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Field efficacy of different insecticides against leaf-eating caterpillar *Spodoptera litura* infesting Soybean

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Abstract
The investigation conducted at Polytechnic in Agriculture, Junagadh Agricultural University, Dhari (Gujarat) during the *kharif* seasons of 2021 and 2022 aimed to assess the field efficacy of various insecticides against the leaf-eating caterpillar *Spodoptera litura* Fabricius infesting soybean. Eight different chemical insecticides were tested during the *kharif* seasons of 2021 and 2022. The results revealed varying mortality levels among the tested insecticides. The highest percentage of mortality was observed in the treatment of chlorantraniliprole + lambda-cyhalothrin 0.075% (83.55%), followed by emamectin benzoate + lufenuron 0.0135% (80.03%), and novaluron + emamectin benzoate 0.0024% (77.66%). respectively, the lowest mortality was recorded in the treatment of quinalphos 0.050% (59.99%), which was statistically comparable to flubendiamide + thiacloprid 0.02% (62.44%). The highest yield of soybean (2510.41 kg/ha) was obtained from the plots treated with chlorantraniliprole + lambda-cyhalothrin 0.075%. This indicates the effectiveness of this particular insecticide combination in enhancing crop productivity. The treatment with emamectin benzoate + lufenuron 0.0135% resulted in the lowest avoidable loss in soybean yield (6.95%), while the treatment with quinalphos 0.050% had the highest avoidable loss (41.42%). The maximum increase in yield over the control was observed in the plots treated with chlorantraniliprole + lambda-cyhalothrin 0.075% (148.06%), followed by emamectin benzoate + lufenuron 0.0135% (130.83%). The treatment of chlorantraniliprole + lambda-cyhalothrin 0.075% resulted in the highest net realization (Rs. 76419/ha), followed by emamectin benzoate + lufenuron 0.0135% (Rs. 67526/ha). This indicates not only high yield but also economic viability.

Keywords: Leaf-eating caterpillar, *Spodoptera litura*, field efficacy, insecticides, yield

Introduction

Soybean (*Glycine max* (L.) Merrill) holds significant importance in India's agricultural landscape, being recognized as a crucial oilseed cash crop. Its nutritional richness has earned it several epithets such as the "Miracle bean," "Golden bean," and "Crop of the planet." This crop is renowned for its balanced composition, offering various essential nutrients. For instance, it contains 40% protein, which encompasses a well-balanced array of essential amino acids. Additionally, soybean provides around 20% oil, which is particularly rich in polyunsaturated fats, including Omega 6 and Omega 5 fatty acids. Moreover, it contains approximately 6-7% total minerals, 5-6% crude fibre, and 17-19% carbohydrates (Chauhan and Joshi, 2005) [4]. Soybean, also referred to as Soja bean, Soya bean, Chinese pea, and Manchurian bean, belongs to the family Fabaceae and the sub-family Faboideae, having originated in Eastern Asia. Introduced to India during the 1870s-1880s, soybean cultivation has become a notable success story within the Indian agricultural sector. Its adaptability and nutritional richness have contributed to its widespread cultivation and recognition as a valuable cash crop.

In the agricultural sector of India, soybean plays a crucial role, occupying a total area of 121.76 lakh hectares and yielding 127.20 lakh tons in 2019-20. The national average yield stands at 1258 kg per hectare. Soybean constitutes 42% of India's total oilseeds production and contributes to 25% of the country's total edible oil production. Leading soybean-producing states include Madhya Pradesh, Maharashtra, Rajasthan, Gujarat, Telangana, Chhattisgarh, and Karnataka (Anonymous, 2022) [2].

To mitigate the yield losses caused by the destructive pest, efforts are required to encourage soybean cultivation on a large scale and to enhance production and productivity, particularly in India and Gujarat. Addressing this challenge involves effectively managing the pests infesting soybean crops. In this regard, the efficacy of various insecticides against *S. litura*, a prevalent pest, was evaluated through field experiments during the *kharif* seasons of 2021 and 2022. The results of these experiments are outlined and discussed herein. Periodical data on pest population was recorded at intervals of 3, 7, and 10 days after each spray application. The data was pooled over the periods of each spray and across the years. Before the application of sprays, *S. litura* population was found to be homogeneous across all treatments, as indicated by non-significant differences in treatment effects in both experimentation years. Furthermore, all insecticidal treatments demonstrated significant reductions in *S. litura* population compared to the control group for up to 10 days post-spray application. This effect was observed in both individual years and when data was pooled over spray periods and across years. These findings highlight the effectiveness of the evaluated insecticides in controlling *S. litura* infestation in soybean crops, thus offering promising solutions to mitigate pest-related yield losses and promote sustainable soybean cultivation practices.

Materials and Methods

Experimental materials and design

The study was conducted at the Agricultural Farm of Polytechnic in Agriculture, Junagadh Agricultural University, located in Dhari, Gujarat. The GJS 3 variety of soybean was chosen for cultivation in this research. The field experiment followed a Randomized Block Design (RBD) with three replications of nine treatments, as detailed in Table 1. Each plot had a gross size of 3.0 x 2.7 meters and a net size of 2.4 x 1.8 meters. Soybean crops were sown with a spacing of 45 cm x 10 cm. The experimental fields received fertilizers at recommended doses to support crop growth and development.

Table 1: Treatment Details of insecticides used against *S. litura* infesting soybean

Tr. No.	Name of insecticides	Trade name and formulation	Conc. (%)	Dose (g or ml/ liter of water)	Source
T_1	Emamectin Benzoate 01.50% + Fipronil 03.50% SC	APEX - 50	0.0063	1.25	Crystal Crop Protection Ltd
T_2	Novaluron 5.25% + Indoxacarb 4.5% SC	Plethora 9.75 SC	0.0171	1.75	ADAMA India Private Limited
T_3	Chlorantraniliprole 4.3% + Abamectin 1.7% SC	Voliam Targo 6 SC	0.063	1.00	Syngenta India Ltd.
T_4	Emamectin Benzoate 5% w/w + Lufenuron 40%w/w WG	Evicent	0.0135	0.30	Syngenta India Ltd.
T_5	Flubendiamide 19.92% + Thiacloprid 19.92% w/w SC	Belt Expert 480 SC	0.0199	0.50	M/S. Bayer India Ltd.
T_6	Novaluron 5.25% + Emamectin benzoate 0.9% SC	MEDAD	0.0024	1.75	Parijat Industries India Pvt. Ltd.
T_7	Chlorantraniliprole 10% +Lambda-Cyhalothrin 5% ZC	Ampligo 15 ZC	0.075	0.50	Syngenta India Ltd.
T_8	Quinalphos 25.00% EC	Celquin 25.00% EC	0.050	2.00	Sumitomo Chemical India Ltd
T_9	Control (unsprayed)	-	-	-	-

Application of treatment

All recommended agronomical practices were meticulously followed throughout the experiment. The insecticides were applied at specified doses twice during the soybean growth cycle: first at the 50 percent flowering stage and then at the 50 percent pod formation stage. Each application utilized 500 liters of water per hectare. The spraying of pesticides was carried out using a knapsack sprayer during the evening hours to ensure optimal effectiveness. To prevent contamination between treatments, strict precautions were taken. The sprayer was thoroughly cleaned before and after each application using soap water. This meticulous cleaning process helped maintain the integrity of the treatments and minimize any potential interference or cross-contamination.

Observation

The number of larvae was assessed by counting them on five randomly selected and tagged plants within each plot. These counts were conducted 24 hours before and at intervals of 3, 7, and 10 days after each spray application throughout both years of experimentation.

$$\text{Corrected percent mortality} = 100 \text{ x } \left(1 - \frac{T_a \text{ x } C_b}{T_b \text{ x } C_a}\right)$$

Where,

T_b = No. of larva observed before treatment.

T_a = No. of larva observed after treatment.

C_b = No. of larva observed before treatment in control plot.

C_a = No. of larva observed after treatment in control plot.

To evaluate the efficacy of the insecticides, the collected data was converted into percentage mortality using a formula originally proposed by Abbott (1925) [1] and subsequently modified by Henderson and Tilton (1955) [6]. This data transformation facilitated statistical analysis to assess the impact of insecticidal treatments on larval populations over time.

The statistical analysis of the collected data was conducted using analysis of variance (ANOVA) techniques, following the methodology outlined by Panse and Sukhatme (1985) [7].

Yield, increase in yield over control, avoidable losses, and economics

Yield

Yield serves as a crucial criterion for assessing the effectiveness of various treatments. To evaluate yield, the soybean crop was harvested at the appropriate maturity stages the last week of October 2021 and the second week of September 2022. Following harvest, seeds were separated from soybean plants within each net plot area, and their weights were recorded for each treatment.

To determine the seed yield in kilograms per hectare for each treatment, the harvested seed weights were aggregated and adjusted based on the plot size. Subsequently, standard statistical techniques, likely including those outlined by Steel and Torrie (1980) [12], were employed for data analysis and interpretation.

The percent increase in yield over control

To calculate the percent increase in yield over the control, the following formula can be used/

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

Where
T = Yield of respective treatment (kg/ha), C = Yield of control (kg/ha)

Avoidable losses
To calculate the avoidable losses due to insect pests' infestation, the formula proposed by Poul (1976) [9] can be utilized. The formula is as follows:

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

Economics
To determine the economics of different treatments evaluated against insect pests infesting soybean, an Incremental Cost-Benefit Ratio (ICBR) was calculated. Here's the step-by-step process for calculating ICBR:

Total Cost of Treatment per Hectare: Calculate the total cost of treatment per hectare for each treatment based on prevailing market prices. This includes the cost of insecticides, labor, equipment, and any other inputs used in the treatment process.

Increase in Yield over Control
Calculate the increase in yield over the control treatment by subtracting the yield obtained in the control treatment from the yield obtained in each insecticidal treatment.

Gross Realization over Control
Determine the gross realization over control for each treatment based on the increased yield (in kilograms per hectare) over control. This is the value of the increased yield in monetary terms, considering the prevailing market price of soybean.

Net Gain per Hectare
Compute the net gain (in rupees per hectare) for each treatment by subtracting the total cost of treatment from the gross realization value over control. This represents the profit generated by each treatment after accounting for the costs involved.

Incremental cost-benefit ratio (ICBR)
Calculate the ICBR for each treatment by dividing the net gain by the total cost of treatment. This provides a measure of the return on investment for each rupee spent on insecticidal treatment.
The gross ICBR values obtained through this calculation indicate the economic viability of each treatment option in terms of the net gain generated per unit cost of insecticidal treatment. Higher ICBR values suggest more economically favourable treatments.

Results and Discussion
Investigations were conducted to assess the efficacy of various insecticides against *S. litura* in soybean fields during the *kharif* seasons of both 2021 and 2022. A total of eight insecticides were tested in these field experiments. The outcomes of these trials are detailed and analyzed below.

First year
When analyzing the results pooled over the first spray periods (Table 2), it was observed that chlorantraniliprole + lambda-cyhalothrin exhibited the highest mortality rate of *S. litura* at 82.50%, which was comparable to the effectiveness of emamectin benzoate + lufenuron at 75.65%. Additionally, emamectin benzoate + lufenuron showed comparable effectiveness to novaluron + emamectin benzoate, resulting in mortalities of 75.65% and 73.11%, respectively. On the other hand, treatments involving novaluron + indoxacarb, chlorantraniliprole + abamectin, emamectin benzoate + fipronil, and flubendiamide + thiacloprid demonstrated comparatively lower efficacy, with mortalities ranging from 67.18% to 59.44%. The least effective treatment, with the lowest mortality rate, was observed with quinalphos at 58.63%.
Similarly, when considering the results pooled over the second spray periods, chlorantraniliprole + lambda-cyhalothrin exhibited the highest mortality rate of *S. litura* at 81.75%, followed closely by emamectin benzoate + lufenuron at 79.77% and novaluron + emamectin benzoate at 77.12%. Again, treatments involving novaluron + indoxacarb, chlorantraniliprole + abamectin, emamectin benzoate + fipronil, and flubendiamide + thiacloprid showed lower efficacy compared to the superior treatments, with mortalities ranging from 71.39% to 62.72%. The least effective treatment, with the lowest mortality rate, was observed with quinalphos at 61.73%.
When examining the pooled data across spray periods in 2021, it became evident that chlorantraniliprole + lambda-cyhalothrin exhibited the highest effectiveness, with a mortality rate of 82.13%. This efficacy was on par with that of emamectin benzoate + lufenuron, which resulted in a mortality rate of 77.71%. Similarly, emamectin benzoate + lufenuron showed comparable effectiveness to novaluron + emamectin benzoate, achieving mortality rates of 77.71% and 75.11%, respectively. These treatments demonstrated significant superiority over all other tested insecticides. On the other hand, novaluron + indoxacarb and chlorantraniliprole + abamectin were identified as moderately effective treatments, with mortality rates of 69.29% and 67.07%, respectively. These were comparable to the effectiveness of emamectin benzoate + fipronil (64.77%) and flubendiamide + thiacloprid (61.08%). The least effective treatment, with the lowest mortality rate, was observed with quinalphos at 60.18%.

Table 2: Bio-efficacy of insecticides against *S. litura* infesting Soybean during *kharif*, 2021

Tr. No.	Treatments	Conc. (%)	Percent mortality of *S. litura* after first spray				Percent mortality of *S. litura* after second spray				Pooled over period over spray
			3 DAS	7 DAS	10 DAS	Pooled over period	3 DAS	7 DAS	10 DAS	Pooled over period	
T_1	Emamectin Benzoate 01.50% + Fipronil 03.50% SC	0.0063	50.22bc (59.06)	56.30cd (69.22)	50.32cd (59.24)	52.28d (62.51)	52.87bc (63.57)	60.57bc (75.86)	51.74bc (61.66)	55.06cd (67.03)	53.67de (64.77)
T_2	Novaluron 5.25% + Indoxacarb 4.5% SC	0.0171	52.41bc (62.79)	59.34bcd (74.00)	53.58bcd (64.76)	55.11cd (67.18)	55.13bc (67.31)	63.92abc (80.67)	54.45abc (66.19)	57.83bc (71.39)	56.47cd (69.29)
T_3	Chlorantraniliprole 4.3% + Abamectin 1.7% SC	0.063	51.20bc (60.73)	58.34bcd (71.96)	52.53bcd (62.70)	53.86cd (65.13)	53.89bc (65.26)	62.45bc (78.61)	52.62abc (63.14)	56.32bcd (69.00)	55.09de (67.07)
T_4	Emamectin Benzoate 5% w/w + Lufenuron 40%w/w WG	0.0135	57.27ab (70.76)	65.99ab (83.45)	58.53ab (72.74)	60.60ab (75.65)	60.19ab (75.29)	72.38ab (90.84)	58.80ab (73.17)	63.79a (79.77)	62.19ab (77.71)
T_5	Flubendiamide 19.92% + Thiacloprid 19.92% w/w SC	0.0199	47.44c (54.26)	55.62cd (68.12)	48.41d (55.94)	50.49d (59.44)	50.06c (58.79)	58.55c (72.77)	48.79c (56.60)	52.47cd (62.72)	51.48e (61.08)
T_6	Novaluron 5.25% + Emamectin benzoate 0.9% SC	0.0024	55.43ab (67.81)	64.69abc (81.72)	56.66abc (69.80)	58.93bc (73.11)	58.26ab (72.32)	69.86ab (88.15)	57.34ab (70.88)	61.82ab (77.12)	60.37bc (75.11)
T_7	Chlorantraniliprole 10% + Lambda-Cyhalothrin 5% ZC	0.075	61.72a (77.55)	72.73a (91.19)	62.56a (78.77)	65.67a (82.50)	62.06a (78.04)	74.20a (92.59)	59.74a (74.61)	65.33a (81.75)	65.50a (82.13)
T_8	Quinalphos 25.00% EC	0.050	46.82c (53.18)	54.91d (66.95)	48.39d (55.76)	50.21d (58.96)	50.01c (58.70)	56.17c (69.00)	49.31c (57.50)	51.83d (61.73)	50.92e (60.18)
T_9	Control (unsprayed)	-	-	-	-	-	-	-	-	-	-
S.Em. + T			2.43	3.07	2.56	1.55	2.49	-	-	1.64	1.13
P			-	-	-	0.95	-	-	-	1.00	0.98
T x P			-	-	-	2.70	-	-	-	2.85	2.78
C.D. at 5% T			7.37	9.31	7.77	5.43	7.57	10.29	7.86	5.68	4.18
P			-	-	-	2.71	-	-	-	2.86	2.75
T x P			-	-	-	7.67	-	-	-	8.11	7.78
C. V.%			10.34	10.05	11.46	10.61	10.22	10.53	10.99	10.68	10.65

* Arcsine transformed value & Figures in parentheses are retransformed value, DAS- Days after spraying

Second year

Pooling the data over the first spray periods from Table 3 revealed that chlorantraniliprole + lambda-cyhalothrin achieved the highest mortality rate of *S. litura* at 82.09%, which was comparable to the effectiveness of emamectin benzoate + lufenuron (79.52%) and novaluron + emamectin benzoate (76.84%). Conversely, treatments involving novaluron + indoxacarb, chlorantraniliprole + abamectin, emamectin benzoate + fipronil, and flubendiamide + thiacloprid demonstrated comparatively lower efficacy, with mortalities ranging from 70.39% to 62.60%. The least effective treatment was observed with quinalphos, resulting in a mortality rate of 60.44%.

Similarly, pooling the data over the second spray periods for 2022 showed that chlorantraniliprole + lambda-cyhalothrin achieved the highest mortality rate of *S. litura* at 87.86%, followed by emamectin benzoate + lufenuron (85.17%) and novaluron + emamectin benzoate (83.57%), which were comparable in effectiveness. Conversely, treatments involving novaluron + indoxacarb, chlorantraniliprole + abamectin, emamectin benzoate + fipronil, and flubendiamide + thiacloprid demonstrated lower efficacy, with mortalities ranging from 64.99% to 75.69%. The lowest mortality rate was observed with the treatment of quinalphos at 59.17%.

The pooled data over periods over sprays (2022) exposed the higher effectiveness of chlorantraniliprole +lambda-cyhalothrin (84.98) which was at par with emamectin benzoate + lufenuron (82.34) and novaluron +emamectin benzoate (80.25). They were significantly superior to all the tested insecticides. Treatments, novaluron + indoxacarb (73.04) and chlorantraniliprole + abamectin (71.38) were found moderately effective and were at par with emamectin benzoate + fipronil (68.49). Flubendiamide + thiacloprid (63.80) which was less effective and at par with quinalphos (59.81).

Table 3: Bio-efficacy of insecticides against *S. litura* infesting Soybean during *kharif*, 2022

Tr. No.	Treatments	Conc. (%)	Percent mortality of *S. litura* after first spray				Percent mortality of *S. litura* after second spray				Pooled over period over spray
			3 DAS	7 DAS	10 DAS	Pooled over period	3 DAS	7 DAS	10 DAS	Pooled over period	
T_1	Emamectin Benzoate 01.50% + Fipronil 03.50% SC	0.0063	55.22bc (67.46)	59.46d (74.18)	49.19bcd (57.28)	54.62cd (66.31)	55.73bc (68.30)	61.06cde (76.58)	55.01cd (67.11)	57.27cd (70.66)	55.94bc (68.49)
T_2	Novaluron 5.25% + Indoxacarb 4.5% SC	0.0171	57.54abc (71.20)	62.85bcd (79.17)	51.23abcd (60.79)	57.21bc (70.39)	59.18abc (73.75)	65.58bcd (82.91)	57.04abcd (70.40)	60.60bc (75.69)	58.90b (73.04)
T_3	Chlorantraniliprole 4.3% + Abamectin 1.7% SC	0.063	56.26bc (69.15)	62.12cd (78.14)	50.03abcd (58.78)	56.14bc (68.67)	58.27abc (72.34)	64.58bcd (81.57)	55.75bcd (68.33)	59.53cd (74.08)	57.84b (71.38)
T_4	Emamectin Benzoate 5% w/w + Lufenuron 40%w/w WG	0.0135	62.85ab (79.17)	72.16ab (90.61)	56.03ab (68.78)	63.68a (79.52)	65.02ab (82.17)	72.78ab (91.24)	64.96ab (82.09)	67.59a (85.17)	65.63a (82.34)
T_5	Flubendiamide 19.92% + Thiacloprid 19.92% w/w SC	0.0199	52.35c (62.68)	57.38d (70.94)	47.40cd (54.18)	52.37cd (62.60)	52.86c (63.55)	57.06de (70.43)	51.35d (60.99)	53.76de (64.99)	53.07cd (63.80)
T_6	Novaluron 5.25% + Emamectin benzoate 0.9% SC	0.0024	60.80ab (76.20)	69.57abc (87.82)	54.64abc (66.51)	61.67ab (76.84)	62.75ab (79.04)	71.56abc (89.99)	64.66abc (81.68)	66.32ab (83.57)	64.00a (80.21)
T_7	Chlorantraniliprole 10%	0.075	64.11a	75.93a	57.58a	65.87a	67.40a	76.51a	66.27a	70.06a	67.97a

	+Lambda-Cyhalothrin 5% ZC		(80.94)	(94.09)	(71.25)	(82.09)	(85.23)	(94.56)	(83.80)	(87.86)	(84.98)
T8	Quinalphos 25.00% EC	0.050	51.70c (61.58)	55.94d (68.64)	45.64d (51.11)	51.09d (60.44)	49.13c (57.18)	53.15e (64.03)	48.62d (56.30)	50.30e (59.17)	50.70d (59.81)
T9	Control (unsprayed)	-	-	-	-	-	-	-	-	-	-
S.Em. + T			2.41	3.19	2.65	1.64	2.91	3.48	3.21	1.85	1.24
P			-	-	-	1.01	-	-	-	1.13	1.07
T x P			-	-	-	2.85	-	-	-	3.20	3.04
C.D. at 5% T			7.70	9.86	8.03	4.68	8.82	10.54	9.73	6.26	4.47
P			-	-	-	2.87	-	-	-	3.22	3.00
T x P			-	-	-	8.11	-	-	-	9.11	8.50
C. V.%			9.77	11.33	11.98	11.14	10.73	11.07	12.13	11.32	11.26

* Arcsine transformed value & Figures in parentheses are retransformed value, DAS- Days after spraying

Pooled over years

The combined analysis of spray data over the years, as presented in Table 4 and Figure 1, revealed that chlorantraniliprole + lambda-cyhalothrin exhibited the highest mortality rate at 83.55%, followed closely by emamectin benzoate + lufenuron at 80.03% and novaluron + emamectin benzoate at 77.66%. Treatments involving novaluron + indoxacarb (71.16%), chlorantraniliprole + abamectin (69.22%), and emamectin benzoate + fipronil (66.63%) were identified as moderately effective in controlling *S. litura* infestations. Conversely, the lowest mortality rates were observed with quinalphos at 59.99% and flubendiamide + thiacloprid at 62.44%, indicating their relatively lower effectiveness compared to other tested insecticides. The present research trials almost similar with the findings of Spinosad 45 SC 0.025 percent, chlorantraniliprole 20 SC 0.006 percent, thiodicarb 75 WP 0.15 percent, indoxacarb 15.8 EC 0.0029 and flubendiamide 480 SC 0.05 percent were found most effective against *S. litura* in soybean (Vinaykumar *et al*., 2013) [13]. Patil *et al.* (2014) [8] study the evaluation of novel insecticides for the management of *S. litura* infesting soybean. Among these insecticides, chlorantraniliprole 18.5 SC (30 g a, i./ha), methomyl 40 SP (300 g a, i./ha) and spinosad 45 SC (75 g a, i./ha) were found effective in protecting the soybean crop. Chlorantraniliprole provides consistent protection from defoliation to soybean from *S. litura* with a high cost-benefit ratio. Sreedhar (2018) [11] recorded the least seedling damage followed by novaluron 5.25% + emamectin benzoate 0.9% SC @ 0.012% & 0.009%. The seedling damage in the treatments of emamectin benzoate 0.025%, novaluron 5.25% + emamectin benzoate 0.9% SC @ 0.009% & 0.012% and chlorfenapyr 10 SC @ 0.01% were on at par with each other.

Sapekar *et al.* (2020) [10] from Parbhani recorded that flubendiamide 39.35% SC @ 3 ml best insecticide amongst all treatments which gives maximum protection against tobacco leaf eating caterpillar with 0.82 larvae / mrl, and it was followed by Spinosad 45% SC @4 ml, chlorantraniliprole 18.5% SC @ 3 ml and lambda-cyhalothrin 5% CS @ 6 ml respectively.

Biradar *et al.* (2023) [3] found that the Average effect showed significance, the lowest incidence of tobacco leaf-eating caterpillar was recorded in chlorantraniliprole 18.50% SC, followed by Lambda-cyhalothrin 4.6% + chlorantraniliprole 9.3% ZC at par with novaluron 5.25% + emamectin benzoate 0.9% w/w SC, the next best treatments were in order as spinetoram 11.7% SC, lambda-cyhalothrin 5% EC and emamectin benzoate 5% SG.

Table 4: Bio-efficacy of insecticides against *S. litura* infesting soybean

Tr. No.	Treatments	Conc. (%)	Percent mortality of *S. litura*		
			***kharif*, 2021**	***kharif*, 2022**	**Pooled over spray over years**
T1	Emamectin Benzoate 01.50% + Fipronil 03.50% SC	0.0063	53.67de (64.77)	55.94bc (68.49)	54.81cd (66.63)
T2	Novaluron 5.25% + Indoxacarb 4.5% SC	0.0171	56.47cd (69.29)	58.90b (73.04)	57.69c (71.16)
T3	Chlorantraniliprole 4.3% + Abamectin 1.7% SC	0.063	55.09de (67.07)	57.84b (71.38)	56.46c (69.22)
T4	Emamectin Benzoate 5% w/w + Lufenuron 40%w/w WG	0.0135	62.19ab (77.71)	65.63a (82.34)	63.91ab (80.03)
T5	Flubendiamide 19.92% + Thiacloprid 19.92% w/w SC	0.0199	51.48e (61.08)	53.07cd (63.80)	52.27de (62.44)
T6	Novaluron 5.25% + Emamectin benzoate 0.9% SC	0.0024	60.37bc (75.11)	64.00a (80.21)	62.19b (77.66)
T7	Chlorantraniliprole 10% +Lambda-Cyhalothrin 5% ZC	0.075	65.50a (82.13)	67.97a (84.98)	66.73a (83.55)
T8	Quinalphos 25.00% EC	0.050	50.92e (60.18)	50.70d (59.81)	50.81e (59.99)
T9	Control (unsprayed)	-	-	-	-
S.Em. + T			1.13	1.24	0.84
Y			0.98	1.07	1.03
T x Y			2.78	3.04	2.91
C.D. at 5% T			4.18	4.47	3.63
Y			2.75	3.00	2.85
T x Y			7.78	8.50	8.06
C. V.%			10.65	11.26	10.96

* Arcsine transformed value & Figures in parentheses are retransformed value

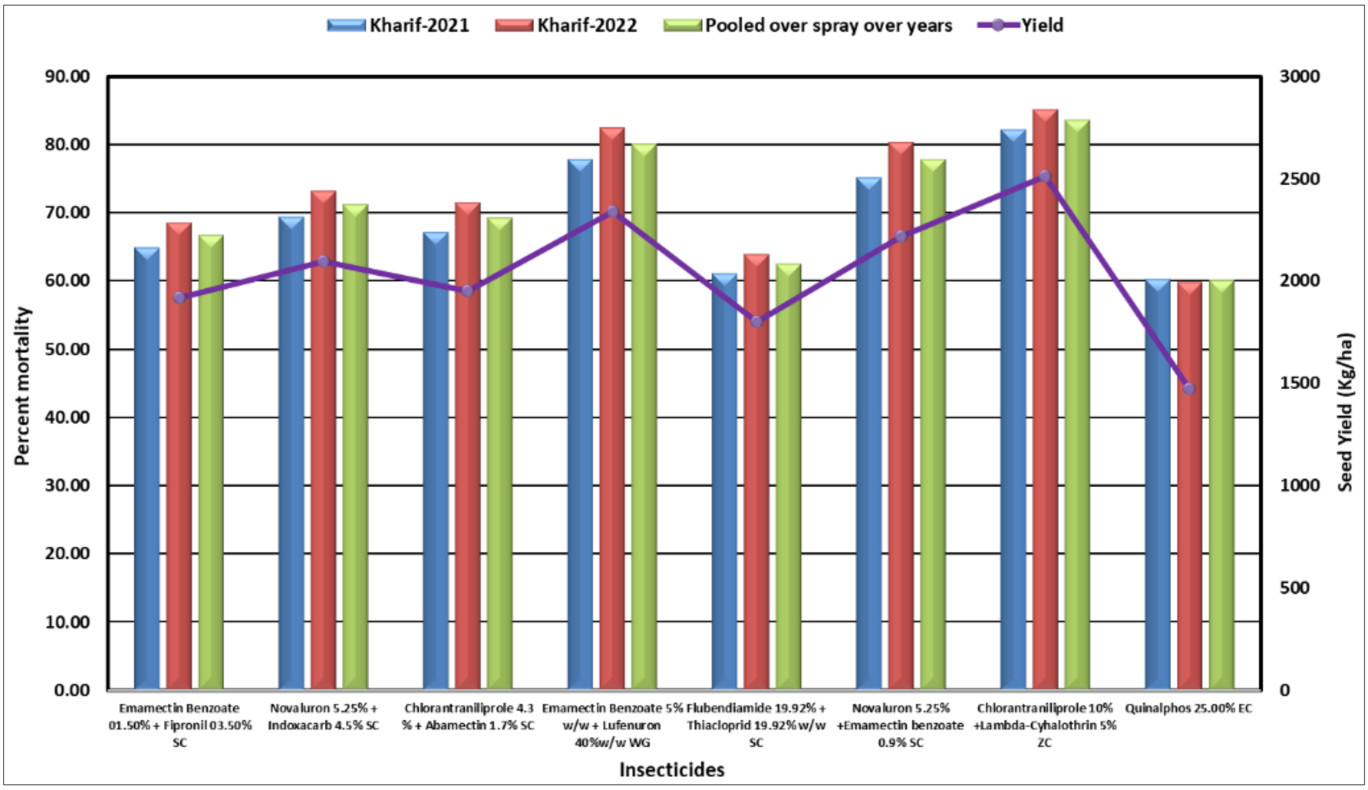

Fig 1: Bio-efficacy of insecticides against *S. litura* infesting soybean

Yield, increase in yield over control, avoidable losses, and economics

Yield

The combined data over the years from the first and second year (Table 5) clearly demonstrated that the highest yield, significantly at 2510.41 kg/ha, was achieved from plots treated with chlorantraniliprole + lambda-cyhalothrin. This yield was on par with yields obtained from plots treated with emamectin benzoate + lufenuron (2336.03 kg/ha), novaluron + emamectin benzoate (2216.05 kg/ha), and novaluron + indoxacarb (2093.75 kg/ha). Plots treated with chlorantraniliprole + abamectin, emamectin benzoate + fipronil, and flubendiamide + thiacloprid produced yields of 1952.16 kg/ha, 1916.66 kg/ha, and 1801.69 kg/ha of soybean, respectively. Comparatively, the lowest yield of 1470.68 kg/ha was recorded in plots treated with quinalphos, which was notably higher than the yield of the untreated control at 1012.00 kg/ha.

Increase in yield

The application of insecticides resulted in a notable increase in yield compared to the control, with the increase ranging from 45.32% to 148.06% (Table 5). The highest increase in seed yield, reaching 148.06%, was observed in plots treated with chlorantraniliprole + lambda-cyhalothrin, followed by emamectin benzoate + lufenuron with a yield increase of 130.83%, novaluron + emamectin benzoate with an increase of 118.98%, and novaluron + indoxacarb with an increase of 106.89%. Additionally, plots treated with chlorantraniliprole + abamectin, emamectin benzoate + fipronil, and flubendiamide + thiacloprid experienced yield increases ranging between 78.03% and 92.90%. Conversely, the lowest increase in yield, at 45.32%, was observed in plots treated with quinalphos.

Avoidable losses

The avoidable loss in soybean yield varied across different treatments, ranging from 6.95% to 59.68% (Table 5). Among the treatments, the lowest avoidable loss of 6.95% was observed in plots treated with emamectin benzoate + lufenuron, followed by novaluron + emamectin benzoate with an avoidable loss of 11.73%, and novaluron + indoxacarb with an avoidable loss of 16.60%. However, the treatments involving chlorantraniliprole + abamectin, emamectin benzoate + fipronil, and flubendiamide + thiacloprid experienced higher avoidable losses ranging from 22.24% to 28.23%. The highest avoidable loss of 41.42% was calculated in plots treated with quinalphos.

Table 5: Impact of insecticides on yield and avoidable loses due to *S. litura* infesting soybean

Tr. No.	Treatments	Conc. (%)	Seed yield (kg/ha)			Increase in yield over control (%)	Avoidable loss (%)
			1st Year *kharif*, 2021	2nd Year *kharif*, 2022	Pooled		
T_1	Emamectin Benzoate 01.50% + Fipronil 03.50% SC	0.0063	1852ab	1981abc	1917bcd	89.39	23.65
T_2	Novaluron 5.25% + Indoxacarb 4.5% SC	0.0171	2068ab	2120abc	2094abc	106.89	16.60
T_3	Chlorantraniliprole 4.3% + Abamectin 1.7% SC	0.063	1883ab	2022abc	1952bcd	92.90	22.24
T_4	Emamectin Benzoate 5% w/w + Lufenuron 40%w/w WG	0.0135	2261a	2411ab	2336ab	130.83	6.95
T_5	Flubendiamide 19.92% + Thiacloprid 19.92% w/w SC	0.0199	1767ab	1836 bc	1802cd	78.03	28.23
T_6	Novaluron 5.25% + Emamectin benzoate 0.9% SC	0.0024	2137ab	2295ab	2216abc	118.98	11.73
T_7	Chlorantraniliprole 10% +Lambda-Cyhalothrin 5% ZC	0.075	2407a	2613a	2510a	148.06	0.00
T_8	Quinalphos 25.00% EC	0.050	1427bc	1514cd	1471de	45.32	41.42

T_9	Control (unsprayed)	-	908c	1116d	1012e	-	59.69
S.Em. + T			259.17	225.51	180.79	-	-
Y			-	-	85.22	-	-
T x Y			-	-	255.68	-	-
C.D. at 5% T			770.03	670.02	513.93	-	-
Y			-	-	242.27	-	-
T x Y			-	-	726.81	-	-
C. V.%			26.86	21.81	23.02	-	-

Economics

The economic evaluation of various insecticides (Table 6) tested against *S. litura* infestations in soybean fields revealed that the highest net realization of Rs 76,419/ha was achieved with chlorantraniliprole + lambda-cyhalothrin. This was followed by emamectin benzoate + lufenuron with Rs 67,526/ha, novaluron + emamectin benzoate with Rs 61,407/ha, and novaluron + indoxacarb with Rs 55,169/ha. The remaining insecticides recorded net realizations ranging between Rs 23,393 to Rs 47,948/ha. Considering the Incremental Cost-Benefit Ratio (ICBR), the highest return of 1:12.71 was obtained with the treatment of chlorantraniliprole + lambda-cyhalothrin, followed by novaluron + emamectin benzoate (1:11.96), emamectin benzoate + fipronil (1:10.15), and quinalphos (1:10.14). The ICBR was calculated as 1:7.74 and 1:6.10 for treatments of novaluron + indoxacarb and flubendiamide + thiacloprid, respectively. Conversely, chlorantraniliprole + abamectin and emamectin benzoate + lufenuron treatments recorded poor ICBRs of 1:3.75 and 1:4.73, respectively. Natikar *et al.* (2016) reported that among the new molecules flubendiamide 480 SC @ 0.2 ml/l was found significantly superior in reducing the larval population and recorded highest grain yield of 2382.00 kg/ha followed by indoxacarb 15.8 EC @ 0.3 ml/l (2217.33 kg/ha) and cyantraniliprole 10 OD @ 0.2 ml/l (2053.33 kg/h). Choudhary and Shrivastava (2007) [5] reported that the application of quinalphos proved to be the most effective in reducing 73.28 percent of the larval population and recorded the highest seed yield (1183.13 kg/ha) at Powarkheda (Madhya Pradesh).

Table 6: Economics of insecticides used for the control of *S. litura* infesting soybean

Insecticides	Conc. (%)	Total quantity of insecticides (Lit or kg/ha)	Cost of insecticides (Rs./ha)	Total Cost of treatment including labour charges (Rs/ha)	Seed yield (kg/ha)	Gross realization (Rs/ha)	Net realization over control (Rs/ha)	Net Profit (Rs/ha)	ICBR
Emamectin Benzoate 01.50% + Fipronil 03.50% SC	0.0063	1.25	3337.50	4137.50	1917	97750	46138	42000	1:10.15
Novaluron 5.25% + Indoxacarb 4.5% SC	0.0171	1.75	5512.50	6312.50	2094	106781	55169	48856	1:7.74
Chlorantraniliprole 4.3% + Abamectin 1.7% SC	0.063	1.00	9300.00	10100.00	1952	99560	47948	37848	1:3.75
Emamectin Benzoate 5% w/w + Lufenuron 40%w/w WG	0.0135	0.30	10987.50	11787.50	2336	119138	67526	55738	1:4.73
Flubendiamide 19.92% + Thiacloprid 19.92% w/w SC	0.0199	0.50	4875.00	5675.00	1802	91886	40274	34599	1:6.10
Novaluron 5.25% + Emamectin benzoate 0.9% SC	0.0024	1.75	3937.50	4737.50	2216	113019	61407	56669	1:11.96
Chlorantraniliprole 10% +Lambda-Cyhalothrin 5% ZC	0.075	0.50	4775.00	5575.00	2510	128031	76419	70844	1:12.71
Quinalphos 25.00% EC	0.050	2.00	1300.00	2100.00	1471	75005	23393	21293	1:10.14
Control (unsprayed)	-	-	-	-	1012	51612	-	-	-

Note: 1. for one spray 500 liter of solution is required per hectare and two sprays were applied during the cropping season
2. Price of soyabean grain: 51 Rs. /kg, Labour charge (Rs/ha) =400/-

Conclusion

The research conducted over two kharif seasons establishes chlorantraniliprole + lambda-cyhalothrin as the standout insecticide against S. litura, showcasing superior efficacy and economic benefits in soybean fields. This combination not only led in mortality rates but also in significantly boosting soybean yields, underlining its potential as a key component in integrated pest management strategies. The economic analysis further highlights its viability, offering the highest net profit and a favorable Incremental Cost-Benefit Ratio. These findings advocate for the strategic inclusion of chlorantraniliprole + lambda-cyhalothrin in pest control practices to optimize soybean production and profitability.

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