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COMPATIBILITY OF INSECTICIDE + FUNGICIDE COMBINATIONS AGAINST FALL ARMYWORM, *SPODOPTERA FRUGIPERDA* AND BANDED LEAF AND SHEATH BLIGHT, *RHIZOCTONIA SOLANI* IN MAIZE

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ABSTRACT

The evaluation of compatibility of new insecticides *viz*., chlorantraniliprole 18.5% SC @ 0.5 ml L^{-1}, spinetoram 11.7 % SC @ 0.5 ml L^{-1} and fungicides *viz*., propiconazole 25% EC @ 1 ml L^{-1} and azoxystrobin 18.2 % + difenoconazole 11.4% SC @ 1ml L^{-1} were tested against Fall armyworm, *Spodoptera frugiperda* and Banded leaf and sheath blight, *Rhizoctonia solani* in maize. Significantly superior treatment recorded was the combination of spinetoram with azoxystrobin + difenoconazole with least mean larval count (0.17 larvae 10 $plants^{-1}$) causing the highest reduction per cent of larval count over control (98.77%) and lowest mean per cent leaf damage (13.55%) with highest yield (48.56 q ha^{-1}) and cost benefit ratio 1:2.38. None of the combinations were recorded with any phytotoxicity symptoms.

Key words : Phisical compatibility, Bio efficacy, *Spodoptera frugiperda, Rhizoctonia solani,* Phytotoxicity, Maize.

Introduction

Maize (*Zea mays* L.), 'queen of cereals' is an important staple food of Indians, ranking third after rice and wheat. It serves multiple purposes such as providing food, feed, and fodder. Maize is a crucial raw material for various industrial products *viz*., starch, oil, protein, alcoholic beverages, sweeteners, cosmetics, bio-fuel *etc*. India is the sixth largest producer of maize with production of 324.70 lakh tonne, productivity of 3260 kg ha^{-1} and occupied in area of 99.61 lakh ha. Andhra Pradesh is the fourth largest producer (19.78 lakh tonne), with highest productivity (6066.00 kg ha^{-1}) with ana area coverage of 3.26 lakh ha (www.indiastat.com). The reason for less productivity of maize is attributed to abiotic stress, diseases and destructive invasive pests. The recently introduced invasive pest, *Spodoptera frugiperda* and banded leaf and sheath blight caused by *Rhizoctonia solani* are major limiting factors for the low productivity of maize in Andhra Pradesh.

Fall armyworm, *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera : Noctuidae) is an invasive, highly polyphagous and migratory pest that poses a serious threat to the maize crop. *S. frugiperda* native of tropical and subtropical regions of the Americas, was first documented in West and Central Africa during widespread outbreaks in 2016 (Goergen *et al*., 2016) and subsequently in Ghana (Cock *et al*., 2017). In India, *S. frugiperda* was reported for the first time from Shivamogga, Karnataka (Sharanabasappa *et al*., 2018) and since, it has spread throughout the country except in Himachal Pradesh and Jammu and Kashmir. FAW, *S. frugiperda* can cause yield losses from 8.30 to 20.60 MT $annum^{-1}$ *i.e.*, 21-53% of production, if left unmanaged (Abrahams *et al.*, 2017). The approximate avoidable yield loss due to FAW, *S. frugiperda* infestation was estimated to be 2 500 kg ha^{-1} (Srinivasan *et al.*, 2022).

Out of 112 diseases documented on maize globally that results in substantial yield losses, banded leaf and sheath blight (BLSB) caused by *Rhizoctonia solani* is identified as the most critical, resulting in significant reduction in crop yield (Sharma and Saxena., 2002). BLSB has emerged as a major economic concern, leading to corn grain losses ranging from 11.00 to 40.00 % and they can reach up to 100.00 % under ideal favourable conditions. Being a soil borne pathogen with oligogenic resistance traits, it is difficult to manage BLSB through crop rotation or by developing resistant varieties. Furthermore, the sclerotia produced by the pathogen can remain viable in the soil for a minimum of two years, which adds to the complexity of controlling this disease.

The occurrence of both FAW, *S. frugiperda* and BLSB disease in maize crop, together creating the alarming situation to farmers resulting in severe crop losses. In such situations, farmers usually blend pesticides to suppress a wide range of insects and diseases with a single combination application rather than separate treatments to save time and operational expenses. It is crucial to examine the bio efficacy and phytotoxicity of combined pesticides as tank mixes and the interactions between different pesticides can be either antagonistic, additive or synergistic (Gandini *et al.*, 2020). The physical incompatibility between insecticide + fungicide combinations might result in the creation of sediments of mixture and these precipitants can clog screens and nozzles resulting in improper application of pesticides.

In recent times, new insecticide and fungicide combinations are being used to manage insect pests and diseases in maize ecosystem. The compatibility and phytotoxic effects of insecticide + fungicide combinations are unknown for many of newer pesticides. Hence, there is an immediate need to determine the compatibility of pesticide combinations, phytotoxicity on maize crop and their bio efficacy in controlling pests and diseases.

Materials and Methods

The field experiment was laid out at Wet land farm, S. V. Agricultural College, Tirupati, with latitude 13.61583° N and longitude 79.373083° E during *rabi*, 2023 - 24. The experiment was laid out in Randomized Block Design (RBD) with seven treatments and three replications with a plot size of 5 m × 5 m with inter- row spacing of 60 cm and 20 cm intra row spacing. Details pertaining insecticides and fungicides their doses are listed (Table 1). Three spraying were given at seedling stage (15 – 25 DAP), tasselling stage (47 – 50 DAP) and milky- dough stage (70-80 DAP). For phytotoxicity studies, insecticide + fungicide combinations were sprayed on maize crop at double the recommended dose was sprayed.

Population count

Total number of larvae present on ten randomly selected maize plants were recorded one day prior to pesticide spray (pre- treatment count) and post treatment counts were taken at an interval of 3,5,7 and 10 days after each spraying. The per cent reduction in larval populations was calculated by using the modified Abbott's formula (Flemming and Retnakaran, 1985).

$$\left.\begin{array}{l}\text{Per cent population}\\ \text{reduction}\end{array}\right\} =$$

$$\left(1-\left(\frac{\begin{array}{c}\text{Post treatment population}\\ \text{in treatment}\end{array}}{\begin{array}{c}\text{Pre treatment population}\\ \text{in treatment}\end{array}}\times\frac{\begin{array}{c}\text{Pre treatment population}\\ \text{in check}\end{array}}{\begin{array}{c}\text{Post treatment population}\\ \text{in check}\end{array}}\right)\right)$$

Per cent leaf damage

Observations on per cent leaf damage was recorded on ten randomly selected plants. The data was recorded based on rating scale (0 - 9) given by Davis and Williams,

Table 1 : Details of insecticide + fungicide combinations used for bio efficacy and phytotoxicity studies against FAW, *S. frugiperda* and BLSB, *R. solani* in maize.

Treatment No.	Treatment details
T_1	Chlorantraniliprole 18.5 % SC @ 0.5 ml L^{-1} +Propiconazole 25 % EC @ 1 ml L^{-1}
T_2	Spinetoram 11.7 % SC @ 0.5 ml + Propiconazole 25 % EC @ 1 ml L^{-1}
T_3	**Bacillus thuringiensis* @ 10 ml L^{-1}+ Propiconazole 25 % @ EC @ 1 ml L^{-1}
T_4	Chlorantraniliprole 18.5 % SC @ 0.5 ml L^{-1} + Azoxystrobin 18.2 % + Difenoconazole 11.4 % SC @ 1ml L^{-1}
T_5	Spinetoram 11.7 % SC @ 0.5ml L^{-1} + Azoxystrobin 18.2 % + Difenoconazole 11.4 % SC @ 1ml L^{-1}
T_6	**Bacillus thuringiensis* @ 10 ml L^{-1} +Azoxystrobin 18.2 % + Difenoconazole 11.4 % SC @ 1ml L^{-1}
T_7	Untreated control

**Bacillus thuringiensis:* Native *Bt* isolate of Tirupati, ANGRAU (cfu = 9.8 ×10^7).

1992. The percentage of damaged plants was calculated using the following formula.

$$\text{Per cent damaged plants} = \frac{\text{No. of damaged plants}}{\text{Total no. of plants}} \times 100$$

Per cent disease severity of Banded leaf and sheath blight, *R. solani*

Observations on banded leaf and sheath disease was recorded from 10 randomly selected plants and the data was recorded using 1-9 scale given by Ahuja and Payak (1983). The per cent disease severity was calculated using the formula:

$$P = \frac{\sum(n \times v)}{Z \times N} \times 100$$

Where,

P= Disease severity

n= Number of sample in each category

v= Numerical value of each category

Z= The highest numerical value of scale

N = Total number of sample

For per cent leaf damage and disease severity, pre treatment count was taken one day prior to application and post treatment data was taken on 7th and 10th day interval after each spray.

Phytotoxicity

Observations were recorded from at 3, 5, 7 and 10 days after spraying for phytotoxic symptoms such as injury to the leaf tip, yellowing, wilting, necrosis, vein clearing, epinasty and hyponasty on the leaves. The extent of phytotoxicity was recorded based on the scale prescribed by Central Insecticide Board and Registration Committee (C.I.B & R.C).

Rating	Per cent injury
0	No Phytotoxicity
1	1 to 10 %
2	11 to 20 %
3	21 to 30 %
4	31 to 40 %
5	41 to 50 %
6	51 to 60 %
7	61 to 70 %
8	71 to 80 %
9	81 to 90 %
10	91 to 100 % phytotoxicity

The per cent injury was calculated by using the formula

$$\text{Per cent injury} = \frac{\text{Total grade points}}{\text{Total no. of max. grade} \times \text{No. of leaves observed}} \times 100$$

Grain yield

The data on grain yield of maize was recorded from each plot. The yield obtained from different treatments were expressed as q ha^{-1}.

Statistical analysis

The data on larval population was subjected to square root transformation and data on per cent leaf damage was subjected to arcsine transformation. Transformed data was analyzed using analysis of variance (ANOVA) through IBM SPSS statistical package version 20 and Duncan's Multiple Range Test (DMRT) ($P \leq 0.05$). Formula for calculating cost benefit ratio:

Increase in yield over control = Grain yield (q ha^{-1}) - Untreated control (q ha^{-1})

Value of additional yield over control = Increase in yield over control (q ha^{-1}) × Cost of the produce (Rs q^{-1})

$$\text{Avoidable yield loss} = \frac{T-C}{T} \times 100$$

Whereas, T - Yield obtained from treatment plot (q ha^{-1}), C - Yield obtained from treatment plot (q ha^{-1})

Gross returns = Grain yield (q ha^{-1}) × Cost of the produce (Rs q^{-1})

Net profit = Gross returns - Total cost of cultivation

$$\text{Cost Benefit ratio} = \frac{\text{Gross returns}}{\text{Total cost of cultivation}} \times 100$$

Results and Discussion

The cumulative effectiveness of treatments at intervals of 3, 5, 7 and 10 days following both the initial and subsequent sprayings demonstrate that the significantly superior treatment recorded was the combination of spinetoram with azoxystrobin + difenoconazole with least mean larval count (0.17 larvae 10 plants^{-1}) causing the highest reduction per cent of larval count over control (98.77%) and lowest mean per cent leaf damage (13.55%) and highest per cent of reduction of leaf damage (83.25%). This treatment was on par with other treatments of combination of spinetoram with propiconazole (mean larval count- 0.41, reduction in number of larvae over control- 97.03 %, mean per cent of leaf damage- 17.39%, reduction in per cent leaf damage over control- 78.50%), chlorantraniliprole with azoxystrobin + difenoconazole (mean larval count- 0.71, reduction in number of larvae over control- 94.98 %, mean per cent of leaf damage- 17.92%, reduction in per

Table 2 : Cumulative efficacy of different insecticide + fungicide combinations against FAW, *S. frugiperda* and BLSB, *R. solani* in maize during *rabi*, 2023-24.

Tr. No.	Treatments	Mean No. of larvae/ 10 Plants*						% leaf damage**						Davis scale of leaf damage	% BLSB disease severity
		PTC	After first spray	After second spray	After third spray	Mean	% ROC	PTC	After first spray	After second spray	After third spray	Mean	% ROC		
T_1	Chlorantraniliprole @ 0.5 ml L^{-1} + Propiconazole @ 1 ml L^{-1}	13.67(3.76)	1.72(1.49)^a	1.06(1.25)^a	0.51(1.00)^a	1.10(1.26)^a	**92.33(72.96)^a**	37.24(37.63)	31.48(34.15)^b	15.15(22.92)^a	20.65(27.04)^a	22.43(28.28)^a	**72.27(58.25)^a**	2.00	0.00
T_2	Spinetoram @ 0.5 mlL^{-1} + Propiconazole @ 1 ml L^{-1}	13.00(3.67)	0.41(0.95)^a	0.54(1.02)^a	0.29(0.89)^a	0.41(0.95)^a	**97.03(80.12)^a**	35.59(36.64)	22.98(28.66)^{ab}	11.63(19.95)^a	17.57(24.79)^a	17.39(24.66)^a	**78.50(62.41)^a**	1.74	0.00
T_3	*Bacillus thuringiensis* 10 ml L^{-1} + Propiconazole @ 1 ml L^{-1}	12.33(3.58)	7.80(2.88)^b	4.93(2.33)^b	4.83(2.33)^b	5.85(2.52)^b	**58.36(49.84)^b**	50.14(45.10)	64.55(53.49)^c	39.45(38.93)^b	45.38(42.37)^b	49.79(44.90)^b	**38.44(38.34)^b**	3.93	0.00
T_4	Chlorantraniliprole @ 0.5 ml L^{-1} + Azoxystrobin + Difenoconazole @ 1 mlL^{-1}	11.67(3.49)	0.94(1.20)^a	0.83(1.15)^a	0.36(1.15)^a	0.71(1.10)^a	**94.98(77.09)^a**	36.33(37.09)	22.07(28.03)^{ab}	14.02(22.00)^a	17.67(24.87)^a	17.92(25.06)^a	**77.84(61.95)^a**	1.80	0.00
T_5	Spinetoram @ 0.5 mlL^{-1} + Azoxystrobin + Difenoconazole @ 1 mlL^{-1}	12.33(3.58)	0.13(0.79)^a	0.38(0.94)^a	0.00(0.94)^a	0.17(0.82)^a	**98.77(83.67)^a**	35.88(36.82)	16.85(24.25)^a	9.80(18.25)^a	13.99(21.98)^a	13.55(21.61)^a	**83.25(65.87)^a**	1.16	0.00
T_6	*Bacillus thuringiensis* 10 ml L^{-1} + Azoxystrobin + Difenoconazole @ 1 mlL^{-1}	11.00(3.58)	7.88(2.89)^b	5.09(2.36)^b	5.06(2.36)^b	6.01(2.55)^b	**57.19(49.16)^c**	56.89(48.99)	65.88(54.29)^c	40.11(39.32)^b	48.58(44.21)^b	51.39(45.82)^b	**36.46(37.16)^b**	4.14	0.00
T_7	Untreated control	12.67(3.63)	15.24(3.97)^c	13.57(3.75)^c	12.91(3.75)^c	13.91(3.80)^c	-	74.02(59.39)	81.42(64.50)^d	82.48(65.29)^c	78.75(62.58)^c	80.88(64.10)^c	-	8.33	2.13
	CD (P = 0.05)	NS	0.29	0.32	0.23	-	-	NS	0.57	0.35	0.52	-	-	-	-
	CV (%)	-	9.13	10.93	8.42	-	-	-	5.75	6.21	6.14	-	-	-	-
	F value	-	137.64	85.55	-	-	-	-	95.20	150.47	75.89	-	-	-	-

*Figures in parentheses are square root transformed values; **Figures in parentheses are arcsine transformed values

Means with in a column followed by the same letter do not differ significantly as per DMRT

PTC= Pre-Treatment Count; % ROC = Per cent Reduction Over Control, NS = Non-Significant

Davis scale of leaf damage: 1 - 9 scale

Bacillus thuringiensis; Native *Bt* formulation of Tirupati, ANGRAU was used (cfu = 9.8×10^7)

cent leaf damage over control- 77.84%), chlorantraniliprole with propiconazole (mean larval count- 1.10, reduction in number of larvae over control- 92.33 %, mean per cent of leaf damage- 22.43%, reduction in per cent leaf damage over control- 72.27%). The combinations of *Bt* with propiconazole was recorded with least efficacy with mean larval count of 5.85 larvae 10 plants^{-1} with reduction over control, 58.36% followed by *Bt* with azoxystrobin + difenoconazole (6.01 larvae 10 plants^{-1} and 57.19 %), whereas, the mean per cent leaf damage and its reduction over control were on par in both treatments (49.79 larvae 10 plants^{-1}, 51.39 38.44 % and larvae 10 plants^{-1}, 36.46%, respectively). The mean per cent larval count and mean per cent leaf damage were recorded maximum in control plot (13.91 larvae 10 plants^{-1}, 80.88%). The mean score for leaf damage of all three sprays were correlating with the efficiency of treatments, which recorded least in combination of spinetoram with azoxystrobin + difenoconazole (1.76), followed by spinetoram with propiconazole (1.74), chlorantraniliprole with azoxystrobin + difenoconazole (1.80), chlorantraniliprole with propiconazole (2.00), *Bt* with propiconazole (3.93) and *Bt* with azoxystrobin + difenoconazole (4.14) and highest record of leaf damage score was recorded in control (8.33).

The incidence of BLSB was very much negligible in the maize plots treated with insecticide + fungicide combinations which were initiated at 20 days after sowing along with the initiation incidence of FAW, *S. frugiperda* on maize. These prophylactic combination sprays might have reduced the BLSB incidence in treated plots whereas 2.13 % BLSB incidence was recorded in the untreated control (Table 2, Fig. 1).

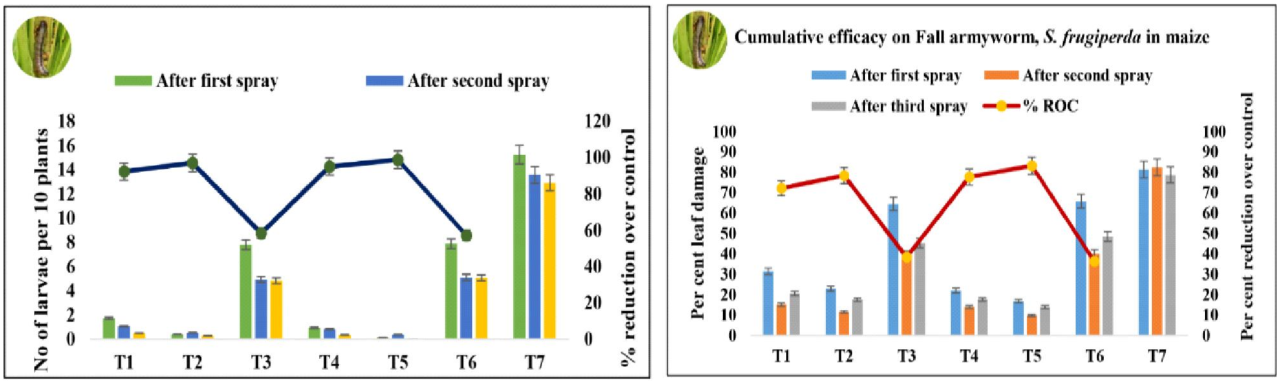

Fig. 1 : Efficacy of different insecticide + fungicide combinations on number of larvae and leaf damage caused by FAW, *S. frugiperda* in maize during rabi, 2023-24. T_1- Chlorantraniliprole +Propiconazole, T_2- Spinetoram + Propiconazole, T_3-**Bt* + Propiconazole, T_4- Chlorantraniliprole + (Azoxystrobin + Difenoconazole), T_5- Spinetoram+ (Azoxystrobin + Difenoconazole), T_6- *Bt* + (Azoxystrobin + Difenoconazole), T_7- Untreated control.

Cost economics of different insecticide + fungicide combination treatments for the management of FAW *S. frugiperda* in maize

The highest yield was recorded in spinetoram with azoxystrobin + difenoconazole (48.56 q ha^{-1}), followed by spinetoram with propiconazole (41.68 q ha^{-1}) which was on par with chlorantraniliprole with azoxystrobin + difenoconazole (40.55), chlorantraniliprole with propiconazole (37.56 q ha^{-1}), *Bt* with azoxystrobin + difenoconazole (33.45 q ha^{-1}), *Bt* with propiconazole (30.25 q ha^{-1}) and lowest yield was obtained from control (20.32 q ha^{-1}). The treatment, spinetoram with azoxystrobin + difenoconazole recorded highest value of additional yield over untreated control (50832.00 Rs ha^{-1}) followed by spinetoram with propiconazole (38448 Rs ha^{-1}), chlorantraniliprole with azoxystrobin + difenoconazole (36414.00 Rs ha^{-1}), chlorantraniliprole with propiconazole (31032 Rs ha^{-1}), *Bt* with azoxystrobin + difenoconazole (23634.00 Rs ha^{-1}), *Bt* with propiconazole (17874.00 Rs ha^{-1}) and same trend was followed in cost - benefit ratios, 1:2.38, 1:2.35, 1:1.97, 1:1.97, 1:1.04 and 1:1.03, respectively (Table 3).

In present study, the combination of spinetoram with azoxystrobin + difenoconazole and propiconazole were found to be more effective against FAW, *S. frugiperda* over the combinations of chlorantraniliprole and *Bt* with fungicides. There are similar studies which reported that the pesticide combinations are more effective than the individual application of insecticides. Stanley *et al.* (2010) found that the combination of diafenthiuron with carbendazim had shown 66.67% mortality of *Conogethus punctiferalis* and diafenthiuron with urea caused 58.14% mortality of *Scirtothrips cardamomi* while diafenthiuron alone caused mortality of 46.67 % and 52.77%, respectively. Siddartha and Revannavar (2014) also reported that combinations of chlorantraniliprole (33.9%), flubendiamide, novaluron with fungicide Saaf® when compared to their individaual mortality with a highest mortality in case of chlorantraniliprole + Saaf® (100%) against diamond back moth, *Plutella xylostella*. The combination of acaricides and fungicides, dicofol + propiconazole was found to be the most effective treatment against rice panicle mite by Venkatreddy *et al.* (2013).

Banded leaf and sheath blight disease was minimal and did not require management with chemical control alone. However, some studies have reported that combinations of insecticides and fungicides can be effective against both insect pests and diseases.

Kataria *et al.* (1989) investigated the interactions of fungicide and insecticide combinations against *Rhizoctonia solani* both *in vitro* and in soil. They found that none of the insecticides reduced the efficacy of any fungicide. In fact, the fungicides provided equal or greater inhibition of fungal growth *in vitro* and offered equally good or better protection against seedling rot when used in combination with insecticides as compared to being used alone. These additive or synergistic effects were most notable for pencycuron + insecticide mixtures *in vitro* and carboxin + insecticide mixtures in the soil.

Raju *et al.* (2016 a) had found that different combinations of insecticide + fungicides-controlled leaf folder larvae with the combinations, flubendiamide (1.01), chlorantraniliprole (1.01), flubendiamide + tricyclazole (1.02), flubendiamide + hexaconazole (1.01), flubendiamide + propiconazole (1.09), chlorantraniliprole + tricyclazole (1.04), chlorantraniliprole + hexaconazole (0.99) and chlorantraniliprole + propiconazole (1.29). The lowest per cent disease incidence of 11.0 was recorded in case of leaf blast with combination treatments, tricyclazole, flubendiamide + tricyclazole, chlorantraniliprole + tricyclazole, buprofezin + tricyclazole

Table 3 : Cost economics for the evaluation of insecticide + fungicide combinations against fall armyworm, *S. frugiperda*.

Tr. No.	Treatments	Dose	Grain yield* ($q\ ha^{-1}$)	Increase in yield over control * ($q\ ha^{-1}$)	Value of additional yield over control (Rs ha^{-1})	Avoidable yield loss** (%)	Total cost of cultivation (Rs ha^{-1})	Gross returns (Rs ha^{-1})	Net profit (Rs ha^{-1})	C : B Ratio
T_1	Chlorantraniliprole 18.5% SC +Propiconazole 25 % EC	0.5 ml L^{-1}+ 1 ml L^{-1}	37.56(6.17)^c	17.24(4.09)^d	31032.00	45.89(44.15)^c	34325.00	67608.00	33283.00	1:1.97
T_2	Spinetoram 11.7 % SC + Propiconazole 25 % EC 0.5	ml L^{-1} + 1 ml L^{-1}	41.68(6.49)^b	21.36(4.56)^b	38448.00	51.24(47.07)^b	31572.50	75024.00	43451.50	1: 2.35
T_3	*Bacillus thuringiensis* + Propiconazole 25 % EC	10 ml L^{-1}+ 1 ml L^{-1}	30.25(5.58)^d	9.93(2.59)^e	17874.00	32.82(33.12)^d	53075.00	54450.00	1375.00	1: 1.03
T_4	Chlorantraniliprole 18.5% SC +Azoxystrobin 18.2% + Difenoconazole 11.4 % SC	0.5 ml L^{-1} + 1 ml L^{-1}	40.55(6.41)^b	20.23(4.44)^c	36414.00	49.88(46.33)^b	39965.00	72990.00	33025.00	1: 1.83
T_5	Spinetoram 11.7 % SC + Azoxystrobin 18.2 % + Difenoconazole 11.4 % SC	0.5 ml L^{-1} + 1 ml L^{-1}	48.56(6.76)^a	28.24(4.94)^a	50832.00	58.15(49.18)^a	37212.50	87408.00	50195.50	1: 2.38
T_6	*Bacillus thuringiensis* + Azoxystrobin 18.2 % + Difenoconazole 11.4 % SC	10 ml L^{-1}+ 1 ml L^{-1}	33.45(5.88)^e	13.13(2.20)^f	23634.00	39.25(29.78)^e	58715.00	60210.00	1495.00	1: 1.04
T_7	Untreated control	-	20.32(4.46)^f	-	0.00	-	20000.00	36576.00	16576.00	-
CD (P=0.05)		-	0.47	2.6	-	0.32	-	-	-	-
CV (%)		-	4.47	5.70	-	2.97	-	-	-	-
F value		-	30.30	51.46	-	510.74	-	-	-	-

Note: Cost of Maize = Rs 1800 q^{-1}. Cost of insecticides i) Chlorantraniliprole 18.5 % SC, Rs 208 10 ml^{-1}, ii) Spinetoram 11.7 % SC, Rs 1134 100 ml^{-1} , iii) Propiconazole 25 % EC, Rs 200 100 ml^{-1}, iv) Azoxystrobin 18.2 % + Difenoconazole 11.4 % SC, Rs 930 100 ml^{-1}, v) *Bacillus thuringiensis*, Rs 50 100 ml^{-1}. Cost of worker: men- 400 day^{-1}, women- 300 day^{-1}.

*Figures in parentheses are square root transformed values; **Figures in parentheses are arcsine transformed values.

Values followed by the same letter in each column are not significantly different as per DMRT.

Table 4 : Phytotoxicity of insecticide + fungicide combinations on maize leaves at double the recommended doses.

No.	Pesticide combinations	Double dose	CLM	R	WL	S	N	W	WP
T_1	Chlorantraniliprole + Propiconazole	1 ml L^{-1}+ 2 ml L^{-1}	Not found	Not found	Not found	Not found	Not found	Not found	Not found
T_2	Spinetoram + Propiconazole	1 ml L^{-1}+ 2 ml L^{-1}	Not found	Not found	Not found	Not found	Not found	Not found	Not found
T_3	*Bacillus thuringiensis* + Propiconazole	20 ml L^{-1}+ 2 ml L^{-1}	Not found	Not found	Not found	Not found	Not found	Not found	Not found
T_4	Chlorantraniliprole + Azoxystrobin + Difenoconazole	1 ml L^{-1}+ 2 ml L^{-1}	Not found	Not found	Not found	Not found	Not found	Not found	Not found
T_5	Spinetoram + Azoxystrobin + Difenoconazole	1 ml L^{-1}+ 2 ml L^{-1}	Not found	Not found	Not found	Not found	Not found	Not found	Not found
T_6	*Bacillus thuringiensis* + Azoxystrobin + Difenoconazole	20 ml L^{-1}+ 2 ml L^{-1}	Not found	Not found	Not found	Not found	Not found	Not found	Not found

CLM = Chlorotic Leaf Margins, **R** = Reddish or purplish veins, **WL** = Wrinkled leaves, **S** = Stunted growth, **N** = Necrosis, **W** = Wilting, **WP** = Whiplashing.

and profenophos + tricyclazole. A less mean dead heart per cent due to stem borer (1.6%) and lowest mean stem rot per cent (8.9%) were recorded in combination treatment of chlorantraniliprole+ propiconazole in rice by Raju *et al.* (2016 a). The effectiveness of chlorantraniliprole + validamycin against major insect pests and diseases of rice was recorded in the studies of Chaudhari *et al.* (2017). The studies conducted by Uma *et al.* (2019) revealed that chlorpyrifos with hexaconazole was effective against coffee white stem borer (*Xylotrechus quadripes*) and leaf rust disease (*Hemileia vastatrix*). Visalakshmi *et al.* (2016) reported that insecticides and fungicide combination on major pests and sheath blight of paddy could be reduced by the combination of flubendiamide with trifloxystroboin + tebuconazole, which recorded with less sheath blight incidence (27.33%) and less leaf folder incidence (2.00% leaf damage) followed by chlorpyriphos with propiconazole (30.13%, 7.92%) when compared to other combinations and untreated control.

Studies on phytotoxicity of insecticide + fungicide combinations

Among different combinations tested with two insecticides (chlorantraniliprole 18.5 % SC and spinetoram 11.7% SC), fungicides (propiconazole 25% EC and azoxystrobin 18.2% + difenoconazole 11.4 SC) and *Bacillus thuringiensis*, the per cent injury recorded was zero, indicating that none of the combinations exhibited phytotoxic symptoms according to the visual rating scale. The pH levels of the tested combinations ranged from 6.1 to 7.3, covering a spectrum from slightly alkaline to slightly acidic, which is considered safe for plants. It is clear that all combinations are compatible at their recommended doses and even the double concentration do not produce any phytotoxic symptoms (Table 4).

The results on phytotoxicity assessments consistently demonstrated that none of the insecticide and fungicide combinations exhibit phytotoxic symptoms.

Present findings were in accordance with earlier reports of Sabitha *et al.* (2020), reported the insecticides, flonicamid, chlorantraniliprole and acephate and fungicides, difenoconazole and azoxystrobin combinations on rice were compatible without any precipitation, sedimentation, slurry, gel, flakes, layering *etc*.

The results are in agreement with Sandhya *et al.* (2021), who investigated physical compatibility of insecticides and fungicides *viz*., lambda cyhalothrin 4.6% + chlorantraniliprole, chlorantraniliprole, flubendiamide, azadirachtin 1500 ppm and two fungicides azoxystrobin + difenoconazole, carbendazim + mancozeb in maize and found that all the eight combinations tested were physically compatible without causing any phytotoxicity symptoms (Kandpal and Srivastava, 2023).

Ogura *et al.* (2023) reported that no phytotoxicity effects were identified when plants were exposed to different fipronil concentrations (up to 0.12 mg kg^{-1}) with 2,4-D, indicating no interaction between pesticides on green manure crops.

Kandpal and Srivastava (2023) stated that the combinations of spinetoram 11.70 SC in combination with metiram 55 + pyraclostrobin 5 WG had shown no phytotoxic symptoms, during the study of efficacy of pesticide combinations against tobacco caterpillar, *S. litura* on soybean.

Conclusion

The cumulative mean efficacy of different insecticide and fungicide combinations after three insecticidal sprays revealed that both the insecticides *viz.*, spinetoram and chlorantraniliprole combined with fungicide azoxystrobin + difenoconazole resulted in better control of FAW, *S. frugiperda* with > 92% reduction of larval population and > 72.60 % reduction in leaf damage compared to untreated control.The mean leaf damage scale was also recorded very less within a range of 1.16 to 2.00 compared to *Bt* + propiconazole (3.93), *Bt* + azoxystrobin + difenoconazole (4.14) and untreated control (8.33). *Bt* at recommended dose was found to be less effective on FAW, *S. frugiperda* in maize under field conditions with 58.36 % larval reduction and 38.44% leaf damage reduction but superior to untreated control with 80.88 % leaf damage and 8.33 leaf damage score.

None of the combinations exhibited phytotoxicity symptoms such as chlorotic leaf margins, reddish or purplish veins, wrinkled leaves, stunted growth, necrosis, wilting, or whiplashing as per the visual rating scale of CIB&RC.

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