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RESEARCH ARTICLE

Assessment of the efficacy of selected botanicals and insecticides against sucking pests, *viz. Bemisia tabaci* (Gennadius), *Empoasca kerri* (Pruthi) and *Caliothrips indicus* (Bagnall) in mungbean

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Abstract

The present investigation was conducted to evaluate the efficacy of various combinations of chemical insecticides and botanical extracts against major sucking pests of mungbean (*Vigna radiata*), namely whitefly (*Bemisia tabaci*), jassid (*Empoasca kerri*) and thrips (*Caliothrips indicus*). This study is the first to systematically assess the performance of integrated treatments combining Imidacloprid, Fipronil and *Emamectin benzoate* with traditional botanicals such as Neem seed kernel extract (NSKE) and *Lantana camara* leaf extract. Botanical extracts were prepared using standard soaking, grinding and filtration methods. Field applications were done using standardized spraying protocols. Observations were recorded a day before spraying and 3, 7 and 15 days after spraying. Data were analysed using analysis of variance and treatment means were compared using Duncan's multiple range test (DMRT) at $p \leq 0.05$. Results revealed that the combined application of Imidacloprid + Fipronil @ 500 g/ha was the most effective in the treatment of all three pest species. It significantly reduced the whitefly, jassid and thrips populations, achieving a maximum reduction of 71.1 %, 66.9 % and 77.5 % respectively, compared to the control. The combination of Imidacloprid + NSKE (T_3) and Imidacloprid + *Lantana camara* leaf extract (T_1) was also notably effective in reducing the number of all types of pests. Other treatments, such as Fipronil + NSKE and *Emamectin benzoate* combinations, showed moderate control. All treatments were effective as compared to the untreated control, though the rate of efficacy varied across various treatments. Benefit-cost ratio analysis supported the economic feasibility of the combination of Imidacloprid + Fipronil at the rate of 500 g/ha. This study supports the use of botanical extracts in combination with conventional insecticides as a potential strategy for effective pest management in mungbean cultivation. NSKE and *Lantana camara* have shown promise as eco-friendly alternatives that can replace or reduce the reliance on chemical pesticides and help minimize environmental pollution. These findings contribute to the development of more sustainable integrated pest management (IPM) strategies in mungbean cultivation and may benefit broader agroecosystems by reducing pesticide dependence and environmental contamination.

Keywords: jassid; *Lantana camara*; mungbean; neem seed kernel extract; thrips; whitefly

Introduction

Mungbean (*Vigna radiata* L. Wilczek) is a short-duration, fast-growing legume crop that is mostly grown in South and Southeast Asia for its soil-enriching properties and high protein seeds. It is grown mainly in rainfed areas of India. India is the world's largest producer and consumer of mung beans. Mungbean cultivation in India is crucial for maintaining food and nutritional security (1, 2). Mungbean is frequently incorporated into multiple cropping systems because of its capacity to fix atmospheric nitrogen, enhance soil health and boost overall productivity (3). However, biotic stresses, particularly insect pests, significantly limit its cultivation. The most significant pests that cause significant economic losses in the production of mungbean are *Caliothrips indicus* (Bagnall), *Empoasca kerri* (Pruthi) and *Bemisia tabaci* (Gennadius) (4, 5). These pests cause leaf curling, chlorosis, stunted growth and decreased pod formation by sucking sap from the phloem tissues. *B. tabaci* also serves as a vector for Mungbean Yellow Mosaic Virus (MYMV), which can reduce yields by up to 85 %. This viral disease is responsible for affecting legumes in South Asia (6, 7). Since synthetic insecticides have rapid knockdown effects, they have been the mainstay of management for these pests. However, persistent and excessive use of chemicals has led to the resurgence of minor pests, the development of insecticide resistance and negative impacts on organisms that are not intended targets, such as pollinators and natural enemies (8, 9). In addition, residue buildup in grains and the environment poses ecological and public health issues (10). Botanical insecticides provide a safer and more environmentally friendly option in this regard. Many bioactivities, such as repellency, oviposition deterrence, feeding inhibition and growth disruption in insect pests, are demonstrated by plant-based products like neem (*Azadirachta indica*), karanj (*Pongamia pinnata*) and garlic extracts (11, 12). Additionally, these botanicals are compatible with IPM strategies, are biodegradable and less harmful to beneficial insects (13, 14). Recent years have seen a focus on combining botanicals with new-generation insecticides, such as spiromesifen, dinotefuran and flonicamid, which have low toxicity to non-target organisms and exhibit distinct modes of action (15, 16). These integrated strategies lessen environmental risks and selection pressure in addition to pest pressure (17). Nevertheless, a search for the most efficient and profitable combinations of these control agents is underway. Field-level testing in various agroclimatic circumstances is required. The goal of the present study was to determine the efficacy of certain botanicals and insecticides in treating three main mungbean sucking pests, viz. *B. tabaci*, *E. kerri* and *C. indicus.* The results of this study focus on achieving sustainable mungbean production using safer pest control methods.

Materials and Methods

Experimental site and design

The field experiment was conducted to evaluate the efficacy of selected new-generation insecticides and botanical extracts against major sucking pests of mungbean. The experimental layout comprised eight treatments, including combinations of chemical insecticides and botanical extracts, with one untreated control. Each treatment was applied to a separate plot in a randomized block design with appropriate replications. The insecticidal solutions were applied using knapsack hand sprayers equipped with cone-type nozzles and spraying was done during morning hours under calm wind conditions to minimize spray drift.

Sampling and observations

Pest population dynamics were monitored by recording the number of whiteflies (*Bemisia tabaci*) and jassids (*Empoasca kerri*) using rectangular split cages, while thrips (*Caliothrips indicus*) were counted visually per 10 randomly selected flowers. Observations were recorded one day before spraying and subsequently at 3, 7 and 15 days after spraying (DAS).

Preparation of botanical extracts

Neem seed kernel extract (NSKE)

Neem seeds were sun-dried and ground into a fine powder using a mortar and pestle. A total of 5 kg of powdered seed was soaked in 10 L of clean water overnight with intermittent stirring. The mixture was then filtered using a clean muslin cloth. The extraction process was repeated 3-4 times to ensure complete extraction. The volume of the extract was adjusted to 100 L by adding water and 0.1 % soap oil was added as a sticker and spreader.

Lantana camara leaf extract

Leaves of *Lantana camara* were collected, shade-dried and crushed into powder form. For preparing a 50 % leaf extract, 250 g of powdered leaves were soaked in 500 mL of water for 24 h. The solution was centrifuged at 4000 rpm for 30 minutes and filtered through a muslin cloth. The final volume was adjusted to 500 mL with water and stored as a stock solution for field application.

Preparation and application of insecticide solutions

The spray solution for each treatment was freshly prepared before application by diluting the required quantity of insecticide formulation in water, making up a final spray volume of 500 L/ha. The active ingredient (a.i.) content was calculated using standard dose determination formulas to ensure accurate field application. The following treatments were evaluated:

T_1: Imidacloprid 17.8 SL @ 20 g a.i./ha + *Lantana camara* leaf extract (5 % w/v)

T_2: Emamectin benzoate 5 SG @ 10 g a.i./ha + NSKE (5 % w/v)

T_3: Imidacloprid 17.8 SL @ 20 g a.i./ha + NSKE (5 % w/v)

T_4: Fipronil 5 SC @ 50 g a.i./ha + NSKE (5 % w/v)

T_5: Fipronil 5 SC @ 50 g a.i./ha + *Lantana camara* leaf extract (5 % w/v)

T_6: Emamectin benzoate 5 SG @ 10 g a.i./ha + *Lantana camara* leaf extract (5 % w/v)

T_7: Imidacloprid 17.8 SL @ 20 g a.i./ha + Fipronil 5 SC @ 50 g a.i./ha

T_8: Untreated control (water spray only)

Estimation of yield

At crop maturity, plants from each treatment plot were harvested and grains were extracted and weighed. The grain yield was expressed in kilograms per hectare (kg/ha) to enable treatment-wise comparison. The experiment was laid out in a Randomized Block Design (RBD) with three replications. Yield data were subjected to Analysis of Variance (ANOVA) to assess the significance of treatment effects on grain yield. All statistical analyses were performed using Microsoft Excel and OPSTAT statistical software (CCS Haryana Agricultural University, Hisar, India).

Benefit-cost ratio (BCR) analysis

For economic evaluation, the Benefit-Cost Ratio (BCR) was calculated for each treatment. The additional return over the untreated control was calculated in Indian rupees and compared against the total cost of insecticidal treatments, including labour and material costs. The BCR provided insights into the economic viability and profitability of each treatment.

Results and Discussion

The results of the present study reveal that the whitefly population before treatment was homogeneous for all the treatments. Treatments were applied at the economic threshold level (ETL) of 4.0 whitefly/plant. At 3 days after spraying (DAS), all treatments significantly decreased the whitefly populations as compared to the control (T_8). The maximum reduction in population (2.1 whiteflies/cage) was recorded in T_7, followed by T_3 and T_1. Treatments T_6, T_5 and T_4 performed well, with populations ranging from 2.9 to 3.1 whiteflies/cage. Treatment T2 proved to be the least effective (3.4 whiteflies/cage) among all the treatments. All treatments proved effective at 7 DAS in comparison to control (Table 1). T_7 again showed the highest efficacy in reducing the pest population (1.6 whiteflies/cage), followed by T_3 (2.1), T_1 (2.6), T_5 and T_4 (2.8-2.9) and T_6 (2.9). T_2 remained the least effective treatment, with 3.3 whiteflies/cage. A similar trend was noted at 15 DAS, where T_7 recorded the lowest population (1.9 whiteflies/cage), proving most effective. T_3, T_1, T_5, T_4 and T_6 followed closely with populations ranging from 2.9 to 3.5 whiteflies/cage. T_2 again recorded the highest population (3.9) as compared to the control. The average population over 3, 7 and 15 DAS confirmed that T_7 (1.9 whiteflies/cage) was significantly effective and helped in achieving a 71.1 % reduction in whitefly population, followed by T_3 (2.5), T_1 (2.8), T_5 (3.0), T_4 and T_6 (3.1) and T_2 (3.5), which showed the least reduction (46.0 %) (Fig. 1). The maximum population was recorded in the control (6.5 whiteflies/cage). Research indicates that imidacloprid, triazophos provide better control of whitefly (18). Research also indicates that thiamethoxam 25 WG and imidacloprid 17.8 SL recorded the lowest population of whitefly (0.80 and 1.16) per trifoliate leaf.

Jassid (*E. kerri*)

No difference was noted in the jassid population before treatment. Treatment given after 3 DAS showed that T_7 proved very effective and reduced the pest population significantly (2.8 jassids/cage). Treatments T_1 (3.1), T_3 (3.4) and T_6 (3.5). T_2 (3.7), T_5 (3.9) and T_4 (4.1) also were able to bring a drastic reduction in pest population. All treatments were superior to the control. At 7 DAS, the minimum jassid population (1.8) was again recorded in T7, followed by T_6 (2.3) and T_3 (2.4) (Table 2). Treatments T_4 (2.9), T_5 (3.1), T_1 (3.2) and T_2 (3.5) were also effective but not to the same extent as T_7. In control maximum population (7.0 jassids/cage) was noted. At 15 DAS, T7 again proved most effective (2.5), followed by T_6 (2.9) and T_3 (3.1). T_5, T_4, T_1 and T_2 ranged from 3.4 to 4.3 jassids/cage. Mean jassid population over the three intervals confirmed T_7 as most effective (2.4 jassids/cage), with 66.9 % reduction, followed by T_6 (2.9; 59.3 %), T_3 (3.0), T_1 (3.4), T_4 and T_5 (3.5) (Fig. 2). Treatment T_2 (3.8) was the least effective, with a 46.2 % reduction compared to control. A similar research indicates that among the tested insecticides, the treatment in which Diafenthiuron 50 WP @ 312.5 g a.i./ha was used was the most effective, leading to 85.9 % and 77.8 % reduction of whitefly and thrips population, respectively (20). The treatment in which Spiromesifen 240 SC @ 120 mL a.i./ha was applied also effectively reduced the number of jassid (about 77.5 % reduction of population). On the contrary, research indicates that Emamectin benzoate 5 % SG was found to be the most effective chemical against jassid and recorded the 0.00 incidence 10 days after application, followed by the Azadirachtin 5 % EC (0.73) (21).

Table 1. Efficacy of different treatments against Whitefly (*B. tabaci*) in Mungbean during *Kharif* 2022

S.No.	Treatments	Dose (g a.i./ha or %)	Whitefly population per cage (Mean ± SE)				Overall mean	% Reduction over control			Overall mean reduction
			Before Spray	3 DAS	7 DAS	15 DAS		3 DAS	7 DAS	15 DAS	
1	Imidacloprid + Lantana leaf extract	25 g a.i./ha + 5 %	4.7 (2.28)	2.8 (1.81)^b	2.6 (1.75)^b	3.1 (1.91)^b	2.8 (1.82)^b	53.7	59.3	56.4	56.4
2	Emamectin benzoate + Lantana leaf extract	5 g a.i./ha + 5 %	3.8 (2.07)	3.4 (1.97)^d	3.3 (1.94)^d	3.9 (2.08)^d	3.5 (2.00)^d	43.3	48.1	46.5	46.0
3	Imidacloprid + NSKE	25 g a.i./ha + 5 %	4.3 (2.19)	2.4 (1.71)^{ab}	2.1 (1.60)^a	2.9 (1.83)^{ab}	2.5 (1.72)^{ab}	59.4	67.2	60.3	62.3
4	Emamectin benzoate + NSKE	5 g a.i./ha + 5 %	4.3 (2.19)	3.1 (1.89)^c	2.9 (1.85)^c	3.4 (1.96)^c	3.1 (1.90)^c	48.9	53.4	53.5	51.9
5	Fipronil + Lantana leaf extract	30 g a.i./ha + 5 %	4.9 (2.32)	3.0 (1.86)^c	2.8 (1.81)^c	3.3 (1.94)^c	3.0 (1.87)^c	50.6	56.1	54.5	53.7
6	Fipronil + NSKE	30 g a.i./ha + 5 %	4.8 (2.30)	2.9 (1.83)^{bc}	2.9 (1.84)^c	3.5 (2.01)^c	3.1 (1.90)^c	52.2	54.0	50.9	52.4
7	Imidacloprid + Fipronil	500 g/ha	4.7 (2.28)	2.1 (1.60)^a	1.6 (1.45)^a	1.9 (1.56)^a	1.9 (1.54)^a	65.6	74.6	73.2	71.1
8	Control (Water spray)	500 L water/ha	4.6 (2.26)	6.0 (2.54)^e	6.3 (2.60)^e	7.2 (2.77)^e	6.5 (2.64)^e	0.0	0.0	0.0	0.0

SEm±: - | 0.07 | 0.05 | 0.08 | 0.03

CD (p = 0.05): NS | 0.22 | 0.14 | 0.23 | 0.08

Values in parentheses indicate square root transformed values ($\sqrt{x + 0.5}$); means followed by different letters are significantly different at $p \leq 0.05$ using Duncan's Multiple Range Test (DMRT).

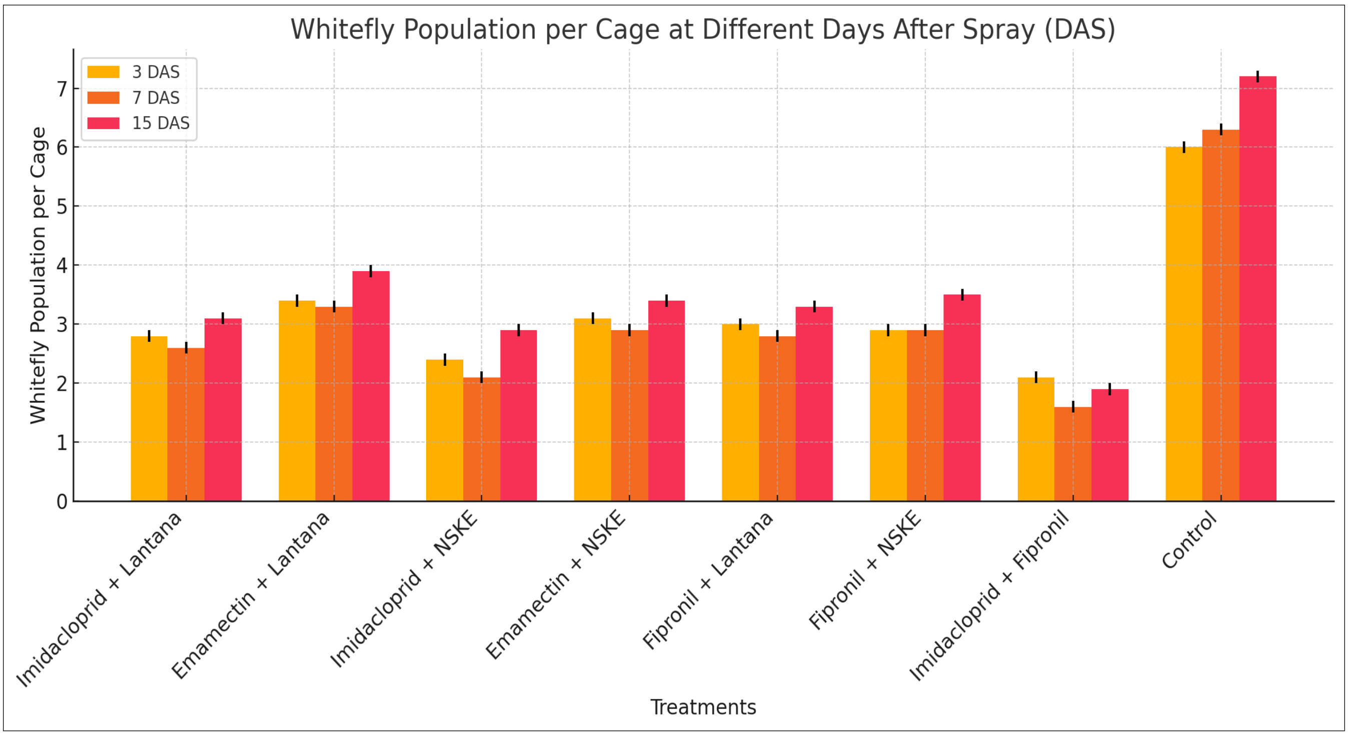

Fig. 1. Efficacy of different treatments against whitefly (*B. tabaci*) in mungbean during *Kharif* Season 2022**.**

Table 2. Efficacy of different treatments against Jassid in Mungbean during *Kharif* 2022

S.No.	Treatments	Dose (g a.i./ha or %)	Jassid Population per Cage (Mean ± SE)				Overall Mean	% Reduction over Control			Overall Mean Reduction
			Before Spray	3 DAS	7 DAS	15 DAS		3 DAS	7 DAS	15 DAS	
1	Imidacloprid + Lantana leaf extract	25 g a.i./ha + 5 %	5.3 (2.41)	3.1 (1.91)^{b}	3.2 (1.92)^{b}	3.7 (2.05)^{b}	3.4 (1.96)^{b}	53.2	54.2	51.7	53.0
2	Emamectin benzoate + Lantana leaf extract	5 g a.i./ha + 5 %	5.1 (2.37)	3.7 (2.05)^{cd}	3.5 (1.98)^{cd}	4.3 (2.20)^{cd}	3.8 (2.08)^{cd}	44.6	50.3	43.8	46.2
3	Imidacloprid + NSKE	25 g a.i./ha + 5 %	5.2 (2.39)	3.4 (1.96)^{bc}	2.4 (1.70)^{a}	3.1 (1.90)^{b}	3.0 (1.86)^{b}	50.0	65.3	59.6	58.3
4	Emamectin benzoate + NSKE	5 g a.i./ha + 5 %	5.1 (2.37)	4.1 (2.14)^{de}	2.9 (1.85)^{b}	3.6 (2.02)^{b}	3.5 (2.00)^{b}	39.1	58.4	53.6	50.3
5	Fipronil + Lantana leaf extract	30 g a.i./ha + 5 %	5.2 (2.39)	3.9 (2.10)^{de}	3.1 (1.89)^{b}	3.4 (1.99)^{b}	3.5 (2.00)^{b}	41.2	55.8	55.2	50.7
6	Fipronil + NSKE	30 g a.i./ha + 5 %	5.4 (2.43)	3.5 (2.00)^{cd}	2.3 (1.67)^{a}	2.9 (1.83)^{a}	2.9 (1.83)^{a}	47.9	67.0	63.0	59.3
7	Imidacloprid + Fipronil	500 g/ha	5.3 (2.41)	2.8 (1.81)^{a}	1.8 (1.50)^{a}	2.5 (1.73)^{a}	2.4 (1.68)^{a}	58.3	74.8	67.7	66.9
8	Control (Water Spray)	500 L	4.9 (2.32)	6.7 (2.67)^{e}	7.0 (2.74)^{e}	7.7 (2.85)^{e}	7.1 (2.76)^{e}	0.0	0.0	0.0	0.0

SEm±: – | 0.07 | 0.09 | 0.06 | 0.05

CD (p = 0.05): NS | 0.22 | 0.27 | 0.19 | 0.16

Values in parentheses indicate square root transformed values ($\sqrt{x + 0.5}$); means followed by different letters are significantly different at $p \leq 0.05$ using Duncan's Multiple Range Test (DMRT).

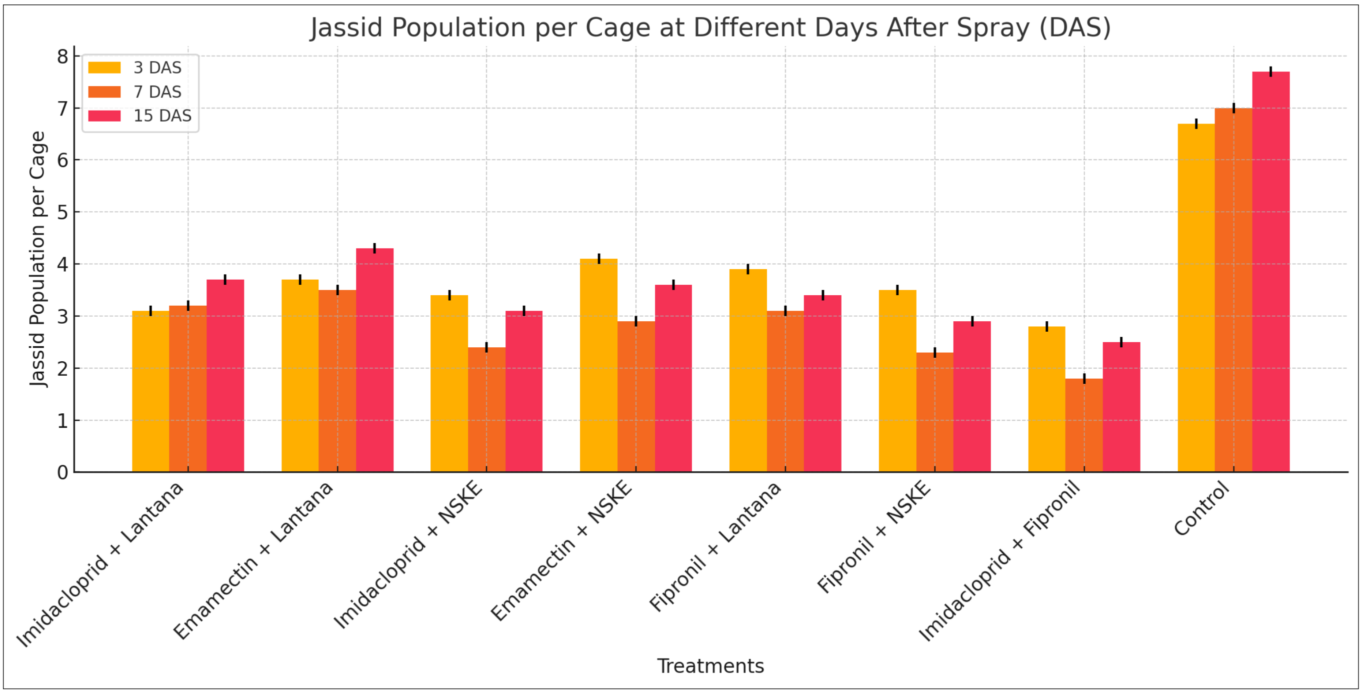

Fig. 2. Efficacy of different treatments against Jassid in Mungbean during *Kharif* 2022.

Thrips (*C. indicus*)

A uniform thrips population was noted across treatments before spraying. At 3 DAS, T_7 recorded the lowest population (2.3 thrips/10 flowers), statistically at par with T_6 (2.7) and followed by T_1 and T_4 (3.3), T_3 (3.4), T_2 and T_5 (3.6). All treatments significantly outperformed the control (8.0 thrips/10 flowers). At 7 DAS, T_7 again showed the lowest thrips population (1.3), followed by T_6 (2.0), T_4 (2.1), T_1 (2.2), T_3 (2.4), T_5 (2.6) and T_2(3.3). At 15 DAS, the trend remained similar with T_7 showing the lowest population (1.9), followed by T_6(2.5), T_1 (2.9), T_3 (3.0), T_2 and T_4(3.1) and T_5 (3.2) (Table 3). The control recorded the highest population (8.3 thrips/10 flowers) (Table 3). The average population at 3, 7 and 15 DAS confirmed T_7 (1.8 thrips/10 flowers) as significantly superior, reducing the thrips population by 78 %, followed by T_6 (2.4; 70.9 %), T_1 (2.8), T_3 and T_4(2.9), T_5 (3.1) and T_2 (3.4), the least effective (Fig. 3). Similar studies indicate that the diafenthiuron 50 WP @ 312 g a.i./ha was the most promising treatment that effectively reduced the population of flower thrips (*Caliothrips indicus*) after both sprays, followed by Spiromesifen 240 SC @ 150 g a.i./ha as compared to standard checks (22). Thiamethoxam 25 WG was applied at 25 g active ingredient per hectare and Triazophos 40 EC at 500 g active ingredient per hectare, for the management of pests in Mungbean.

Table 3. Efficacy of different treatments against thrips in mungbean during *Kharif* 2022

S. No.	Treatments	Dose (g a.i./ha or %)	Thrips Population/10 Flowers (Mean ± SE)				Overall Mean	% Reduction over Control			Overall Mean Reduction
			Before Spray	3 DAS	7 DAS	15 DAS		3 DAS	7 DAS	15 DAS	
1	Imidacloprid + Lantana leaf extract	25 g a.i./ha + 5 %	6.0 (2.55)	3.3 (1.94)^{bc}	2.2 (1.64)^{bc}	2.9 (1.84)^{bc}	2.8 (1.81)^{bc}	58.8	75.0	65.0	66.3
2	Emamectin benzoate + Lantana leaf extract	5 g a.i./ha + 5 %	5.4 (2.43)	3.6 (2.03)^{cd}	3.3 (1.95)^{de}	3.1 (1.90)^{cd}	3.4 (1.96)^{cd}	54.6	62.1	62.3	59.7
3	Imidacloprid + NSKE	25 g a.i./ha + 5 %	5.7 (2.49)	3.4 (1.98)^{bc}	2.4 (1.69)^{bc}	3.0 (1.86)^{bc}	2.9 (1.85)^{bc}	57.0	72.6	63.9	64.5
4	Emamectin benzoate + NSKE	5 g a.i./ha + 5 %	6.1 (2.57)	3.3 (1.95)^{bc}	2.1 (1.61)^{bc}	3.1 (1.90)^{cd}	2.9 (1.83)^{bc}	58.4	75.6	62.2	65.4
5	Fipronil + Lantana leaf extract	30 g a.i./ha + 5 %	6.2 (2.59)	3.6 (2.03)^{cd}	2.6 (1.75)^{cd}	3.2 (1.93)^{cd}	3.1 (1.90)^{cd}	54.8	70.7	61.0	62.1
6	Fipronil + NSKE	30 g a.i./ha + 5 %	5.9 (2.53)	2.7 (1.79)^{ab}	2.0 (1.58)^{ab}	2.5 (1.74)^{ab}	2.4 (1.70)^{ab}	66.3	76.9	69.6	70.9
7	Imidacloprid + Fipronil	500 g/ha	5.9 (2.53)	2.3 (1.67)^{a}	1.3 (1.34)^{a}	1.9 (1.53)^{a}	1.8 (1.52)^{a}	71.4	85.0	77.7	78.0
8	Control (Water Spray)	500 L	6.1 (2.57)	8.0 (2.91)^{e}	8.7 (3.04)^{e}	8.3 (2.97)^{e}	8.3 (2.97)^{e}	0.0	0.0	0.0	0.0

SEm±: – | 0.08 | 0.07 | 0.08 | 0.05

CD (p = 0.05): NS | 0.25 | 0.20 | 0.25 | 0.15

Values in parentheses indicate square root transformed values ($\sqrt{x}$ + 0.5); means followed by different letters are significantly different at $p \leq 0.05$ using Duncan's Multiple Range Test (DMRT).

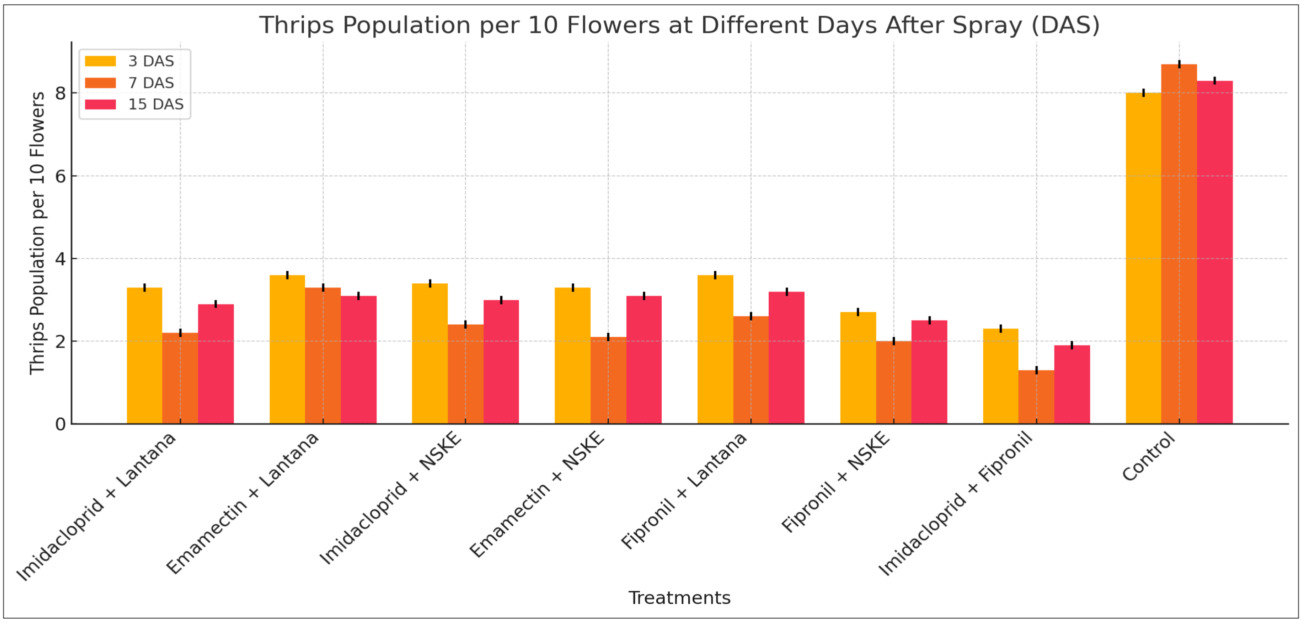

Fig. 3. Efficacy of different treatments against thrips in mungbean during *Kharif* 2022.

Effect on yield

The results of the mungbean yield studies showed that the highest grain yield was recorded in T_7, followed by T_6 and T_1 (7.13 q/ha). Treatments T_4 (6.83 q/ha), T_2 (6.43 q/ha) and T_5 (6.37 q/ha) showed low yields, but the lowest yield was observed in the control (5.73 q/ha) (Table 4). Research indicates that significant yield improvement in mungbean when insecticide combinations were used against major sucking pests (23). Similarly, Research also indicates that combining neonicotinoids with botanical extracts improved yield by maintaining lower pest pressure throughout the crop growth period. The increased yield in T_1 and T_6 treatments, which included *Lantana camara* and NSKE extracts, further supports the potential role of botanicals in IPM frameworks. Conversely, the lower yields recorded in T_2, T_4 and T_5 may be due to either the relatively reduced efficacy of certain combinations or the slower action of botanical components. Similar observations were recorded in the previous research, which indicates variable performance of botanicals depending on environmental conditions and pest pressure (25).

Economics of treatments

Maximum net profit was obtained in T_7 (Rs. 19588.50 per hectare) followed by T_6 (₹13770.20 per hectare), T_1 (₹10057.00 per hectare) and T_3 (₹9737.20 per hectare) (Table 5). Moderate profits were noted in T_4 (₹7010.50 per hectare) and T_2 (₹4508.50 per hectare). The minimum net profit was recorded in T_5, but it was better than the untreated control. The highest profit in T_7 can be attributed to the effective suppression of sucking pests, leading to higher yields and a better benefit-cost ratio. Research indicates that reported that integrating chemical insecticides with botanicals such as NSKE improved pest control efficiency while maintaining economic feasibility in mungbean (26). On the other

Table 4. Efficacy of different treatments against sucking pests based on seed yield of mungbean during *Kharif* 2022

S.No.	Treatments	Dosage g/ml a.i./ha	Total	Mean
1	Imidacloprid + Lantana leaf extract	25g a.i./ha +5 %	21.4	7.13
2	Emmamectin Benzoate + Lantana leaf extract	5g a.i./ha +5 %	19.3	6.43
3	Imidacloprid + NSKE	25g a.i./ha +5 %	21.5	7.17
4	Emmamectin Benzoate + NSKE	5g a.i./ha + 5 %	20.5	6.83
5	Fipronil + Lantana leaf extract	30g a.i./ha +5 %	19.1	6.37
6	Fipronil + NSKE	30g a.i./ha +5 %	23.3	7.77
7	Imidacloprid + Fipronil	500 g/ha	25.3	8.43
8	Control (Water Spray)	500 L	17.2	5.73
			SEm±	**0.16**
			CD at 5 %	**0.49**

Table 5. Cost: Benefit ratio of different treatments used for the management of sucking pests in mungbean during *Kharif* 2022

Sr. No.	Treatments	Dosage g/mL a.i./ha	Cost of treatment (Rs/ha)	Yield (q/ha)	Saved yield over control (q/ha)	Benefit due to treatment (Rs/ha)	Net return (Rs/ha)	Cost: Benefit ratio	Rank
1	Imidacloprid + Lantana leaf extract	25g a.i./ha +5 %	800	7.13	1.40	10857	10057.00	1:12.5	II
2	Emmamectin Benzoate + Lantana leaf extract	5g a.i./ha +5 %	920	6.43	0.70	5428.5	4508.50	1:4.9	V
3	Imidacloprid + NSKE	25g a.i./ha +5 %	1430	7.17	1.44	11167.2	9737.20	1:6.8	III
4	Emmamectin Benzoate + NSKE	5g a.i./ha + 5 %	1520	6.83	1.10	8530.5	7010.50	1:4.6	VI
5	Fipronil + Lantana leaf extract	30g a.i./ha +5 %	1375	6.37	0.64	4963.2	3591.20	1:2.6	VII
6	Fipronil + NSKE	30g a.i./ha +5 %	2050	7.77	2.04	15820.2	13770.20	1:6.7	IV
7	Imidacloprid + Fipronil	500 g/ha	1350	8.43	2.70	20938.5	19588.50	1:14.5	I
8	Control (Water Spray)	500 L	-	5.73	-	-	-	-	-

*Minimum support price of mungbean during 2021-22- ₹7755/q; Labour charge-₹300/day; sprayer charge- ₹50/day hand, the moderate profits observed in treatments like T_2 and T_4 may be due to partial pest control or relatively lower yields. Research indicates that although botanicals contribute to ecological sustainability, their standalone or less potent combinations may yield comparatively lower profits under high pest pressure (27).

Conclusion

The present study clearly demonstrated the comparative efficacy of new-generation insecticides and botanical extracts in managing major pests of mungbean, namely whitefly (*Bemisia tabaci*), jassid (*Empoasca kerri*) and thrips (*Caliothrips indicus*). Among all the tested treatments, the combination of Imidacloprid + Fipronil @ 500 g/ha proved to be the most effective in significantly reducing the population of all three pests. A maximum reduction of 71.1 %, 66.9 % and 78 % was noted in the pest populations respectively in comparison with control. The reduction in pests supported the growth of plants and resulted in the highest grain yield (8.43 q/ha) and the maximum net profit (₹19588.50/ha), with a Benefit-Cost Ratio (BCR) of 1:14.51, indicating its superior efficacy and economic viability. Other effective treatments included Fipronil + NSKE @ 30 g a.i./ha + 5 % and Imidacloprid + NSKE @ 25 g a.i./ha + 5 %, both of which performed reasonably well in pest suppression and yield enhancement. The botanical extract-based combinations demonstrated promising potential, particularly in reducing chemical input and contributing to sustainable pest management. Conversely, the combination of Emamectin benzoate + Lantana camara leaf extract @ 5 g a.i./ha + 5 % was the least effective treatment, both in terms of pest suppression and yield improvement. Overall, the integration of chemical insecticides with botanical extracts offers a promising strategy for effective and eco-friendly pest management in mungbean cultivation. The results strongly support the use of Imidacloprid + Fipronil @ 500 g/ha for the control of pests under field conditions. However, for long-term sustainability, continued exploration and optimization of botanical alternatives are essential to reduce pesticide reliance and mitigate resistance development.

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Authors' contributions

MK[1] contributed to conceptualization, experiment execution and data curation. LP assisted in conceptualization and performed data analysis. PY contributed to experimental work and data curation. MK[2] participated in conceptualization and statistical data analysis. PK provided supervision, guided methodology development and reviewed the manuscript. AK contributed to drafting the final manuscript and revising its content. CK was involved in manuscript preparation and refinement. VK, VY and AY assisted in drafting and improving the manuscript structure. AS contributed to final draft preparation and language polishing. SK participated in manuscript revision and formatting. RM provided input to the final draft and ensured accuracy of the content. DR contributed to the revision process and final approval of the manuscript. All authors read and approved the final version of the manuscript. [MK[1] stands for Manish Kumar and MK[2] stands for Meeta Kumari].

Compliance with ethical standards

Conflict of interest: The authors declare that there is no conflict of interest regarding the publication of this research.

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