *Metarhizium anisopliae* against tomato leaf miner wasn't directly demonstrated in prior research, the effectiveness of *Bacillus thuringiensis* reported by Akashe *et al*. (2010) against serpentine leaf miner suggests potential efficacy against related pests. The treatment modules of bio-pesticides like *M. anisopliae* and *B. bassiana* have also shown good performance in registering the minimum fruit infestation due to *H. armigera*. These kinds of results were also observed in the reports of Chaudhari *et al*. (2014), Phukon*et al*. (2014), Adsure and Mohite (2015), Chaudhari *et al.* (2017) and Patil *et al.* (2018), who reported effectiveness of *M. anisopliae* and *B. bassiana* against tomato fruit borer *H. armigera*. Treatment Module 5, which utilized botanicals and bio-pesticides such as Azadirachtin 10,000 ppm, showed significant efficacy in reducing fruit infestation by the tomato fruit borer. This result is supported by numerous studies conducted by Aggarwal *et al*. (2006), Mehata *et al*. (2010) and others, indicating the widespread recognition of Azadirachtin formulations for managing *H. armigera* infestations. Additionally, combinations of treatments involving NSE and *HaNPV* demonstrated effectiveness, corroborating findings from previous studies by Karabhantal and Awaknavar (2012), Jat and Ameta (2013) and others. Treatment modules incorporating bio-pesticides like *Metarhizium anisopliae* and *B. bassiana* displayed promising results in reducing fruit infestation by *H. armigera*. These findings are consistent with studies conducted by Chaudhari *et al*. (2014, 2017) and others, indicating the potential of bio-pesticides as an alternative or complementary approach to chemical pesticides in integrated pest management strategies. Regarding the yield, treatment module M5 (botanicals and bio-pesticides) including the application of Azadirachtin 10,000 ppm by the earlier workers like Mehata *et al*. (2010), Wagh *et al*. (2012), Shafie and Abdelraheem (2012) reported maximum yield of tomato fruit and therefore, these findings are in close agreement with the present findings. Similarly, Karabhantal and Awaknavar (2012), Jat and Ameta (2013), Rahman *et al*. (2014) and Satish *et al*. (2018) obtained the maximum yield of tomato fruit by using NSE and *HaNPV* in combination treatments and therefore, these results are in agreement with the present findings. The study also evaluated the Incremental Cost Benefit Ratio (ICBR) of each treatment module to assess their economic viability. Treatment Module 5 showed the highest ICBR, indicating favourable economic returns relative to its cost. These results are in line with previous research by Sushil *et al*. (2006) and Amutha and Manisegaran (2006), supporting the economic benefits of utilizing botanicals and bio-pesticides in pest management. Combinations of treatments involving NSE and *HaNPV* also demonstrated economically better ICBR, consistent with findings from previous studies.

Conclusion

The current study provides valuable insights into the efficacy of different treatment modules against tomato pests and their economic viability. The findings underscore the importance of integrated pest management strategies, combining botanicals, bio-pesticides, and microbial agents, in ensuring sustainable tomato production while minimizing environmental hazard and economic costs associated with pest control. Further research could explore optimization strategies for these treatment modules and investigate their long-term effects on pest populations and crop yields.

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Conflicts of interest

There are no apparent conflicts of interest.

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