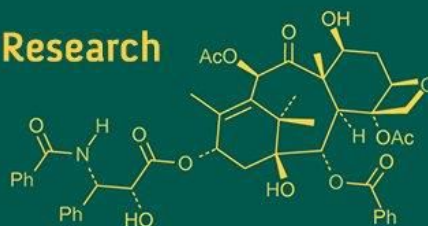
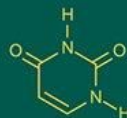
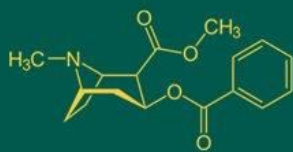


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Evaluation of combined efficacy of entomopathogenic fungi with insecticides against chilli thrips, *S. dorsalis* under field conditions

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Abstract

A field experiment was conducted at Anand Agricultural University, Anand during *Kharif-rabi*, 2023-24 to assess the combine-efficacy of various insecticides and myco-insecticides against chilli thrips, *S. dorsalis* infesting chilli. Among the twelve treatment combination of entomopathogenic fungi and insecticides, *L. lecanii* 1% WP + cyantraniliprole 10.26 OD and cyantraniliprole 10.26 OD alone were found most effective in reducing of *S. dorsalis* incidence on chilli. The treatment combinations of *M. anisopliae* 1% WP + cyantraniliprole 10.26 OD, spinetoram 11.7 SC alone and spirotetramat 15.31 OD alone were falls under mediocre in their effectiveness. *L. lecanii* 1% WP + cyantraniliprole 10.26 OD treated plots produced the highest (97.17 q/ha) green chilli yield followed by cyantraniliprole 10.26 OD (93.67 q/ha) and *M. anisopliae* 1% WP + cyantraniliprole 10.26 OD (91.00 q/ha) with 90.52, 83.67 and 78.43 percent increases in yield over control, respectively.

Keywords: Field experiment, Anand agricultural university, kharif-rabi 2023-24

Introduction

India exhibits a wide range of climate and geographical conditions, providing ample opportunity to grow various vegetable crops around the year. India stood second in producing different vegetables worldwide (Devi and Kumar, 2020) [6]. Among the different vegetable crops, chilli (*Capsicum annum* L.) is a member of the Solanaceae family, typically grown in the world's tropical and warmer temperature regions for its green fruit and pungency. It originated in South and Central America, while the Portuguese introduced it in the 17th century in India. The chilli fruit contains oleoresin, an essential oil utilized to create products with added value in the culinary, beverage and pharmaceutical industries (Pandit *et al.*, 2020) [14].

Chilli crop is susceptible to pest infestations owing to its delicate nature and cultivation in intensive farming systems. Numerous insect-pests have been observed attacking chilli crops at various stages of their growth and cause yield loss ranging from 50 to 90 percent (Kumar, 1995) [10]. Around 55 species of insect pests have been reported on chilli crops (Jadhav *et al.*, 2004) [9]. The major reported includes thrips (*Scirtothrips dorsalis* Hood), whiteflies (*Bemisia tabaci* Gennadius), aphids (*Aphis gossypii* Glover), armyworm (*Spodoptera litura* Fabricius), jassids (*Amrasca bigutulla bigutulla* Ishida), fruit borer (*Helicoverpa armigera* Hubner) and mites (*Polyphagotarsonemus latus* Banks) (Sorensen, 2005) [17]. Among all insect-pests of agro-ecosystem, various species of thrips are a major group of sucking pest that cause significant economic losses in horticultural crops and also act as a vector for serious plant viruses. In chilli, thrips is India's most prominent insect-pest that causes 30-50 percent yield loss (Bhede *et al.*, 2008) [4]. It was first time collected by Ramakrishna Ayyar on shoots and fruits of chilli in Coimbatore (India) during the year 1916 and sent to Douglas Hood, who described it as a new species in 1919 and named as *Scirtothrips dorsalis* Hood. It is commonly known as chilli thrips, dreaded chilli thrips (Singh, 1944) [16], Assam thrips or tea thrips (Dev, 1964) [5] and comes under the family Thripidae in the order Thysanoptera.

The gravid females of *S. dorsalis* oviposit the eggs into the plant tissues with the help of a saw-like ovipositor (Ananthakrishnan, 1984) [2]. Both nymphs and adults of thrips cause damage by scrapping the epidermis and sucking the cell sap from tender leaves, growing

shoots and exhibiting characteristic upward curling of leaves and reduction in leaf size. According to Sanap and Nawale (1987)^[15], adults and nymphs of *S. dorsalis* suck the cell sap of leaves, causing rolling of the leaf upward and leaf size reduction. In pepper plants, severe infestations can cause a visual alteration known as 'chilli leaf curl' locally called "Kokadava" (Amin, 1979)^[11].

Presently, people are more concerned about the environment and their own health and prefer natural alternatives to synthetic chemicals. Biopesticides are becoming more and more popular due to their advantages in terms of target specificity, efficacy, biodegradability and suitability for use in integrated pest management (IPM) programmes. The biological control of insect-pests with pathogens, parasites and predators has received particular attention in recent years. Among these microorganisms, entomopathogenic fungi are prominent biological control agents that have been the subject of intense research for over 100 years (Vega *et al.*, 2012)^[9]. The fungal species *Metarhizium anisopliae* and *Lecanicillium lecanii* are the most used bio-pesticides for the biological control of various crop's insect-pests including thrips. However, using entomopathogenic fungi in insect-pest control programs for field crops is the excessive time required to kill the target insect (Lomer *et al.*, 2001)^[11]. For this reason, the combined use of entomopathogenic

fungi plus sublethal doses of chemical insecticides has been found to be a promising alternative for reducing the amount of chemicals used for pest control, thus protecting the health of the environment and the agricultural workers.

Material and Methods

A field experiment was carried out at Entomology farm of B. A. College of Agriculture, Anand Agricultural University, Anand, Gujarat during *kharif-Rabi*, 2023-24. Chilli variety GAVC-141 (Anand Tej) sowing in the gross plot size of 3.0 × 6.0 m (Net plot: 1.8 × 4.8 m) at a spacing of 60 × 60 cm. The chilli crop was grown by following all standard agronomical practices. The experiment was laid out in Randomized Complete Block Design (Factorial) with three level of M (myco-insecticide) and four level of I (insecticide), which gives out total 12 treatment combinations (M₁I₁, M₁I₂, M₁I₃, M₁I₄, M₂I₁, M₂I₂, M₂I₃, M₂I₄, M₃I₁, M₃I₂, M₃I₃, M₃I₄). The experiment conducted along with three replications with a view to evaluate combine-efficacy of various insecticides and bio-pesticides against *S. dorsalis*. Both insecticides and myco-insecticides were tested in combination with half dose and alone with full dose as well as with control (no application).

The treatment details for this investigation are as described below in Table 1.

Table 1: Details of treatment combinations

Sr. No.	Symbol	Treatment Combinations	Dose (g or mL/ 10 litre of water)
1	M ₁ I ₁	<i>M. anisopliae</i> 1% WP	40
2	M ₁ I ₂	<i>M. anisopliae</i> 1% WP + Spinetoram 11.7 SC	20 + 5
3	M ₁ I ₃	<i>M. anisopliae</i> 1% WP + Spirotetramat 15.31 OD	20 + 4
4	M ₁ I ₄	<i>M. anisopliae</i> 1% WP + Cyantraniliprole 10.26 OD	20 + 6
5	M ₂ I ₁	<i>L. lecanii</i> 1% WP	40
6	M ₂ I ₂	<i>L. lecanii</i> 1% WP + Spinetoram 11.7 SC	20 + 5
7	M ₂ I ₃	<i>L. lecanii</i> 1% WP + Spirotetramat 15.31 OD	20 + 4
8	M ₂ I ₄	<i>L. lecanii</i> 1% WP + Cyantraniliprole 10.26 OD	20 + 6
9	M ₃ I ₁	Control	-
10	M ₃ I ₂	Spinetoram 11.7 SC	10
11	M ₃ I ₃	Spirotetramat 15.31 OD	12
12	M ₃ I ₄	Cyantraniliprole 10.26 OD	12

Treatment wise application of insecticides was given at appearance of pest in the treated plot by using knapsack sprayer with required concentration. Subsequent spray was given after 15 days of first spray. The observations of *S. dorsalis* population were recorded prior to spraying as well as 3, 7, 10 and 14 days after each spray from ten randomly selected plants in each net plot. For recording observations of chilli thrips (*S. dorsalis*), From each plant, three twigs from the plant canopy (*i.e.*, bottom, middle, and top) were selected and tapped three times on white paper to record the thrips population (Bagle, 1993)^[3]. The data obtained were analyzed by following standard statistical technique (Steel and Torrie, 1980)^[18] after using suitable transformation. Chilli fruits were harvested at different intervals and weighted treatment wise from each net plot area. The chilli fruit were weighted in kg and converted on hectare basis. The percent increased yield over control was also calculated by using following formula.

$$\text{Yield increased over control} = 100 \times \frac{T-C}{C}$$

Where,

T = Yield of respective treatment (kg /ha)

C = Yield of control (kg/ha)

The avoidable losses due to *S. dorsalis* incidence was calculated by applying formula which is given under.

$$\text{Avoidable loss (\% in yield)} = \frac{\text{Yield in treatment which gave the highest yield} - \text{Yield in any other treatment}}{\text{Yield in treatment which gave the highest yield}} \times 100$$

Results and Discussion

Effect of Entomopathogenic Fungi and Insecticides Against Chilli Thrips, *S. dorsalis*

Pooled results of entomopathogenic fungi and insecticides as well as their interaction effects against thrips infesting chilli are presented in Table 2 and 3, respectively. The data revealed that there was uniform population of chilli thrips, *S. dorsalis* before spray as the treatment difference was found non-significant.

Effect of Entomopathogenic fungi (M)

The data on the individual effect of entomopathogenic fungi on *S. dorsalis* infesting chilli are presented in Table 2. Before first spray, more or less equal population of *S. dorsalis* was observed.

In pooled over periods of first spray, the significantly lowest thrips population (6.58/ 3 twigs) was recorded in the plots treated with *L. lecanii* 1% WP (ICAR-NBAIR V-18). Entomopathogenic fungi *M. anisopliae* 1% WP (AAUBC-Ma15) was the least effective against *S. dorsalis* population as recorded 7.97 thrips per three twigs and at with the control in pooled. The same trend was also observed in the second spray pooled. In which, *L. lecanii* 1% WP (ICAR-NBAIR V-18) showed significantly lowest thrips population (4.38/ 3 twigs) while, *M. anisopliae* 1% WP (AAUBC-Ma15) was observed highest (5.85/ 3 twigs) thrips population than *L. lecanii* 1% WP and also control (5.50/ 3 twigs). In pooled over sprays, the significantly lowest thrips population *i.e.* 5.45 thrips per three twigs was noted in the plots treated with *L. lecanii* 1% WP (ICAR-NBAIR V-18) whereas, *M. anisopliae* 1% WP (AAUBC-Ma15) was recorded highest (6.84/ 3 twigs) thrips population. Overall, *L. lecanii* 1% WP (ICAR-NBAIR V-18) was the best effective entomopathogenic fungi as compared to *M. anisopliae* 1% WP (AAUBC-Ma15). Further, *M. anisopliae* 1% WP (AAUBC-Ma15) was failed to manage the thrips population as recorded higher thrips population than control.

Effect of insecticides (I)

The pooled data on insecticide effect on chilli thrips are presented in Table 2. The population of chilli thrips was found homogenous in all the insecticidal treatments before spray as the treatment difference was non-significant. All

the insecticidal treatments significantly reduced the larval population than control in first spray and second spray as well as in pooled over spray analysis. The population of *S. dorsalis* was significantly lowest (5.12/ 3 twigs) in the plots treated with cyantraniliprole 10.26 OD after first spray (Table 2).

The insecticide spirotetramat 15.31 OD was illustrated as next best effective treatment after first spray by recording 6.95 thrips per three twigs and it was at par with spinetoram 11.7 SC (8.08 thrips/ 3 twigs). In contrast, the control plots were recorded 9.55 thrips per three twigs.

After the second spray (Table 2), cyantraniliprole 10.26 OD treated plots was exhibited statistically the lowest thrips population (3.22/ 3 twigs) followed by spirotetramat 15.31 OD and spinetoram 11.7 SC. In which, thrips population were recorded 4.65 and 5.80 per three twigs, respectively. The control plots showed significantly highest (7.79/ 3 twigs) chilli thrips population.

The data on pooled over sprays clearly illustrated that all treatments significantly differed from each other (Table 2). The plots treated with cyantraniliprole 10.26 OD exhibited the lowest thrips population *i.e.* 4.12 thrips per three twigs. The next best effective treatment was spirotetramat 15.31 OD in which 5.75 thrips was recorded per three twigs followed by spinetoram 11.7 SC (6.90 thrips/ 3 twigs). The plots without treatments were recorded 8.62 thrips per three twigs.

Table 2: Efficacy of entomopathogenic fungi and insecticides against chilli thrips, *S. dorsalis*

Treatments		No. of thrips/ 3 twigs at indicated spray			
		Before spray	First spray pooled	Second spray pooled	Pooled over sprays
Myco-insecticides (M)					
M ₁ : <i>M. anisopliae</i> 1% WP (AAUBC-Ma15)		3.50 (11.75)	2.91 (7.97)	2.52 (5.85)	2.71 (6.84)
M ₂ : <i>L. lecanii</i> 1% WP (ICAR-NBAIR V-18)		3.47 (11.54)	2.66 (6.58)	2.21 (4.38)	2.44 (5.45)
M ₃ : Control (No Myco-insecticides)		3.46 (11.47)	2.83 (7.51)	2.45 (5.50)	2.64 (6.47)
S. Em. ±	M	0.08	0.04	0.04	0.02
	P	-	0.04	0.04	0.14
	S	-	-	-	0.02
	M x P	-	0.08	0.07	0.05
	P x S	-	-	-	0.04
	M x P x S	-	-	-	0.08
C.D. at 5 %	M	NS	0.12	0.11	0.07
	P	-	0.13	0.12	NS
	S	-	-	-	0.06
	M x P	-	NS	NS	NS
	P x S	-	-	-	0.12
	M x P x S	-	-	-	NS
Insecticides (I)					
I ₁ : Control (No Insecticide)		3.50 (11.75)	3.17 (9.55)	2.88 (7.79)	3.02 (8.62)
I ₂ : Spinetoram 11.7 SC		3.49 (11.68)	2.93 (8.08)	2.51 (5.80)	2.72 (6.90)
I ₃ : Spirotetramat 15.31 OD		3.47 (11.54)	2.73 (6.95)	2.27 (4.65)	2.50 (5.75)
I ₄ : Cyantraniliprole 10.26 OD		3.45 (11.40)	2.37 (5.12)	1.93 (3.22)	2.15 (4.12)
S. Em. ±	I	0.09	0.04	0.04	0.03
	P	-	0.04	0.04	0.14
	S	-	-	-	0.02
	I x P	-	0.09	0.09	0.06
	P x S	-	-	-	0.04
	I x P x S	-	-	-	0.09
C.D. at 5 %	I	NS	0.13	0.12	0.09
	P	-	0.13	0.12	NS
	S	-	-	-	0.06
	I x P	-	NS	NS	NS
	P x S	-	-	-	0.12
	I x P x S	-	-	-	NS
C.V. (%)		8.48	10.28	11.47	10.68

Note: 1. Figures in parenthesis are retransformed values and those outside are $\sqrt{X + 0.5}$ transformed values.

2. NS: Non significant, Sig.: Significant

Interaction Effect of Entomopathogenic Fungi with Insecticides (M x I)

The combined effect of entomopathogenic fungi and insecticides was tested in combination at half dose each and compared with their full dose as well as with untreated control. The pooled over periods of first spray and second spray as well as pooled over sprays results presented in Table 3. Chilli thrips population was found more or less equal in all the treatments before spray as treatment difference was non-significant.

Pooled data of first spray (Table 3) clearly stated that all the treatments were significantly superior to the control (M₃I₁). Among the different combinations, *L. lecanii* 1% WP + cyantraniliprole 10.26 OD (M₂I₄) @ 20 g + 6 mL per 10 litre of water treated plots were found significantly lowest (4.43/ 3 twigs) population of thrips than rest of the treatments except cyantraniliprole 10.26 OD alone (M₃I₄) @ 12 mL per 10 litre of water. In which, 5.26 thrips were recorded per three twigs and at par with the most effective combination treatment M₂I₄ on one hand while, with *M. anisopliae* 1% WP + cyantraniliprole 10.26 OD (5.70/ 3 twigs) and spinetoram 11.7 SC alone (6.21 thrips/ 3 twigs) on other hand of chronological order. The other combined treatments spirotetramat 15.31 OD alone (M₃I₃), *L. lecanii* 1% WP + spirotetramat 15.31 OD (M₂I₃), *L. lecanii* 1% WP alone (M₂I₁), *M. anisopliae* 1% WP + spirotetramat 15.31 OD (M₁I₃), *L. lecanii* 1% WP + spinetoram 11.7 SC (M₂I₂) and *M. anisopliae* 1% WP alone (M₁I₁) recorded 6.52, 6.79, 7.34, 7.57, 8.08 and 8.62 thrips per 3 twigs, respectively. Significantly the highest (10.26/ 3 twigs) thrips was registered in the plots treated with *M. anisopliae* 1% WP + spinetoram 11.7 SC (M₁I₂) @ 20 g + 8 mL per 10 litre of water but superior to control.

Second spray pooled data are presented Table 3 and illustrated significant differences among the treatments. The lowest *S. dorsalis* population (2.81/ 3 twigs) was observed in the chilli plots treated with the combination of *L. lecanii* 1% WP + cyantraniliprole 10.26 OD (M₂I₄) @ 20 g + 6 mL per 10 litre of water and it was at par with cyantraniliprole 10.26 OD alone (M₃I₄) @ 12 mL per 10 litre of water (3.11 thrips/ 3 twigs). The plots treated with *M. anisopliae* 1% WP + cyantraniliprole 10.26 OD (M₁I₄) @ 20 g + 6 mL per 10 litre of water and spinetoram 11.7 SC alone (M₃I₂) @ 10 mL per 10 litre of water noticed 3.78 and 3.95 thrips per three twigs, respectively and at par with the second-best treatment cyantraniliprole 10.26 OD alone (M₃I₄) on one side while other side it was at par with spirotetramat 15.31 OD alone (M₃I₃) @ 10 mL per 10 litre of water (4.17 thrips/ 3 twigs) and *L. lecanii* 1% WP + spirotetramat 15.31 OD (M₂I₃) @ 20 g + 5 mL per 10 litre of water (4.83 thrips/ 3 twigs). Treatments *L. lecanii* 1% WP alone (M₂I₁) @ 40 g per 10 litera of water, *M. anisopliae* 1% WP + spirotetramat 15.31 OD (M₁I₃) @ 20 g + 5 mL per 10 litre of water and *L. lecanii* 1% WP + spinetoram 11.7 SC (M₂I₂) @ 20 g + 4 mL per 10 litre of water were recorded 4.98, 5.36 and 5.70 thrips per 3 twigs, respectively. The chilli plots sprayed with *M. anisopliae* 1% WP + spinetoram 11.7 SC (M₁I₂) @ 20 g + 4 mL per 10 litre of water exhibited highest thrips i.e. 8.14 per three twigs followed by *M. anisopliae* 1% WP alone (M₁I₁) @ 40 g per 10 litre of water (6.63/ 3 twigs). However, all the treatments were significantly superior to control (M₃I₁).

The overall pooled of two sprays (Table 3) clearly indicated that lowest *S. dorsalis* population (3.58 thrips/ 3 twigs) was

observed in chilli plants treated with the combination of *L. lecanii* 1% WP + cyantraniliprole 10.26 OD (M₂I₄) @ 20 g + 6 mL per 10 litre of water and at par with cyantraniliprole 10.26 OD alone (M₃I₄) @ 12 mL. In which, 5.26 thrips were recorded per three twigs and at par with the most effective combination treatment M₂I₄ on one hand while, with *M. anisopliae* 1% WP + cyantraniliprole 10.26 OD (5.70/ 3 twigs) and spinetoram 11.7 SC alone (6.21 thrips/ 3 twigs) on other hand of chronological order.

The other combined treatments spirotetramat 15.31 OD alone (M₃I₃), *L. lecanii* 1% WP + spirotetramat 15.31 OD (M₂I₃), *L. lecanii* 1% WP alone (M₂I₁), *M. anisopliae* 1% WP + spirotetramat 15.31 OD (M₁I₃), *L. lecanii* 1% WP + spinetoram 11.7 SC (M₂I₂) and *M. anisopliae* 1% WP alone (M₁I₁) recorded 6.52, 6.79, 7.34, 7.57, 8.08 and 8.62 thrips per 3 twigs, respectively. Significantly the highest (10.26/ 3 twigs) thrips was registered in the plots treated with *M. anisopliae* 1% WP + spinetoram 11.7 SC (M₁I₂) @ 20 g + 8 mL per 10 litre of water but superior to control.

Second spray pooled data are presented Table 3 and illustrated significant differences among the treatments. The lowest *S. dorsalis* population (2.81/ 3 twigs) was observed in the chilli plots treated with the combination of *L. lecanii* 1% WP + cyantraniliprole 10.26 OD (M₂I₄) @ 20 g + 6 mL per 10 litre of water and it was at par with cyantraniliprole 10.26 OD alone (M₃I₄) @ 12 mL per 10 litre of water (3.11 thrips/ 3 twigs). The plots treated with *M. anisopliae* 1% WP + cyantraniliprole 10.26 OD (M₁I₄) @ 20 g + 6 mL per 10 litre of water and spinetoram 11.7 SC alone (M₃I₂) @ 10 mL per 10 litre of water noticed 3.78 and 3.95 thrips per three twigs, respectively and at par with the second-best treatment cyantraniliprole 10.26 OD alone (M₃I₄) on one side while other side it was at par with spirotetramat 15.31 OD alone (M₃I₃) @ 10 mL per 10 litre of water (4.17 thrips/ 3 twigs) and *L. lecanii* 1% WP + spirotetramat 15.31 OD (M₂I₃) @ 20 g + 5 mL per 10 litre of water (4.83 thrips/ 3 twigs). Treatments *L. lecanii* 1% WP alone (M₂I₁) @ 40 g per 10 litera of water, *M. anisopliae* 1% WP + spirotetramat 15.31 OD (M₁I₃) @ 20 g + 5 mL per 10 litre of water and *L. lecanii* 1% WP + spinetoram 11.7 SC (M₂I₂) @ 20 g + 4 mL per 10 litre of water were recorded 4.98, 5.36 and 5.70 thrips per 3 twigs, respectively.

The chilli plots sprayed with *M. anisopliae* 1% WP + spinetoram 11.7 SC (M₁I₂) @ 20 g + 4 mL per 10 litre of water exhibited highest thrips i.e. 8.14 per three twigs followed by *M. anisopliae* 1% WP alone (M₁I₁) @ 40 g per 10 litre of water (6.63/ 3 twigs). However, all the treatments were significantly superior to control (M₃I₁).

The overall pooled of two sprays (Table 3) clearly indicated that lowest *S. dorsalis* population (3.58 thrips/ 3 twigs) was observed in chilli plants treated with the combination of *L. lecanii* 1% WP + cyantraniliprole 10.26 OD (M₂I₄) @ 20 g + 6 mL per 10 litre of water and at par with cyantraniliprole 10.26 OD alone (M₃I₄) @ 12 mL per 10 litre of water (4.12 thrips/ 3 twigs). The plots treated with *M. anisopliae* 1% WP + cyantraniliprole 10.26 OD (M₁I₄) @ 20 g + 6 mL per 10 litre of water illustrated 4.70 thrips per three twigs and was at par with the second-best treatment cyantraniliprole 10.26 OD alone (M₃I₄) on one side while other side with spinetoram 11.7 SC alone (M₃I₂) @ 10 mL per 10 litre of water (5.02 thrips/ 3 twigs) and spirotetramat 15.31 OD alone (M₃I₃) @ 8 mL per 10 litre of water (5.31 thrips/ 3 twigs). The plots treated with *L. lecanii* 1% WP + spirotetramat 15.31 OD (M₂I₃), *L. lecanii* 1% WP alone

(M₂I₁), *M. anisopliae* 1% WP + spirotetramat 15.31 OD (M₁I₃), *L. lecanii* 1% WP + spinetoram 11.7 SC (M₂I₂) and *M. anisopliae* 1% WP alone (M₁I₁) recorded 5.55, 6.10, 6.42, 6.84 and 7.62 thrips per 3 twigs, respectively and fall under mediocre group of effectiveness. The chilli plots sprayed with *M. anisopliae* 1% WP + spinetoram 11.7 SC

(M₁I₂) @ 20 g + 4 mL per 10 litre of water was recorded significantly highest thrips *i.e.* 9.17 per three twigs followed by *M. anisopliae* 1% WP alone (M₁I₁) @ 40 g per 10 litre of water (7.62/ 3 twigs). However, all the treatments were significantly superior to control (M₃I₁).

Table 3: Efficacy of entomopathogenic fungi with insecticides against chilli thrips, *S. dorsalis*

Sr. No.	Treatment Symbol	Treatment combinations	No. of thrips/ 3 twigs at indicated spray			
			Before spray	First spray pooled	Second spray pooled	Pooled over sprays
1.	M ₁ I ₁	<i>M. anisopliae</i> 1% WP	3.5 (11.75)	3.02 (8.62)	2.67 (6.63)	2.85 (7.62)
2.	M ₁ I ₂	<i>M. anisopliae</i> 1% WP + Spinetoram 11.7 SC	3.52 (11.89)	3.28 (10.26)	2.94 (8.14)	3.11 (9.17)
3.	M ₁ I ₃	<i>M. anisopliae</i> 1% WP + Spirotetramat 15.31 OD	3.47 (11.54)	2.84(7.57)	2.42 (5.36)	2.63 (6.42)
4.	M ₁ I ₄	<i>M. anisopliae</i> 1% WP + Cyantraniliprole 10.26 OD	3.49 (11.68)	2.49 (5.70)	2.07 (3.78)	2.28 (4.70)
5.	M ₂ I ₁	<i>L. lecanii</i> 1% WP	3.53 (11.96)	2.80 (7.34)	2.34 (4.98)	2.57 (6.10)
6.	M ₂ I ₂	<i>L. lecanii</i> 1% WP + Spinetoram 11.7 SC	3.52 (11.89)	2.93 (8.08)	2.49 (5.70)	2.71 (6.84)
7.	M ₂ I ₃	<i>L. lecanii</i> 1% WP + Spirotetramat 15.31 OD	3.50 (11.75)	2.70 (6.79)	2.21 (4.38)	2.46 (5.55)
8.	M ₂ I ₄	<i>L. lecanii</i> 1% WP + Cyantraniliprole 10.26 OD	3.36 (10.79)	2.22 (4.43)	1.82 (2.81)	2.02 (3.58)
9.	M ₃ I ₁	Control	3.47 (11.54)	3.69 (13.12)	3.64 (12.75)	3.66 (12.90)
10.	M ₃ I ₂	Spinetoram 11.7 SC	3.43 (11.26)	2.59 (6.21)	2.11 (3.95)	2.35 (5.02)
11.	M ₃ I ₃	Spirotetramat 15.31 OD	3.45 (11.4)	2.65 (6.52)	2.16 (4.17)	2.41 (5.31)
12.	M ₃ I ₄	Cyantraniliprole 10.26 OD	3.51 (11.82)	2.40 (5.26)	1.90 (3.11)	2.15 (4.12)
S. Em. ±		M x I	0.08	0.08	0.07	0.05
		M x I x P	-	0.15	0.15	0.11
		M x I x S	-	-	-	0.11
		M x I x P x S	-	-	-	0.16
C.D. at 5 %		M x I	NS	0.24	0.05	0.16
		M x I x P	-	NS	NS	NS
		M x I x S	-	-	-	NS
		M x I x P x S	-	-	-	NS
C.V. (%)			8.49	10.28	11.47	10.68

Note: 1. Figures in parenthesis are retransformed values and those outside are $\sqrt{X + 0.5}$ transformed values.
2. NS: Non-significant, Sig.: Significant

Thus, it can be concluded that the treatment *L. lecanii* 1% WP + cyantraniliprole 10.26 OD @ 20 g + 6 mL per 10 litre of water was found to be more effective based on thrips incidence in chilli. However, *M. anisopliae* 1% WP + spinetoram 11.7 SC @ 20 g + 4 mL per 10 litre of water was the least effective in reducing the incidence of *S. dorsalis* infesting chilli.

Findings of earlier researchers pertaining to combine efficacy of *M. anisopliae* and *L. lecanii* with modern group of insecticides against chilli thrips, *S. dorsalis* infesting chilli are not available. The results of the present investigation are similar to the findings of Hadiya *et al.* (2016) [8], who reported that the best treatment for chilli thrips was *V. lecanii* rather than *M. anisopliae*. Similarly, cyantraniliprole 10 OD at 1.50 g per litre was observed as the most significant treatment in decreasing the thrips population (Mirala and Gopali, 2019) [12]. Fernandez-Grandon *et al.*, (2020) [7] stated that combinations of biopesticides with pesticide that have different mode of actions have the potential to improve the efficacy of the individual components and reduce the build-up of resistance. Combined application of *M. anisopliae* with spirotetramat resulted in significant mortality (64.63%) in *A. gossypii* (Nawaz *et al.*, 2022) [13]. while, combination of *B. bassiana* and spinetoram effectively reduced onion thrips, *Thrips tabaci* (Wakil *et al.*, 2023) [20].

Impact on Yield of Green Chilli Fruit

The data on the fruit yield of chilli are presented in Table 4. The data on the fruit yield of chilli exhibited that all the treated plots registered significantly higher yield than the control. Among the different combinations of entomopathogenic fungi and insecticides, the highest (97.17 q/ha) chilli fruit yield was obtained from the plots treated with *L. lecanii* 1% WP + cyantraniliprole 10.26 OD (M₂I₄) and it was at par with cyantraniliprole 10.26 OD alone (93.67 q/ha), *M. anisopliae* 1% WP + cyantraniliprole 10.26 OD (91.00 q/ha) and spinetoram 11.7 SC alone (86.00 q/ha). The chilli fruits harvested from spirotetramat 15.31 OD alone treated plots registered 81.00 q/ha yield and significantly not differ from *M. anisopliae* 1% WP + cyantraniliprole 10.26 OD (M₁I₄) and spinetoram 11.7 SC alone (M₃I₂) on the one hand, while with *L. lecanii* 1% WP + spirotetramat 15.31 OD (M₂I₃) (74.00 q/ha) and *L. lecanii* 1% WP alone (M₂I₁) (71.33 q/ha) on other hand. The chilli plots treated with *M. anisopliae* 1% WP + spirotetramat 15.31 OD (M₁I₃) and *L. lecanii* 1% WP + spinetoram 11.7 SC (M₂I₂) were obtained 67.00 and 64.66 q/ha chilli fruit yield. The lowest (59.67 q/ha) chilli fruit yield was noted in the plots of *M. anisopliae* 1% WP and it was at par with plots treated with *M. anisopliae* 1% WP + spinetoram 11.7 SC (M₁I₂) (61.83 q/ha). These two inferior treatments were also at par with control (51.00 q/ha).

Table 4: Impact of entomopathogenic fungi with insecticides on yield green chilli fruit yield and avoidable losses due to chilli thrips

Sr. No.	Treatment code	Combinations detail	Yield (q/ha)	Increase in yield over control (%)	Avoidable loss (%)
1	M ₁ I ₁	<i>M. anisopliae</i> 1% WP	61.83	21.24	36.37
2	M ₁ I ₂	<i>M. anisopliae</i> 1% WP + Spinetoram 11.7 SC	59.67	17.00	38.59
3	M ₁ I ₃	<i>M. anisopliae</i> 1% WP + Spirotetramat 15.31 OD	67.00	31.37	31.05
4	M ₁ I ₄	<i>M. anisopliae</i> 1% WP + Cyantraniliprole 10.26 OD	91.00	78.43	6.35
5	M ₂ I ₁	<i>L. lecanii</i> 1% WP	71.33	39.86	26.59
6	M ₂ I ₂	<i>L. lecanii</i> 1% WP + Spinetoram 11.7 SC	64.66	26.78	33.46
7	M ₂ I ₃	<i>L. lecanii</i> 1% WP + Spirotetramat 15.31 OD	74.00	45.10	23.84
8	M ₂ I ₄	<i>L. lecanii</i> 1% WP + Cyantraniliprole 10.26 OD	97.17	90.53	-
9	M ₃ I ₁	Control	51.00	-	47.51
10	M ₃ I ₂	Spinetoram 11.7 SC	86.00	68.63	11.50
11	M ₃ I ₃	Spirotetramat 15.31 OD	81.00	58.82	16.64
12	M ₃ I ₄	Cyantraniliprole 10.26 OD	93.67	83.67	3.60
S. Em. (M × I) ±			4.32	-	-
CD at 5 %			12.66	-	-
CV (%)			10.1	-	-

Increase in yield over control

The increase in yield over control ranged from 21.24 to 90.53 percent due to the application of entomopathogenic fungi and insecticide in combination or alone. Maximum (90.53%) chilli fruit yield was increased in the plots treated with *L. lecanii* 1% WP + cyantraniliprole 10.26 OD (M₂I₄) followed by cyantraniliprole 10.26 OD alone (83.67 %) and *M. anisopliae* 1% WP + cyantraniliprole 10.26 OD (78.43%). The plots treated with spinetoram 11.7 SC and spirotetramat 15.31 OD only increased 68.63 and 58.82 percent yield of chilli fruit. The remaining treatments increased below fifty percent chilli fruit yield. The lowest (17.00 %) increase in yield was recorded in *M. anisopliae* 1% WP + spinetoram 11.7 SC followed by *M. anisopliae* 1% WP (21.24 %).

Avoidable losses

Avoidable losses in yield of chilli fruit was concerned, it varied from 3.60 to 47.51 percent in different treatments (Table 4). The avoidable loss was the lowest (3.60 %) cyantraniliprole 10.26 OD followed by *M. anisopliae* 1% WP + cyantraniliprole 10.26 OD (6.35%), spinetoram 11.7 SC (11.50 %) and spirotetramat 15.31 OD (16.64 %). Treatments *L. lecanii* 1% WP + spirotetramat 15.31 OD, *L. lecanii* 1% WP, *M. anisopliae* 1% WP + spirotetramat 15.31 OD and and *L. lecanii* 1% WP + spinetoram 11.7 SC were computed 20 to 35 percent avoidable losses in chilli fruit yield. The highest (28.59 %) avoidable loss was calculated in the treatment *M. anisopliae* 1% WP + spinetoram 11.7 SC followed by *M. anisopliae* 1% WP (36.37 %).

Conclusion

From the foregoing results it can be concluded that among all insecticidal and myco-insecticidal combinations evaluated, *L. lecanii* 1% WP + cyantraniliprole 10.26 OD (M₂I₄) and cyantraniliprole 10.26 OD alone (M₃I₄) were found more effective treatment combination to protect chilli crop from incidence of *S. dorsalis* with the green chilli fruit yield of treatments 97.17 and 93.67 q/ha, respectively. Whereas, *M. anisopliae* 1% WP + cyantraniliprole 10.26 OD, spinetoram 11.7 SC alone (M₃I₂) and spirotetramat 15.31 OD alone (M₃I₃) were found next best combinations in chilli against *S. dorsalis*.

Conflict of Interest: The authors declare that they have no conflict of interest.

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