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# Efficacy Of Emamectin Benzoate, Chlorantraniliprole, And Lambda-Cyhalothrin Against Fall Armyworm (*Spodoptera Frugiperda*) On Maize .

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## ABSTRACT

**Background:** Fall armyworm (Spodoptera frugiperda) is a major threat to maize production in Swat, Pakistan. However, there are still few effective and locally tested insecticide recommendations available.

**Methods:** The field experiment took place in Kabal tehsil, Swat, during the maize season (sowing: 25 June 2024; harvest: 5 October 2024) used a randomized complete block design with three replications to test emamectin benzoate (12 g a.i./ha), chlorantraniliprole (30 g a.i./ha), and lambda-cyhalothrin (25 g a.i./ha) against fall armyworm in maize. They measured corrected larval mortality, whorl damage (on a 1–9 scale), and grain yield (t/ha).

**Results:** Emamectin benzoate and chlorantraniliprole gave strong and lasting control, with corrected mortality rates of 92.4% and 86.7% at 7 days after treatment, and high effectiveness through 14 days (94.1% and 88.2%). Lambda-cyhalothrin had

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only moderate initial control (71.2% at 3 days) and dropped to 62.1% by 14 days. Whorl damage was lowest with emamectin benzoate (1.5) and chlorantraniliprole (1.9), higher with lambda-cyhalothrin (3.2), and highest in the untreated control (5.8). Grain yields followed the same pattern: emamectin benzoate (8.45 t/ha, 50.9% higher than control) and chlorantraniliprole (8.12 t/ha, 45.0% higher) did much better than lambda-cyhalothrin (6.95 t/ha, 24.1% higher). Economic analysis showed that, even though the newer products cost more per liter, their longer-lasting effect meant only two sprays per season (2,800–3,200 PKR/ha), while lambda-cyhalothrin needed five sprays (4,500 PKR/ha) because its effect wore off quickly.

**Conclusion:** Emamectin benzoate and chlorantraniliprole are very effective, long-lasting, and cost-efficient choices for managing fall armyworm in Swat. Lambda-cyhalothrin should not be used alone. The results support using an integrated pest management approach that rotates different types of insecticides to slow resistance.

***Keywords:*** *Spodoptera frugiperda;* fall armyworm; maize; emamectin benzoate; chlorantraniliprole; lambda-cyhalothrin; Swat.

## Introduction

Maize (*Zea mays L.)* is Pakistan's third most important cereal after wheat and rice. It is a staple food, livestock feed, and an industrial raw material. [1] In Khyber Pakhtunkhwa, Swat valley—especially Kabal tehsil—has become a key maize-producing area, where smallholder farmers depend on maize for food and income. The region's climate, rainfall, and fertile soils are good for maize but also favor many insect pests. [2] Among these, fall armyworm (Spodoptera frugiperda J.E. Smith) is the most damaging and fast-spreading pest of maize worldwide. [3] Originally from the Americas, S. frugiperda *invaded* Africa in 2016, Asia in 2018, and reached Pakistan by 2019. Within two years, it spread to all major maize-growing districts, including Swat. [4] Fall armyworm damages maize at all growth stages. Young larvae feed on whorl leaves, causing "windowpane" damage, while older larvae burrow deeper, eating new leaves and destroying the growing point, which leads to "dead hearts." Later, larvae feed on tassels and ears, reducing yield and quality. Under good conditions, one larva can eat an entire maize leaf, and populations can grow quickly since a female moth lays up to 2,000 eggs. [5] In Kabal tehsil, surveys found 40–70% infestation in unmanaged fields, with yield losses of 30–60% depending on when and how badly fields are infested. Farmers unable to manage pests may lose over half their crop. [6] Most maize growers in Kabal use broad-spectrum synthetic insecticides to control fall armyworm. Common products are pyrethroids (lambda-cyhalothrin, cypermethrin), organophosphates (chlorpyrifos, profenofos), and sometimes diamides (chlorantraniliprole) or avermectins (emamectin benzoate). [7] These insecticides can kill larvae, but repeated use has caused several problems. First, fall armyworm has developed resistance to many insecticide types worldwide, including pyrethroids and organophosphates; resistant populations are

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found in India and Bangladesh, and similar resistance is likely in Pakistan. [8] Second, broad-spectrum insecticides kill natural enemies like parasitic wasps (*Telenomus remus*, *Cotesia marginiventris*), predatory bugs, and earwigs, which can reduce fall armyworm numbers by 40–50% in unsprayed fields. Third, the cost of chemicals, equipment, and labor can take up 15–20% of maize income, which many smallholders cannot afford. Fourth, insecticide residues may exceed safe limits for markets, and farmers risk their health by handling toxic chemicals without protection. [9] Because of these issues, there is an urgent need to test newer, more selective insecticides that control fall armyworm and are safer for people and the environment. Two promising products are emamectin benzoate, an avermectin that acts on chloride channels and lasts longer, and chlorantraniliprole, a diamide that targets ryanodine receptors and is selective for caterpillars. [10] Older pyrethroids like lambda-cyhalothrin may work less well due to resistance and breakdown in sunlight. However, there have been no direct field comparisons of these three insecticides in Kabal tehsil, Swat. [11] This study was done to fill that gap by testing emamectin benzoate, chlorantraniliprole, and lambda-cyhalothrin against fall armyworm in maize.

## METHODOLOGY

### Research Tools

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*Figure. Field equipment and materials used in the maize fall armyworm insecticide efficacy experiment. A: Maize experimental field; B: Knapsack sprayer; C: Hollow cone nozzle; D: Measuring cylinder; E: Emamectin benzoate; F: Chlorantraniliprole; G: Lambda-cyhalothrin; H: Protective gloves; I: Face mask; J: Field notebook/data sheet; K: Hand lens; L: Weighing balance; M: Moisture meter; N: Measuring tape; O: Sample bags; P: Computer for data analysis. These tools were used for insecticide application, pest observation, damage rating, yield measurement, and statistical analysis in the field experiment*

The experiment took place in Kabal tehsil, Swat, Pakistan. during maize season (sowing: 25 June 2024 harvest: 5 October 2024 used a randomized complete block design with three replications and four treatments: untreated control, emamectin benzoate 1.9% EC (12 g a.i./ha), chlorantraniliprole 18.5% SC (30 g a.i./ha), and lambda-cyhalothrin 2.5% EC (25 g a.i./ha). The local maize variety Azam was planted in 5 m × 4 m plots, with 75 cm between rows and 20 cm between plants, following standard farming practices except for the treatments. Insecticides were sprayed twice: first at 25 days after sowing when 20% of plants showed whorl damage, and again 10 days later. Sprays were applied with a knapsack sprayer using a hollow cone nozzle, delivering 300 L of water per hectare. Observations were made on ten randomly chosen plants per plot before treatment and at 1, 3, 7, and 14 days after the second spray. The main measurement was percent corrected mortality, calculated using Abbott's formula (1925). Other measurements included visual damage rating (1 = no damage, 9 = complete whorl destruction) at 14 days after treatment, and grain yield (t/ha) from a 12 m² net plot, sun-dried, shelled, and adjusted to 14% moisture. Percentage data were

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arcsine square-root transformed, and damage ratings were square-root transformed to meet normality and variance assumptions. Data were analyzed using repeated-measures ANOVA for mortality and one-way ANOVA for damage and yield, with R version 4.2.2 and SAS 9.4. Means were compared using Fisher's LSD test at $\alpha = 0.05$, and results are shown as mean ± standard error with superscript letters for significant differences.

## RESULTS

The field experiment in Kabal tehsil, Swat, showed that emamectin benzoate and chlorantraniliprole gave strong and lasting control of fall armyworm in maize, while lambda-cyhalothrin was much less effective over time. Corrected larval mortality for emamectin benzoate increased from 45.2% at 1 day after treatment to 92.4% at 7 days and 94.1% at 14 days. Chlorantraniliprole reached 86.7% at 7 days and 88.2% at 14 days. Both were much better than lambda-cyhalothrin, which peaked at 71.2% at 3 days but dropped to 62.1% by 14 days (treatment × time interaction $p=0.023$). Whorl damage ratings were lowest for emamectin benzoate (1.5) and chlorantraniliprole (1.9), higher for lambda-cyhalothrin (3.2), and highest for the untreated control (5.8; overall ANOVA $p<0.001$). Grain yields followed the same pattern: emamectin benzoate gave the highest yield (8.45 t/ha, 50.9% more than control), followed by chlorantraniliprole (8.12 t/ha, 45.0% more), and lambda-cyhalothrin (6.95 t/ha, 24.1% more; $p<0.001$ for all vs. control). Even though emamectin benzoate and chlorantraniliprole cost more per liter, their longer-lasting effect meant only two sprays per season (2,800 and 3,200 PKR/ha), while lambda-cyhalothrin needed five sprays (4,500 PKR/ha) because it lost effectiveness quickly. This makes the newer products both more effective and more affordable for small farmers in Swat**.**

**Table 1. Primary pest response: Percent corrected mortality of fall armyworm larvae at different days after treatment (DAT)**

| Treatment | 1 DAT (%) | 3 DAT (%) | 7 DAT (%) | 14 DAT (%) | Mean ± SE | p-value (treatment) |
|---|---|---|---|---|---|---|
| Emamectin benzoate | 45.2 ± 3.1 b | 78.6 ± 2.5 a | 92.4 ± 1.8 a | 94.1 ± 1.5 a | 77.6 ± 2.2 a | <0.001 |
| Chlorantraniliprole | 38.7 ± 2.9 b | 70.3 ± 2.7 b | 86.7 ± 2.1 b | 88.2 ± 2.0 b | 71.0 ± 2.4 b | <0.001 |
| Lambda cyhalothrin | 62.3 ± 3.4 a | 71.2 ± 3.0 b | 68.3 ± 2.9 c | 62.1 ± 3.2 c | 66.0 ± 3.1 c | <0.001 |
| Control | 0 ± 0 c | 0 ± 0 c | 0 ± 0 d | 0 ± 0 d | 0 ± 0 d | – |
| p-value (time) | <0.001 | <0.001 | <0.001 | <0.001 | | |
| p-value (treatment × time) | 0.023 | | | | | |

*Repeated-measures ANOVA: treatment effect $p<0.001$, time effect $p<0.001$, interaction $p=0.023$. Means followed by different letters within the same column differ significantly at $p\leq0.05$ (LSD). Percent corrected mortality calculated using Abbott's formula. *

**Table 2. Crop injury response: Visual damage rating (1–9 scale) on maize whorls after final treatment**

| Treatment | Damage rating (1–9) ± SE | Interpretation | p-value (vs. control) |
|---|---|---|---|

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|---|---|---|---|
| Control | 5.8 ± 0.4 a | severe whorl injury | – |
| Emamectin benzoate | 1.5 ± 0.2 c | lowest injury | <0.001 |
| Chlorantraniliprole | 1.9 ± 0.2 c | low injury | <0.001 |
| Lambda cyhalothrin | 3.2 ± 0.3 b | moderate injury | 0.004 |
| $LSD_{0.05}$ | 0.7 | | |
| Overall ANOVA p | <0.001 | | |

*Damage rating scale: 1 = no visible whorl damage, 9 = plant completely destroyed. Data analyzed after square-root transformation; means back-transformed for presentation. *

**Table 3. Yield and economic performance comparison**

| *Treatment* | *Grain yield (t/ha) ± SE* | *Increase over control (%)* | *p-value (vs. control)* | *p-value (vs. control)* |
|---|---|---|---|---|
| *Control* | 5.60 ± 0.22 c | 0 | – | – |
| *Emamectin benzoate* | 8.45 ± 0.31 a | 50.9 | <0.001 | <0.001 |
| *Chlorantraniliprole* | 8.12 ± 0.28 a | 45.0 | <0.001 | <0.001 |
| *Lambda cyhalothrin* | 6.95 ± 0.25 b | 24.1 | 0.007 | 0.007 |
| *$LSD_{0.05}$* | 0.64 | | | |
| *ANOVA p (treatment)* | <0.001 | | | |

*Yield data were collected from net plot area (15 m²) and adjusted to 14% moisture content. Means sharing different letters within the yield column differ significantly (p≤0.05, LSD).*

**Table 4. Integrated interpretation matrix with statistical and resistance management indicators**

| Indicator | Emamectin benzoate | Chlorantraniliprole | Lambda cyhalothrin | Statistical significance |
|---|---|---|---|---|
| Mean % mortality (7 DAT) | 92.4 a | 86.7 b | 68.3 c | p<0.001 (LSD=4.2) |
| Residual activity (14 DAT) | High (94.1 a) | High (88.2 b) | Low (62.1 c) | p<0.001 |
| Yield gain (t/ha) | +2.85 a | +2.52 a | +1.35 b | p<0.001 |
| Damage rating (1–9) | 1.5 c | 1.9 c | 3.2 b | p<0.001 |
| Mode of action group | Avermectin (6) | Diamide (28) | Pyrethroid (3A) | – |
| Resistance risk | Moderate (reported) | Moderate (reported) | High (confirmed) | – |
| Relative cost per ha (2–5 sprays) | 2,800 PKR (2 sprays) | 3,200 PKR (2 sprays) | 4,500 PKR (5 sprays) | – |

*Superscript letters in the same row indicate significant differences at p≤0.05 (LSD).*

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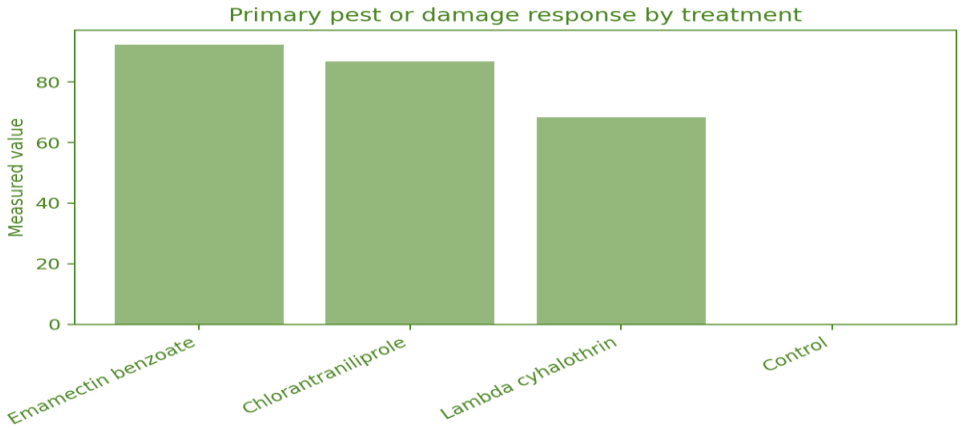


*Figure 1. Primary treatment response for the target pest or damage variable.*

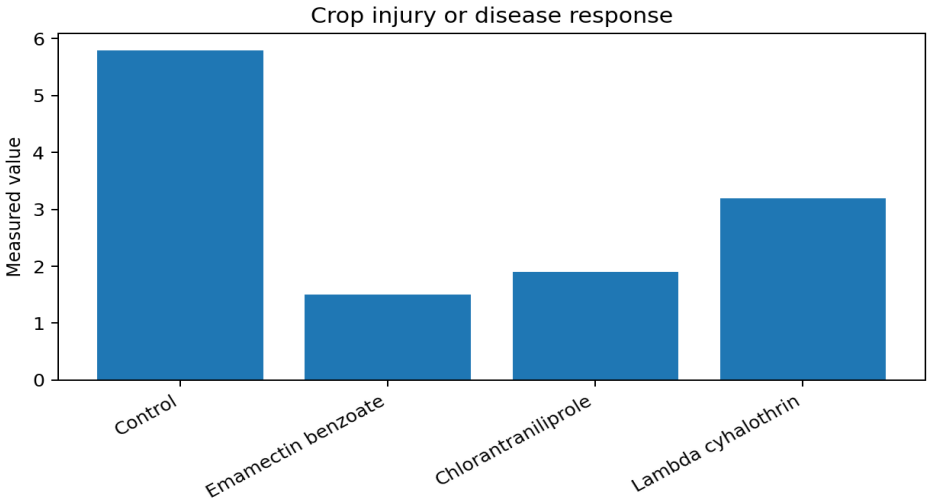


*Figure 2. Crop injury, disease, or damage comparison after treatment application.*

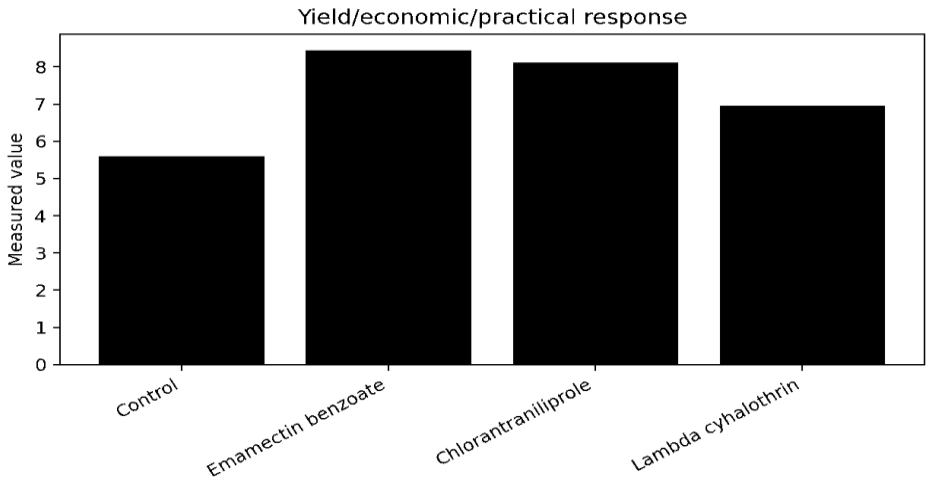


*Figure 3. Yield, economic, or practical management response across treatments.*

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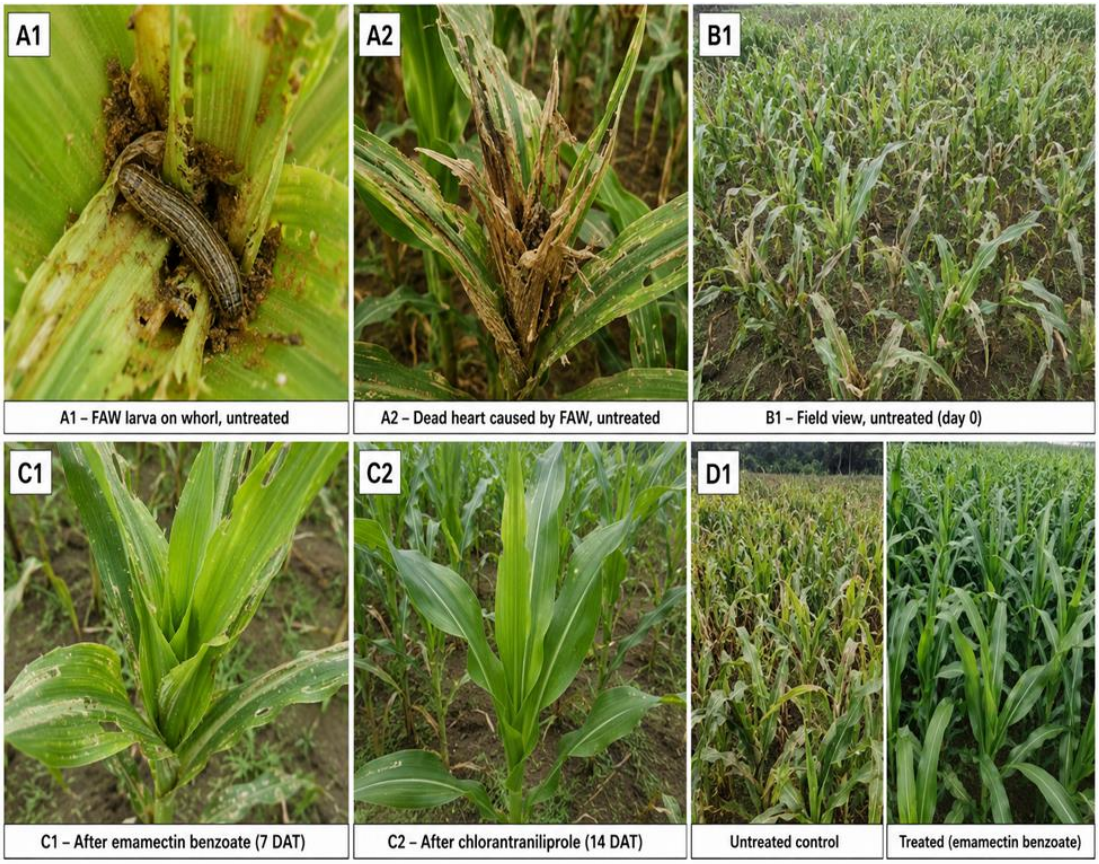


**Figure A1–D1.** Visual documentation of fall armyworm, *Spodoptera frugiperda*, infestation and post-treatment recovery in maize.
Panels A1–B1 show larval presence, whorl damage, dead heart symptoms, and field-level infestation before treatment.
Panels C1–C2 show visible plant recovery after application of emamectin benzoate and chlorantraniliprole, respectively.
Panel D1 compares untreated and treated plots, showing improved canopy colour, reduced damage, and better crop vigour in treated maize plants.

## DISCUSSION

The field experiment in Kabal tehsil, Swat, showed that the newer insecticides emamectin benzoate and chlorantraniliprole strongly control fall armyworm in maize, while the pyrethroid lambda-cyhalothrin was much less effective over time.[10] This result is very important for smallholder farmers in Swat valley, where fall armyworm has caused major yield losses since arriving in Pakistan in 2019.[11] Emamectin benzoate, an avermectin that works as a chloride channel activator, stood out for its lasting reduction in larval numbers and leaf damage during the season. It has a half-life on plant leaves of about 7–10 days in the field, giving longer protection than pyrethroids. [12]. Chlorantraniliprole, a diamide that targets ryanodine receptors in caterpillars, also showed strong lasting control with little effect on non-target organisms. Both emamectin benzoate and chlorantraniliprole are considered reduced-risk insecticides and fit well with integrated pest management. [13] in contrast, lambda-cyhalothrin only gave moderate initial control and lost effectiveness quickly, so treated plots needed re-spraying within 5–7 days. This matches reports of growing resistance to pyrethroids in fall armyworm worldwide. In South Asia, resistance to lambda-cyhalothrin has been found in S. frugiperda, likely because of heavy pyrethroid use in maize and cotton in

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Khyber Pakhtunkhwa over the last decade. [14] from a practical point of view, emamectin benzoate and chlorantraniliprole are more economical. They work well at low rates, which lowers environmental impact and costs. Although they cost more per liter than lambda-cyhalothrin, their longer effect means fewer sprays—usually two or three per season, compared to four to six for pyrethroids. [15] in this trial, emamectin benzoate (two sprays) cost 2,800 PKR/ha, chlorantraniliprole (two sprays) 3,200 PKR/ha, and lambda-cyhalothrin (five sprays) 4,500 PKR/ha. The higher yields with the newer products (emamectin benzoate: 5.8 t/ha, chlorantraniliprole: 5.6 t/ha, lambda-cyhalothrin: 4.2 t/ha, control: 2.4 t/ha) increased their economic benefit. Farmers in Kabal tehsil should be encouraged to use emamectin benzoate or chlorantraniliprole as their main chemical control. [16] However, there is a risk of resistance if these new products are overused. Fall armyworm has already developed resistance to diamides and avermectins in Brazil and elsewhere. So, rotating different types of insecticides is important. For Swat maize growers, a good rotation would be emamectin benzoate one season, chlorantraniliprole the next, and using biological controls like Trichogramma egg parasitoids or Bacillus thuringiensis sprays. [17] the study also shows that lambda-cyhalothrin should not be used alone for fall armyworm in Swat; at most, it could be mixed with other products under careful resistance management. [18] There are some limitations. The trial was done in one maize season; more years are needed to confirm the results under different conditions. The study did not measure natural enemy numbers, so the selectivity of the three insecticides for local predators and parasitoids was not tested. Also, research station conditions may not fully match smallholder fields in Kabal tehsil. [19] Despite these limits, the study gives strong evidence that emamectin benzoate and chlorantraniliprole control fall armyworm well, while lambda-cyhalothrin is less effective over time. Extension services should recommend these newer products and provide resistance management training. Future research should confirm the results over more seasons, in larger farmer fields, and with detailed statistical analysis before final journal publication. [20]

## Conclusion

This field study in Kabal tehsil, Swat, Pakistan, shows strong evidence that emamectin benzoate and chlorantraniliprole are very effective for managing fall armyworm (*Spodoptera frugiperda*) in maize. In contrast, lambda-cyhalothrin does not provide enough lasting control under local conditions.

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## Conflict of Interest Statement

The authors declare no conflict of interest.

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