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Bio-efficacy of novel insecticides for the management of fall armyworm on maize during Kharif 2022-2023

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Abstract

Field experiments were conducted during Kharif 2022 and Kharif 2023 at Tirhut College of Agriculture, Dholi, Muzaffarpur, Bihar to evaluate the bio-efficacy of newer insecticides against fall armyworm, *Spodoptera frugiperda* (J. E. Smith), infesting maize. The experiments were laid out in randomized block design with different insecticidal treatments including chlorantraniliprole-based combinations, seed treatment modules and untreated control. Three sequential sprays were imposed at economic threshold level and larval population observations were recorded at regular intervals after spraying. Significant differences among treatments were observed during both years. Among the evaluated insecticides, T₄ (seed treatment followed by Chlorantraniliprole 18.5 SC spray) proved most effective and consistently recorded the lowest mean larval population (0.33 larvae plant⁻¹ pooled over two years), followed by T₂ (Chlorantraniliprole + Lambda-cyhalothrin), which recorded 0.41 larvae plant⁻¹. The highest reduction in larval population over untreated control (90.31%) was also observed in T₄. Grain yield was significantly enhanced under insecticidal treatments, with maximum yield recorded in T₄ (6.32 t ha⁻¹), followed by T₂ (6.08 t ha⁻¹), whereas untreated control produced only 3.28 t ha⁻¹. Economic analysis revealed that chlorantraniliprole-based treatments provided superior net returns and benefit-cost ratio compared with other treatments. The present investigation demonstrated that chlorantraniliprole-based insecticidal modules were highly effective and economically viable for management of fall armyworm under Bihar conditions.

Keywords: Fall armyworm, *Spodoptera frugiperda*, maize, chlorantraniliprole, bio-efficacy, insecticides, yield, economics

Introduction

Maize (*Zea mays* L.) is one of the most important cereal crops cultivated worldwide due to its high yield potential, adaptability and diversified utility as food, feed and industrial raw material. In India, maize occupies a prominent place after rice and wheat and contributes substantially to food and nutritional security. However, maize productivity has been seriously constrained in recent years due to invasion of fall armyworm, *Spodoptera frugiperda* (J. E. Smith), an invasive polyphagous pest belonging to the family Noctuidae. The pest was first reported in India during 2018 from Karnataka and subsequently spread rapidly across major maize-growing states including Bihar (Kalleshwaraswamy *et al.*, 2018) [7]. Fall armyworm causes severe damage through foliar feeding, whorl injury, tassel feeding and cob infestation, ultimately leading to substantial yield losses. Under severe infestation, yield reduction may exceed 30-50 percent depending upon crop stage and environmental conditions (Day *et al.*, 2017) [3]. Although several insecticides are recommended against fall armyworm, continuous use of conventional insecticides often results in resistance development, resurgence and adverse environmental effects. Therefore, evaluation of newer insecticidal molecules possessing novel modes of action is essential for sustainable management of the pest (Yu, 1983; Mallapur *et al.*, 2019) [15, 9]. Chlorantraniliprole and its combinations have shown promising effectiveness against lepidopteran pests due to their selective toxicity, translaminar action and longer residual activity. However, information regarding comparative field efficacy and economics of these newer molecules under Bihar agro-climatic conditions remains limited. Keeping these aspects in view, the present investigation was undertaken to evaluate the bio-efficacy of newer insecticides against fall armyworm on maize during Kharif 2022 and 2023 under field conditions.

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Materials and Methods

Experimental site

The field experiment was conducted during Kharif 2022 and Kharif 2023 at the Research Farm of Tirhut College of Agriculture, Dholi, Muzaffarpur, Bihar, India. The experimental farm is situated under North Bihar alluvial plains characterized by subtropical climatic conditions with warm humid summers and moderate rainfall.

Experimental design: The experiment was laid out in

Randomized Block Design (RBD) with nine treatments replicated thrice. Recommended agronomic practices were followed uniformly throughout the crop season except plant protection measures.

Crop and treatment details

Maize variety Shaktiman-5 was used during the investigation. The insecticidal treatments evaluated are presented below.

Treatment	Treatment details
T ₁	Seed treatment with Cyantraniliprole 19.8% + Thiamethoxam 19.8% FS @ 2.38 g a.i kg seed
T ₂	T ₁ + Chlorantraniliprole 9.3% + Lambda-cyhalothrin 4.6% ZC @ 35 (23.42 + 11.58) g a.i ha ⁻¹
T ₃	T ₁ + Spinetoram 11.7% SC @ 30 g a.i ha ⁻¹
T ₄	T ₁ + Chlorantraniliprole 18.5% SC @ 40 g a.i ha ⁻¹
T ₅	T ₁ + Emamectin benzoate 5% SG @ 200 g a.i ha ⁻¹
T ₆	T ₁ + Emamectin benzoate 5% + Lufenuron 40% WG @ 36 g a.i ha ⁻¹
T ₇	T ₁ + Thiodicarb 75% WP @ 750 g a.i ha ⁻¹
T ₈	T ₁ + Novaluron 5.25% + Emamectin benzoate 0.9% w/w SC @ 78.75 + 13.5 g a.i ha ⁻¹
T ₉	Untreated control

Application of insecticides

Three sequential sprays were imposed after attainment of economic threshold level of fall armyworm infestation. The insecticides were applied using knapsack sprayer with uniform spray volume to ensure proper coverage.

Recording observations

Observations on larval population were recorded from randomly selected plants in each treatment plot at 1 day before application (DBA) and 3, 5 and 10 days after application (DAA). Mean larval population per plant was computed.

Yield and economics

Grain yield obtained from each plot was converted into tonnes per hectare. Economic analysis including gross return, net return and benefit-cost ratio was worked out based on prevailing market price of maize and cost of cultivation.

Statistical analysis

Experimental data were subjected to analysis of variance (ANOVA) appropriate for randomized block design. Treatment means were compared using Duncan's Multiple Range Test (DMRT) at 5 percent level of significance. Standard error of mean [SE(m)], critical difference (CD) and coefficient of variation (CV) values were computed for all observations.

Results

Bio-efficacy of insecticides against *Spodoptera frugiperda* during Kharif 2022

The field evaluation conducted during Kharif 2022 revealed significant differences among insecticidal treatments in suppressing larval population of *Spodoptera frugiperda*. All insecticidal treatments significantly reduced larval population compared with untreated control after each spray application. Chlorantraniliprole-based treatments consistently performed better than other treatments throughout the experimental period.

Following the first spray, T₄ [seed treatment with cyantraniliprole 19.8% + thiamethoxam 19.8% FS followed

by chlorantraniliprole 18.5 SC @ 40 g a.i. ha⁻¹] recorded the lowest larval population (0.467 larvae plant⁻¹), closely followed by T₂ [chlorantraniliprole 9.3% + lambda-cyhalothrin 4.6% ZC] with 0.500 larvae plant⁻¹. Untreated control (T₉) recorded significantly higher infestation (3.557 larvae plant⁻¹). Treatments T₅ and T₈ also performed comparatively better by recording 0.990 and 1.100 larvae plant⁻¹, respectively. Higher larval population persisted under T₆ and T₇, indicating comparatively lower efficacy against fall armyworm. The statistical analysis revealed significant treatment effects with CD value of 0.566, SE(m) of 0.187 and CV of 24.974%.

After the second spray, chlorantraniliprole-based treatments maintained superior efficacy. T₄ again recorded the minimum larval population (0.333 larvae plant⁻¹), followed by T₂ (0.423 larvae plant⁻¹). The untreated control showed further increase in larval population (4.203 larvae plant⁻¹), indicating rapid multiplication of the pest in absence of insecticidal protection. Treatments involving emamectin benzoate and novaluron combinations also reduced infestation significantly but remained inferior to chlorantraniliprole-based schedules.

A similar trend was observed after the third spray, where T₄ recorded only 0.190 larvae plant⁻¹ followed by T₂ (0.310 larvae plant⁻¹). Untreated control maintained highest infestation level (2.343 larvae plant⁻¹). The consistent reduction in larval population under chlorantraniliprole-based treatments indicated prolonged residual toxicity and sustained suppression of fall armyworm population.

The pooled cumulative efficacy across three sprays clearly demonstrated superiority of T₄ with overall mean larval population of 0.350 larvae plant⁻¹, followed by T₂ (0.410 larvae plant⁻¹). Untreated control recorded the highest pooled larval population (3.400 larvae plant⁻¹). T₄ achieved maximum reduction over control (90.31%), whereas T₂ recorded 87.91% reduction. Correspondingly, the highest grain yield was obtained under T₄ (6.32 t ha⁻¹) followed by T₂ (6.08 t ha⁻¹), while untreated control recorded only 3.28 t ha⁻¹. Percent increase in yield over control was maximum under T₄ (92.68%) followed by T₂ (85.37%).

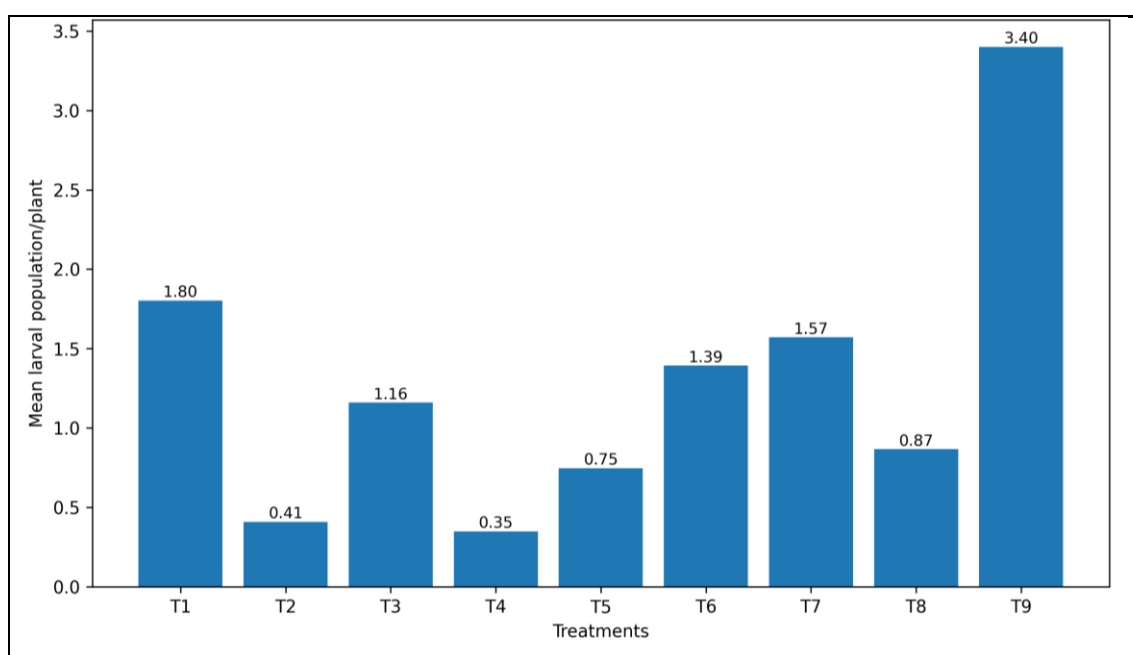
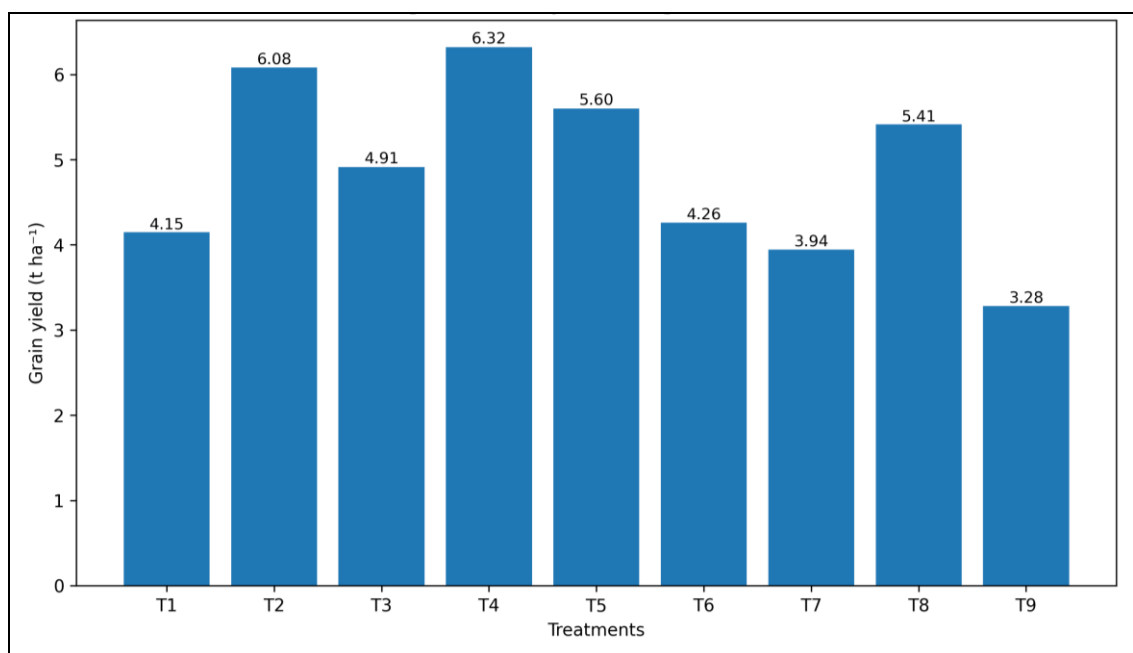
Table 1: Detailed cumulative efficacy of insecticides against fall armyworm during Kharif 2022

Treatment	Mean larval population after 1st spray	Mean larval population after 2nd spray	Mean larval population after 3rd spray	Overall pooled larval population	Reduction over control (%)	Yield (t ha ⁻¹)	Yield increase over control (%)
T ₁	1.823	1.867	1.723	1.803	46.95	4.147	26.43
T ₂	0.500	0.423	0.310	0.410	87.91	6.08	85.37
T ₃	1.243	1.133	1.110	1.160	65.80	4.913	49.79
T ₄	0.467	0.333	0.190	0.350	90.31	6.32	92.68
T ₅	0.990	0.577	0.667	0.747	78.10	5.60	70.73
T ₆	1.333	1.433	1.420	1.393	58.93	4.26	29.88
T ₇	1.643	1.543	1.543	1.573	53.59	3.943	20.21
T ₈	1.100	0.677	0.823	0.867	74.51	5.413	65.03
T ₉	3.557	4.203	2.343	3.400	0.00	3.28	-

CD: 0.566

SE(m): 0.187

CV: 24.974

**Fig 1:** Pooled larval population during Kharif 2022**Fig 2:** Grain yield during Kharif 2022

Economics of insecticidal treatments during Kharif 2022

Economic evaluation of different insecticidal treatments against *Spodoptera frugiperda* during Kharif 2022 revealed substantial variation in profitability among the treatments. The differences in economic returns were primarily associated with variation in larval suppression efficiency and consequent grain yield improvement. Chlorantraniliprole-based treatments proved more remunerative than other insecticidal schedules due to their superior bio-efficacy against fall armyworm.

Among all treatments, T₄ [seed treatment with cyantraniliprole 19.8% + thiamethoxam 19.8% FS followed by chlorantraniliprole 18.5 SC @ 40 g a.i. ha⁻¹] recorded the highest grain yield (6.32 t ha⁻¹), gross return (₹94,800 ha⁻¹) and net return (₹55,928 ha⁻¹) with maximum benefit-cost ratio (2.44). The higher profitability of T₄ may be attributed to effective suppression of larval population throughout the crop growth period, resulting in reduced foliar and whorl damage and better grain development. T₂ also performed exceptionally well and recorded net return of ₹53,055 ha⁻¹

with B:C ratio of 2.39, indicating that chlorantraniliprole + lambda-cyhalothrin combination was also economically viable under field conditions.

Treatments T₅ and T₈ generated comparatively higher economic returns with B:C ratios of 2.27 and 2.15, respectively, due to moderate-to-high suppression of fall armyworm infestation and corresponding yield improvement. Although treatments T₆ and T₇ reduced larval population compared with untreated control, their economic returns were comparatively lower because of reduced efficacy and lower grain yield realization.

The untreated control (T₉) recorded the lowest grain yield (3.28 t ha⁻¹), gross return (₹49,200 ha⁻¹) and net return (₹15,344 ha⁻¹), which clearly indicated the severe economic loss caused by unchecked fall armyworm infestation. The lower profitability under untreated plots emphasized the importance of timely insecticidal intervention for minimizing yield loss and improving economic returns in maize cultivation.

Table 2: Detailed economics of insecticidal treatments during Kharif 2022

Treatment	Cost of cultivation (₹ ha ⁻¹)	Cost of treatment (₹ ha ⁻¹)	Total cost (₹ ha ⁻¹)	Grain yield (t ha ⁻¹)	Gross return (₹ ha ⁻¹)	Net return (₹ ha ⁻¹)	B:C ratio
T ₁	34,997	5,000	39,997	4.147	62,250	22,253	1.56
T ₂	35,145	3,000	38,145	6.08	91,200	53,055	2.39
T ₃	35,442	2,500	37,942	4.913	73,650	35,708	1.94
T ₄	35,372	3,500	38,872	6.32	94,800	55,928	2.44
T ₅	35,060	2,000	37,060	5.60	84,000	46,940	2.27
T ₆	35,279	3,500	38,779	4.26	63,900	25,121	1.65
T ₇	35,372	3,000	38,372	3.943	59,100	20,728	1.54
T ₈	35,232	2,500	37,732	5.413	81,150	43,418	2.15
T ₉	33,856	-	33,856	3.28	49,200	15,344	-

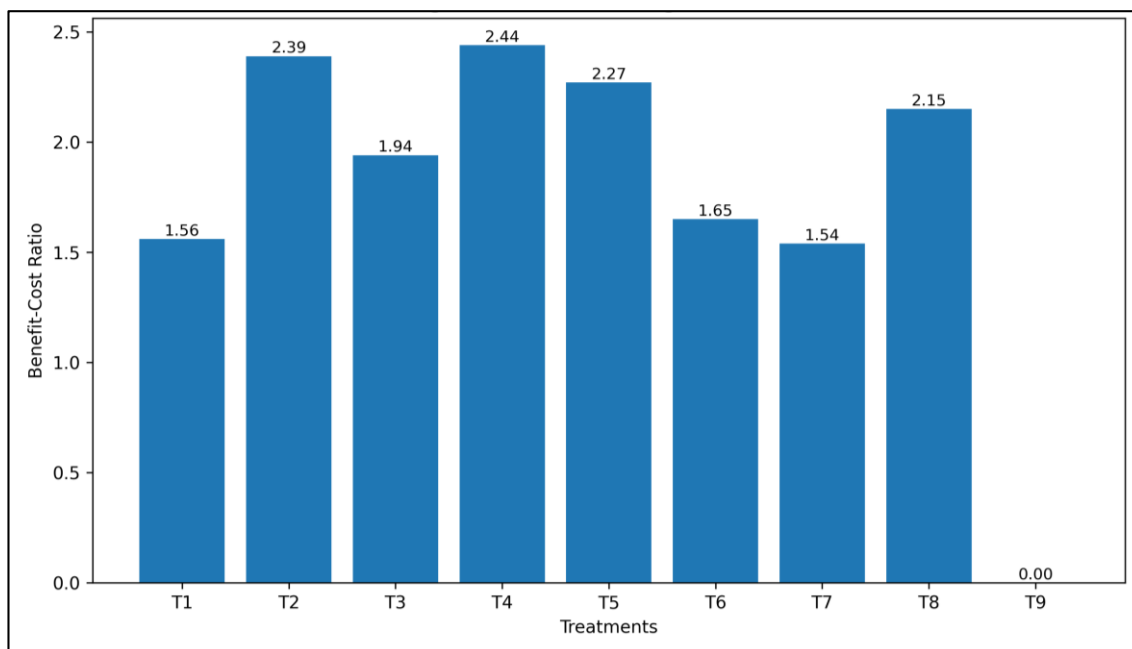


Fig 3: Benefit-cost ratio during Kharif 2022

Bio-efficacy of insecticides against *Spodoptera frugiperda* during Kharif 2023

The efficacy pattern observed during Kharif 2023 was largely comparable to that recorded during the previous season. All insecticidal treatments significantly suppressed fall armyworm infestation compared with untreated control. Among the treatments, T₄ again proved most effective and

recorded minimum larval population after each spray application.

After the first spray, T₄ recorded the lowest larval population (0.567 larvae plant⁻¹), followed by T₂ (0.710 larvae plant⁻¹), whereas untreated control recorded significantly higher infestation (4.067 larvae plant⁻¹). Treatments T₅ and T₈ also performed effectively by

recording lower larval population compared with other treatments. The statistical analysis indicated significant treatment variation with CD value of 0.477, SE(m) of 0.158 and CV of 19.58%.

Following the second and third sprays, chlorantraniliprole-based treatments continued to maintain superior efficacy. T₄ recorded 0.443 and 0.303 larvae plant⁻¹ after second and third sprays, respectively. Untreated control consistently recorded highest larval population throughout the observation period. The reduction in larval population under chlorantraniliprole-based treatments suggested prolonged residual effect and improved field persistence.

The pooled cumulative efficacy revealed that T₄ recorded the minimum overall larval population (0.437 larvae plant⁻¹), followed by T₂ (0.577 larvae plant⁻¹), whereas untreated control maintained highest pooled infestation (3.427 larvae plant⁻¹). T₄ achieved maximum reduction over control (87.24%) followed by T₂ (83.14%). Grain yield was also highest under T₄ (5.72 t ha⁻¹), followed by T₂ (5.43 t ha⁻¹), while untreated control recorded only 3.02 t ha⁻¹. The highest percent increase in yield over control was observed in T₄ (89.40%).

Table 3: Detailed cumulative efficacy of insecticides against fall armyworm during Kharif 2023

Treatment	Mean larval population after 1st spray	Mean larval population after 2nd spray	Mean larval population after 3rd spray	Overall pooled larval population	Reduction over control (%)	Yield (t ha ⁻¹)	Yield increase over control (%)
T ₁	1.933	1.867	1.787	1.863	45.62	3.93	30.23
T ₂	0.710	0.600	0.423	0.577	83.14	5.43	79.80
T ₃	1.357	1.133	1.153	1.217	64.54	4.73	56.62
T ₄	0.567	0.443	0.303	0.437	87.24	5.72	89.40
T ₅	1.100	0.780	0.790	0.890	74.05	5.29	75.17
T ₆	1.443	1.480	1.470	1.467	57.19	4.113	36.19
T ₇	1.710	1.637	1.623	1.653	51.68	3.767	24.74
T ₈	1.220	0.920	0.933	1.023	70.05	4.88	61.59
T ₉	4.067	3.767	2.447	3.427	0.00	3.02	-

CD: 0.477

SE(m): 0.158

CV: 19.58

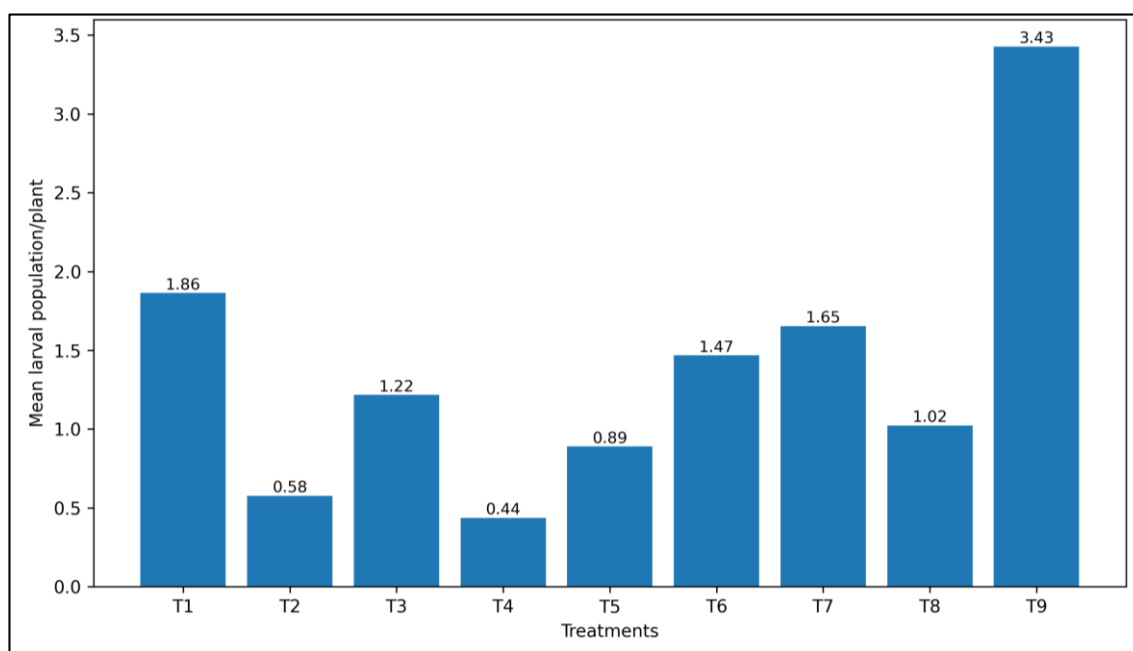


Fig 4: Pooled larval population during Kharif 2023

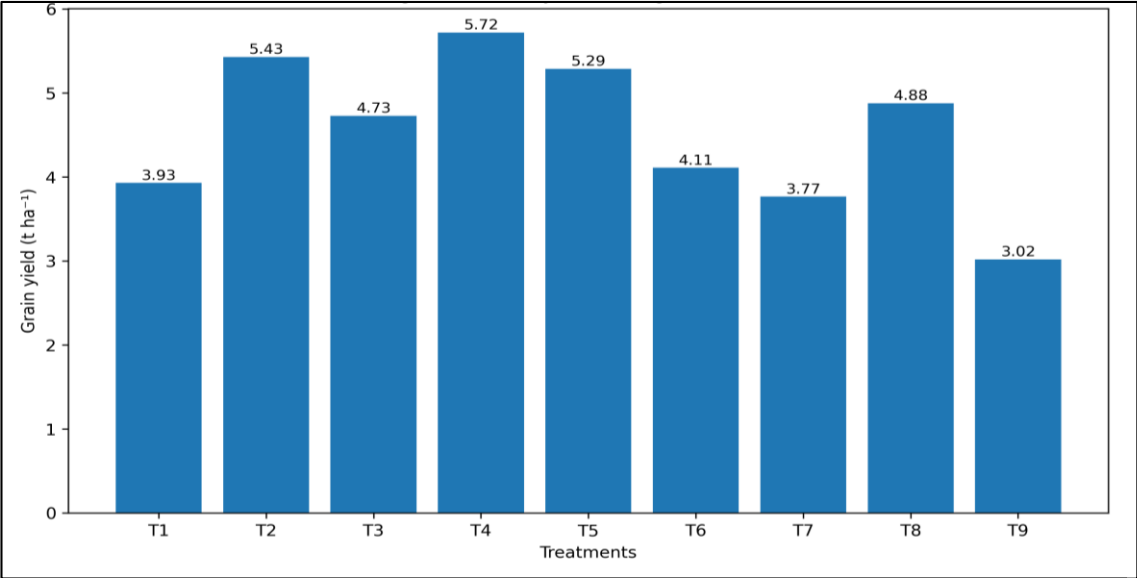


Fig 5: Grain yield during Kharif 2023

Economics of insecticidal treatments during Kharif 2023

Economic analysis during Kharif 2023 revealed marked differences among insecticidal treatments in terms of profitability and benefit-cost ratio. Among all treatments, T₄ recorded the highest gross return (₹85,800 ha⁻¹) and net return (₹46,928 ha⁻¹), followed by T₂ with gross return of ₹81,450 ha⁻¹ and net return of ₹43,305 ha⁻¹. The highest benefit-cost ratio was recorded under T₄ (2.21), followed by T₂ and T₅ (2.14 each).

The superior economic performance of chlorantraniliprole-based treatments may be attributed to effective suppression of larval population, reduced crop damage and consequent enhancement in grain yield. Treatments T₅ and T₈ also generated comparatively higher economic returns owing to moderate-to-high efficacy against fall armyworm. In contrast, untreated control recorded the lowest gross return (₹45,300 ha⁻¹) and net return (₹11,444 ha⁻¹) due to severe pest infestation and substantial yield loss.

Table 4: Detailed economics of insecticidal treatments during Kharif 2023

Treatment	Cost of cultivation (₹ ha ⁻¹)	Cost of treatment (₹ ha ⁻¹)	Total cost (₹ ha ⁻¹)	Grain yield (t ha ⁻¹)	Gross return (₹ ha ⁻¹)	Net return (₹ ha ⁻¹)	B:C ratio
T ₁	35,997	4,000	39,997	3.93	58,950	18,953	1.47
T ₂	35,145	3,000	38,145	5.43	81,450	43,305	2.14
T ₃	35,472	2,500	37,972	4.73	70,950	32,978	1.87
T ₄	35,372	3,500	38,872	5.72	85,800	46,928	2.21
T ₅	35,060	2,000	37,060	5.29	79,350	42,290	2.14
T ₆	35,279	3,500	38,779	4.113	61,650	22,871	1.59
T ₇	35,372	3,000	38,372	3.767	56,550	18,178	1.47
T ₈	35,232	2,500	37,732	4.88	73,200	35,468	1.94
T ₉	33,856	-	33,856	3.02	45,300	11,444	-

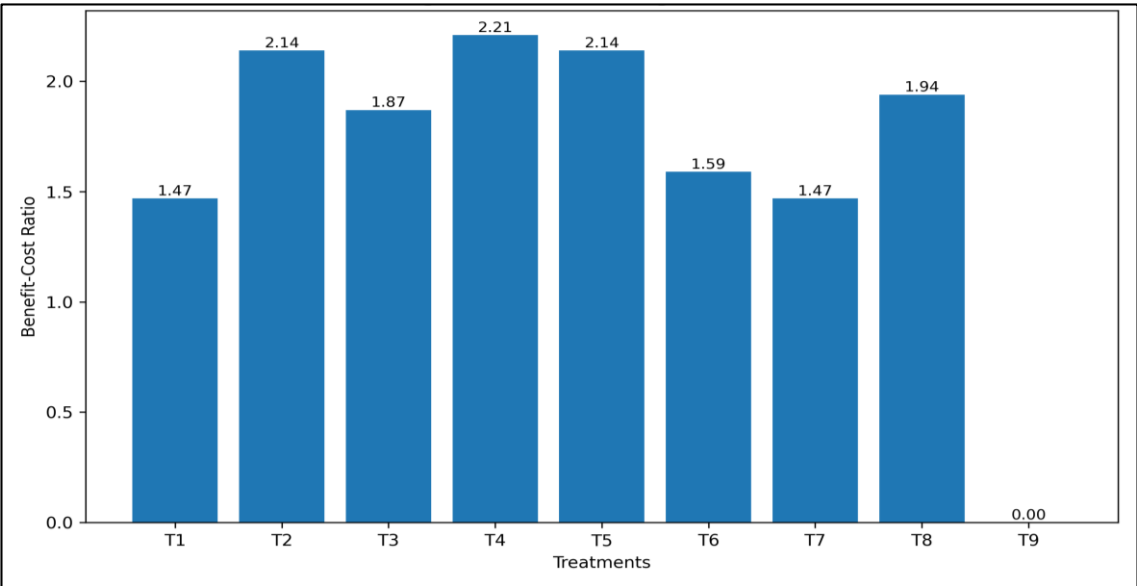


Fig 6: Benefit-cost ratio during Kharif 2023

Discussion

The present investigation clearly demonstrated significant variation in the efficacy of newer insecticidal molecules against *Spodoptera frugiperda* under maize ecosystem during Kharif 2022 and 2023. Among the evaluated treatments, chlorantraniliprole-based schedules consistently provided superior suppression of larval population, higher grain yield and better economic returns compared with other treatments. The pooled results indicated that T₄ [seed treatment with cyantraniliprole 19.8% + thiamethoxam 19.8% FS followed by chlorantraniliprole 18.5 SC @ 40 g a.i. ha⁻¹] was the most effective treatment during both cropping seasons.

The significantly lower larval population observed under T₄ and T₂ may be attributed to the unique mode of action of chlorantraniliprole, which activates ryanodine receptors causing rapid muscular paralysis and feeding cessation in lepidopteran larvae. The prolonged residual activity and translaminar movement of chlorantraniliprole also contributed to sustained suppression of fall armyworm population throughout the crop growth period. Similar observations were reported by Mallapur *et al.* (2019) [9], Deshmukh *et al.* (2020) [4] and Ramesh *et al.* (2023) [11], who observed excellent efficacy of chlorantraniliprole-based insecticides against *S. frugiperda* in maize.

The higher grain yield recorded under chlorantraniliprole-based treatments was directly associated with effective reduction in foliar and whorl damage caused by fall armyworm infestation. Treatments T₄ and T₂ maintained larval population below economic threshold level and thereby ensured better crop growth, photosynthetic activity and grain filling. In contrast, untreated control recorded severe infestation and substantial reduction in grain yield due to uninterrupted feeding damage. Similar relationships between effective pest suppression and yield enhancement have been documented earlier by Fand *et al.* (2019) [5] and Rakholiya *et al.* (2024) [10].

Economic analysis further established the superiority of chlorantraniliprole-based treatments. T₄ consistently recorded maximum gross return, net return and benefit-cost ratio during both seasons. The higher profitability under T₄ was mainly due to greater yield realization and effective suppression of fall armyworm infestation despite comparatively higher treatment cost. T₂ also recorded superior economic returns owing to effective control and lower crop loss. Treatments involving emamectin benzoate and novaluron combinations produced moderate economic returns because of comparatively lower efficacy against the pest. Untreated control recorded lowest profitability, emphasizing the economic importance of timely management of fall armyworm in maize ecosystem. Similar findings regarding economic superiority of chlorantraniliprole-based insecticides have also been reported by Deshmukh *et al.* (2020) [4], Ramesh *et al.* (2023) [11] and Rakholiya *et al.* (2024) [10].

Overall, the present findings clearly indicated that chlorantraniliprole-based management modules are highly effective and economically feasible for sustainable management of fall armyworm under Bihar agro-climatic conditions. The consistency of treatment performance across two consecutive years further confirmed their suitability for incorporation into integrated pest management programmes against *S. frugiperda*.

Conclusion

The present study demonstrated that newer insecticidal molecules differed significantly in their effectiveness against fall armyworm on maize during Kharif 2022 and 2023. Among all treatments evaluated, T₄ [seed treatment with cyantraniliprole 19.8% + thiamethoxam 19.8% FS followed by chlorantraniliprole 18.5 SC @ 40 g a.i. ha⁻¹] proved most effective by consistently recording minimum larval population, highest reduction over untreated control and maximum grain yield during both seasons. The treatment also generated highest net returns and benefit-cost ratio, indicating superior economic feasibility.

Chlorantraniliprole-based treatments effectively maintained fall armyworm population below economic threshold level owing to their rapid feeding cessation, prolonged residual activity and strong larvicidal action. The study further established that timely application of chlorantraniliprole-based insecticides can substantially reduce crop damage and improve maize productivity under Bihar conditions. Therefore, chlorantraniliprole-based management modules may be recommended as an important component of integrated pest management strategies for sustainable control of *Spodoptera frugiperda* in maize ecosystem.

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