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Research Article

Comparative Efficacy of Various Biopesticides against Spotted Bollworm (*Earias insulana* Boisduval) in Cotton under Field Conditions of Sindh, Pakistan

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ABSTRACT

The spotted bollworm, *Earias insulana*, is one of the most destructive insect pests of cotton, causing significant yield losses worldwide. Reliance on synthetic insecticides for its management raises concerns over environmental safety, resistance development, and high input costs. Therefore, eco-friendly bio-pesticides are increasingly being evaluated as sustainable alternatives. This study assessed the efficacy and economic viability of different bio-pesticides against *E. insulana* under field conditions, compared with the synthetic insecticide lambda-cyhalothrin 5% EC. Results revealed that neem oil consistently exhibited the highest efficacy among botanicals, with overall larval population reductions of 75.88%, 65.68%, and 68.85% after the first, second, and third sprays, respectively. Tobacco extract ranked second, with reductions of 70.35%, 63.61%, and 65.17%. Other botanicals, including Tooh, Akk, and Datura, showed moderate to low suppression ranging from 50-62%. In contrast, lambda-cyhalothrin recorded the highest control efficiency across all sprays, with reductions of 81.15%, 80.90%, and 78.55%. Control plots, however, showed a steady increase in larval populations, confirming the severity of untreated infestations. The cost-benefit analysis indicated that although lambda-cyhalothrin provided the maximum yield (3961.6 kg/ha), neem oil emerged as the most economically viable option with the highest Incremental Cost-Benefit Ratio (ICBR 1:85.9). Akk and tobacco also demonstrated favorable profitability, whereas Datura was the least effective and least profitable. In conclusion, although synthetic insecticides ensured the greatest pest suppression, neem oil and other botanicals proved to be cost-effective, eco-friendly alternatives, supporting their integration into sustainable pest management strategies for cotton.

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Introduction

Cotton (*Gossypium hirsutum* L.; Malvaceae) is a major cash crop of Pakistan and is commonly referred to as the "silver fiber" (Haider et al., 2015). It is cultivated in more than 80 tropical and subtropical countries worldwide (Noureen et al., 2016; Ma et al., 2021), and is commercially produced in over 50 countries (Smith and Cothren, 1999). Cotton is primarily grown for its fiber and oil (Oosterhuis, 2001). In Pakistan, cotton contributes approximately 10.5% to value-added agriculture and around 2.4% to the national GDP (Frederick et al., 2019). It plays a vital role in the country's economic development and financial stability (Khan et al., 2022).

However, the average cotton yield in Pakistan is approximately 570.99 kg/ha, which is significantly lower than the global average (Tokel et al., 2022). Among the major insect pests of cotton, the spotted bollworm (*Earias insulana* Boisd.), pink bollworm (*Pectinophora gossypiella*), and American bollworm (*Helicoverpa armigera*) are of critical concern (Bakhsh et al., 2005; Ahmed and Qasim, 2011). *E. insulana* is one of the most destructive pests, causing extensive damage to floral buds (squares), flowers, and bolls (Kranthi et al., 2005; Qasim and Hussain, 2015; Qasim et al., 2018). It is considered an early- to mid-season pest (Abro et al., 2004). The eggs and larvae of *E. insulana* typically appear in the field from the second week of July to mid-October, reaching peak populations between July and September, with larval abundance highest in August and September (Ibargutxi et al., 2006). Bollworms can cause yield losses ranging from 30% to 40% (Arshad et al., 2015).

Farmers primarily depend on synthetic chemical insecticides to manage these pests, which has led to several issues including pesticide resistance (Li, 1972; Rath et al., 2006), pest resurgence (He et al., 2007), environmental pollution, threats to human health and wildlife, food safety concerns, and contamination of soil and water resources (Zahi et al., 2013).

Therefore, there is an urgent need to explore alternative, eco-friendly pest control strategies such as the use of bio-pesticides. Plant-based extracts have long been used successfully as insect antifeedants and repellents (Ignacimuthu et al., 2003). Azadirachtin, a compound extracted from the neem tree (*Azadirachta indica*), has been shown to reduce insect growth, inhibit feeding, cause anatomical abnormalities, disrupt molting, and induce mortality (Arivoli and Tennyson, 2013; Mordue and Nisbet, 2000). Crude neem seed extract and the insecticide Thiodan have been found effective against *E. insulana* in okra (Sohail et al., 2015), while neem oil-based products such as Nimbicidine have shown promising results in suppressing both pink and spotted bollworms in cotton (Sinzogan et al., 2006).

This study aims to evaluate the insecticidal potential of various plant extracts as botanical pesticides. Botanicals affect insect pests through multiple mechanisms, including disruption of digestive, respiratory, and nervous systems; interference with sensory perception, molting, metamorphosis, and hormonal regulation; and through repellency and antifeedant activity (Sahayaraj and Paulraj, 1998). Insecticides of biological and mineral origin are increasingly being developed and applied on crops, fruits, and vegetables (Wyss et al., 2005; Prakash et al., 2008; Khuhro et al., 2020). Botanical pesticides are characterized by low mammalian toxicity, minimal risk of resistance and resurgence, and do not negatively impact plant growth, food quality, or the environment. They are affordable, accessible, and especially suitable for use in organic agriculture.

Thus, the objective of this study is to assess the extent of damage caused by the spotted bollworm on cotton and to evaluate the efficacy of selected plant extracts and a conventional insecticide in managing this pest, with the goal of identifying the most effective and eco-friendly option for sustainable pest control.

Materials and Methods

Experimental site and design

The experiments were conducted during the Kharif seasons of 2020 and 2021 at the experimental fields of the Plant Protection Research Institute, Tandojam. The experimental layout followed a Randomized Complete Block Design (RCBD) with three replications. Each plot measured 30 × 40 m. The treatments included five botanical extracts, a synthetic pesticide (Karate 5EC; Lambda-cyhalothrin), and an untreated control. The objective was to evaluate the efficacy of various botanicals and identify the most effective treatment for managing *E. insulana*.

Preparation of botanical extracts

For neem (*Azadirachta indica*) oil preparation, neem seeds were crushed and wrung to extract the oil. For the other botanicals viz., tobacco (*Nicotiana tabacum*), tooh (*Citrullus colocynthis*), datura (*Datura stramonium*), and akk (*Calotropis procera*), fresh leaves (4 kg of each) were chopped, ground, and boiled in water at 100°C for 40 min. After cooling, the extracts were filtered using muslin cloth. One gram of Saraf detergent was added to each liter of plant extract as a surfactant to enhance adherence.

Application of treatments

Treatments were applied using a manual sprayer during early morning hours at 15-day intervals, starting from the initial infestation of *E. insulana*. Precautions were taken to minimize spray drift and avoid contamination of adjacent plots. Care was also taken to prevent droplet coalescence and soil seepage, ensuring uniform coverage of each plot. The sprayer was thoroughly cleaned after each application. Control plots remained unsprayed throughout the experiment. Lambda-cyhalothrin (5% EC) and neem oil were applied at 2 ml/L of water, while other botanicals were used at 4 kg/acre.

Each treatment was applied three times during periods of high pest infestation. Pre-treatment data were recorded 24 h before each spray, while post-treatment data were collected at 24, 48, 72, and 96 h, and one week after each application.

Data collection

Observations were recorded regularly from germination to harvest. Pre-treatment data were collected 24 h before each spray, and post-treatment assessments were made at specified intervals (24, 48, 72, and 96 h and 7 days after spray). The percentage reduction in pest population was calculated using Abbott's formula (Abbott, 1925).

Statistical analysis

Data were subjected to analysis of variance (ANOVA) using the software STATISTIX 8.1. Means were compared using Duncan's Multiple Range Test (DMRT) and the Least Significant Difference (LSD) test to determine statistically significant differences among treatments.

Results

Efficacy of bio-pesticides against *E. insulana* after first spray

The efficacy of different bio-pesticides against *E. insulana* in cotton after the first spray varied considerably across treatments and observation intervals. Pre-treatment larval populations were statistically similar across all treatments, indicating uniform initial infestation.

Among the bio-pesticides, neem oil proved most effective, causing a sharp decline in larval populations, with the lowest post-treatment counts recorded across all time intervals and an overall reduction of 75.88%. Tobacco extract ranked second, maintaining moderate suppression of larvae throughout the observation period, with 70.35% reduction.

Tooh, datura, and akk showed relatively lower efficacy. Tooh resulted in 60.91% reduction, while datura and akk achieved 59.79% and 61.86% reductions, respectively (Table 1). Although these treatments suppressed larval populations compared to the control, their effect was significantly weaker than neem oil and tobacco.

In comparison, the synthetic insecticide lambda cyhalothrin 5% EC was the most effective treatment, leading to a drastic decline in larval numbers soon after application and sustaining control throughout the observation period, with an overall reduction of 81.15% (Table 1).

Conversely, the control plots showed a continuous increase in larval populations, reaching the highest counts at one week post-treatment, confirming the natural progression of infestation in the absence of any control measure. The individual infestations of *E. insulana* at each interval are given in Table 1.

Efficacy of bio-pesticides against *E. insulana* after second spray

The results showed that all bio-pesticide treatments caused varying levels of reduction in *E. insulana* infestation compared to the control. Among the tested bio-pesticides, neem oil proved to be the most effective, recording a consistent reduction across all post-treatment intervals. After 24 h, the pest population decreased from 9.55 to 6.19 larvae, and remained relatively lower throughout the observation period, leading to an overall reduction of 65.68%. Tobacco extract ranked second in efficacy with a reduction of 63.61%, showing slightly higher larval counts than neem oil but still significantly lower than the untreated control.

Table 1. Effect of first spray of various bio-pesticides on *E. insulana* in cotton.

Treatments	Pre-treatment	Post treatment					Overall % reduction
		24 h	48 h	72 h	96 h	1 week	
Neem oil	6.88±0.2a	2.99±0.19a	1.99±0.19a	2.82±0.26a	3.7±0.23a	4.45±0.23a	75.88
Tobacco	6.89±0.2a	3.19±0.23b	4.31±0.26b	4.12±0.21b	4.17±0.22b	5.38±0.22b	70.35
Tooh	6.79±0.2a	4.74±0.24c	5.84±0.23b	6.62±0.47b	6.25±0.18bc	6.76±0.21b	60.91
Datura	6.89±0.2a	5.45±0.22d	5.98±0.21c	6.58±0.23b	6.72±0.16c	6.44±0.17b	59.79
Akk	6.97±0.2a	3.54±0.22d	4.94±0.26d	6.91±0.23c	6.81±0.21d	6.93±0.22c	61.86
Lambda cyhalothrin 5% EC	6.8±0.21a	0.98±0.1d	1.31±0.16e	1.75±0.21d	3.27±0.18de	3.73±0.18d	81.15
Control	6.79±0.2a	7.74±0.24e	7.93±0.23f	8.35±0.47e	9.76±0.21e	9.94±0.2e	

Moderate suppression of the pest population was observed with Akk and, which achieved 57.95% and 57.82% overall reduction, respectively. These treatments showed intermediate effects, with fluctuations in larval counts over the observation period. Datura was the least effective among the bio-pesticides, causing only 55.55% reduction, with relatively higher post-treatment larval counts.

In comparison, the chemical insecticide Lambda-cyhalothrin 5% EC was markedly superior to all bio-pesticides. It drastically reduced larval counts within 24 h (from 9.83 to 2.37 larvae) and maintained the lowest population levels throughout, resulting in the highest overall reduction of 80.90% (Table 2). Contrariwise, in the control, larval counts continued to rise steadily from 9.51 (pretreatment) to 18.93 (after one week), confirming that natural mortality or environmental factors had negligible impact without treatment. The individual infestations of *E. insulana* at each interval are given in Table 2.

Table 2. Effect of second spray of various bio-pesticides on *E. insulana* infestation in cotton.

Treatments	Pre-treatment	Post treatment					Overall % reduction
		24 h	48 h	72 h	96 h	One week	
Neem oil	9.55±0.19a	6.19±0.19a	6.22±0.21a	5.92±0.22a	6.6±0.22a	7.55±0.17a	65.68%
Tobacco	9.56±0.19a	6.39±0.23b	6.41±0.26b	6.49±0.22b	7.28±0.22b	7.87±0.21b	63.61%
Tooh	9.50±0.2a	7.94±0.24c	7.94±0.23b	7.72±0.47b	8.28±0.21c	8.04±0.22c	57.82%
Datura	9.62±0.19a	8.65±0.22d	8.08±0.21c	7.68±0.23b	9.31±0.56c	8.35±0.22cd	55.55%
Akk	9.77±0.18a	6.84±0.23de	7.04±0.26d	8.07±0.23c	8.36±0.25d	9.49±0.22cd	57.95%
Lambda-cyhalothrin 5% EC	9.83±0.21a	2.37±0.17e	2.72±0.15d	3.62±0.19c	4.36±0.2d	5.01±0.18d	80.90%
Control	9.51±0.19a	9.61±0.23f	10.71±0.24e	12.93±0.29d	14.03±0.31e	18.93±0.29e	

Efficacy of bio-pesticides against *E. insulana* after third spray

The third spray of different bio-pesticides showed significant variation in their efficacy against *E. insulana* on cotton. Neem oil proved most effective among botanicals, recording the highest overall reduction (68.85%), followed by tobacco (65.17%). Akk, Tooh, and Datura were comparatively less effective, with reductions of 53.87%, 52.06%, and 50.86%, respectively (Table 3). In contrast, the synthetic insecticide lambda-cyhalothrin 5% EC provided the maximum overall reduction (78.55%), clearly outperforming all botanical treatments. Overall, neem oil and tobacco emerged as promising bio-pesticides, though less effective than the chemical control. The individual infestations of *E. insulana* at each interval are given in Table 3.

Cost-benefit analysis of bio-pesticides against *E. insulana* in cotton

The cost-benefit analysis of different bio-pesticides for the management of *E. insulana* on cotton revealed significant variation in yield improvement and profitability across treatments (Table 4). The highest yield was recorded with lambda-cyhalothrin 5% EC (3961.6 kg/ha), which resulted in an additional yield of 1877.2 kg/ha over control and a net profit of Rs. 272,080. However, its input cost was higher (Rs. 7,000/ha), leading to a comparatively moderate Incremental Cost-Benefit Ratio (ICBR) of 1:40.22.

Table 3. Effect of the third spray of various bio-pesticides on *E. insulana* in cotton.

Treatments	Pre-treatment	Post Treatment					Overall % reduction
		24 h	48 h	72 h	96 h	One week	
Neem oil	13.21±0.28 a	4.39±0.19 e	3.41±0.2 d	4.71±0.22 d	5.02±0.22 c	7.45±0.22 d	68.85%
Tobacco	13.38±0.37 a	4.59±0.23 de	3.76±0.24 cd	5.39±0.22 c	5.59±0.22 c	8.6±0.22 c	65.17%
Tooh	13.08±0.24 a	6.14±0.24 c	5.04±0.23 b	7.47±0.18 b	9.82±0.47 b	9.98±0.21 b	52.06%
Datura	13.01±0.23 a	6.85±0.22 b	5.18±0.21 b	7.94±0.16 b	9.78±0.23 b	9.66±0.17 b	50.86%
Akk	13.09±0.27 a	5.04±0.23 d	4.23±0.25 c	8.03±0.21 b	9.55±0.26 b	10.15±0.22 b	53.87%
Lambda-cyhalothrin 5% EC	13.41±0.25 a	1.67±0.12 f	2.31±0.13 e	3.09±0.18 e	4.12±0.18 d	6.01±0.18 e	78.55%

Among the bio-pesticides, neem oil produced the maximum yield (3803.6 kg/ha) with an additional yield of 1719.2 kg/ha and a net profit of Rs. 255,480. Despite the relatively low treatment cost (Rs. 2,000/ha), neem oil recorded the highest ICBR (1:85.9), making it the most economically efficient option. Similarly, akk was also highly profitable, giving an additional yield of 995.6 kg/ha with a net return of Rs. 147,540 and an ICBR of 1:82.9.

Other botanicals such as tobacco (3467.6 kg/ha yield, ICBR 1:78.2) and tooh (2973.6 kg/ha yield, ICBR 1:74.1) also showed favorable economic returns compared to control. In contrast, datura was the least profitable treatment, with only 301.6 kg/ha additional yield, a net profit of Rs. 43,840, and the lowest ICBR (1:32.3). Overall, while the synthetic insecticide lambda-cyhalothrin ensured the highest yield and net profit, bio-pesticides, particularly neem oil and akk, proved to be more cost-effective and eco-friendly alternatives due to their superior cost-benefit ratios.

Table 4. Cost-benefit ratio of managing *E. insulana* on cotton using bio-pesticides.

Treatments	Yield in Kg/ha	Additional Yield over control	Price of additional yield over control	Cost of treatment over control Rs/ha	Net profit/ loss over control	ICBR
Neem oil	38.03.6	1719.2	257880	2000	255480	1:85.9
Tobacco	3467.6	1383.2	207480	2650	204830	1:78.2
Tooh	2973.6	889.2	133380	1800	131580	1:74.1
Datura	2386.00	301.6	45240	1400	43840	1:32.3
Akk	3080.4	995.6	149340	1400	147540	1:82.9
Lambda-cyhalothrin 5%EC	3961.6	1877.2	281580	7000	272080	1:40.22
Control	2084.4					

Discussion

The field experiments were conducted to develop effective control strategies for the management of *E. insulana* on cotton. The efficacy of different bio-pesticides and a chemical insecticide was evaluated against the spotted bollworm. Various botanicals were tested, including neem, tobacco, bitter apple, datura, and milkweed, along with the insecticide Karate 5EC (lambda-cyhalothrin), and an untreated control. The application doses included lambda-cyhalothrin at 2 ml per liter of water, neem oil at 2 ml per liter of water, and other botanicals at 4 kg per acre.

The results revealed that all treatments significantly reduced pest infestation compared to the untreated control. The lowest infestation was observed with lambda-cyhalothrin (0.98 ± 0.1), followed by neem oil (2.99 ± 0.19) and tobacco (3.19 ± 0.23), while the highest infestation was recorded in the control (7.74 ± 0.24). Other botanicals such as datura, bitter apple, and milkweed showed moderate reductions in infestation. After 48 h of the first spray, a highly significant difference was recorded among treatments ($F = 109.32$, $p < 0.001$). Again, lambda-cyhalothrin showed the lowest infestation (1.31 ± 0.16), followed by neem oil (1.99 ± 0.19) and tobacco (4.31 ± 0.26), while the highest infestation persisted in the control (7.93 ± 0.23). A similar trend was observed at 72 and 96 h, and one week after treatment.

At one week after application, the maximum reduction in infestation (81.45%) was recorded with lambda-cyhalothrin, followed by neem oil (75.88%), tobacco (70.35%), datura (59.79%), bitter apple (69.91%), and milkweed (61.86%). The lowest pest infestation at this stage was recorded with lambda-cyhalothrin (3.73 ± 0.18), followed by neem oil (4.45 ± 0.23), tobacco (5.38 ± 0.22), bitter apple (6.44 ± 0.16), datura (6.76 ± 0.21), and milkweed (6.93 ± 0.22), compared to the untreated control (9.94 ± 0.20). Similar trends were observed after the second and third sprays.

Overall, lambda-cyhalothrin proved to be the most effective treatment, showing the greatest reduction in infestation and the highest pest mortality. Among the botanicals, neem oil was found to be the most effective, providing superior control compared to other plant extracts. Tobacco also showed promising results, while datura, bitter apple, and milkweed exhibited relatively moderate effects.

The cost-benefit analysis indicated that the highest additional yield was obtained with lambda-cyhalothrin (1877.2 kg/ha), followed by neem oil (1719.2 kg/ha), tobacco (1383.2 kg/ha), bitter apple (889.2 kg/ha), datura (301.6 kg/ha), and milkweed (995.6 kg/ha), compared to the control. The benefit-cost ratio was highest for neem oil (1:85.9), followed by milkweed (1:82.9), tobacco (1:78.2), bitter apple (1:74.1), lambda-cyhalothrin (1:40.2), and datura (1:32.3).

These findings are in agreement with previous studies. Wyss et al. (2005) reported the superior efficacy of Padan 4G insecticide against *E. insulana*, with significant reduction in infestation. Panda et al. 2004; Jatoi et al.,) similarly observed the effectiveness of synthetic insecticides. Among botanicals, neem oil has been consistently reported as effective against bollworms (Saljoki et al., 2002), rice borers (Pathak et al., 1981; Parveen and Dhaniwali, 2001), maize stem borer and rice leaf folder (Ho et al., 2003; Bora et al., 2004), and thrips (Bhatnagar and Sharma, 1999). Bhankirin and Panwhar (2000) further confirmed the efficacy of neem formulations against neonate larvae of stem borers, while neem seed kernel extract was also found effective across multiple crops (Saxena et al., 1985; Gangoli et al., 1998). Collectively, these studies support the present findings, confirming that neem oil is the most promising botanical for spotted bollworm management in cotton.

Conclusion

The present study demonstrated that among the tested botanicals, neem oil was the most effective in reducing infestation of *E. insulana* and showed strong potential for the management of spotted bollworm in cotton. Although the chemical insecticide lambda-cyhalothrin proved to be the most effective overall, neem oil provided superior eco-friendly control compared to other botanicals and offered the best cost-benefit ratio.

Recommendations

It is therefore, recommended that neem oil be considered as a sustainable alternative for the management of *E. insulana* in cotton production systems. Further studies should be conducted to evaluate its effectiveness under different field conditions, in combination with other integrated pest management (IPM) strategies, and against a broader spectrum of insect pests.

Authors' Contributions

Conceived ideas, gave technical inputs, and supervised the research: AW Rind & BK Solangi, Overall management of the article, did the analysis, wrote abstract, methodology, wrote results and discussion section and did necessary corrections: AW Rrind,BK Solangi & I. Khatri, Wrote the introduction section of the article: RMLakho & SEA Rahimoon, MYR and SER : Wrote conclusion, studied former studies, and did citations: RM Lakho & SEA Rahimoon , Checked plagiarism and made corrections: AW Rind, SAR and MYR: Compiled research data and gave technical inputs: MY Rahimoon & SEA Rahimoon.

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Conflict of Interest

The authors declare no conflict of interest.

Sustainable Development Goals Targeted

SDG 2: Zero Hunger

SDG 12: Responsible Consumption and Production

SDG 15: Life on Land

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