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Management of Fall Armyworm In Maize Crop through various Insecticides at District Swat, Khyber Pakhtunkhwa.

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Abstract
The fall armyworm (Spodoptera frugiperda) is a major insect pest of maize, causing significant damage to crop worldwide. The experiment was conducted at farmer field in district Swat to check the effectiveness of various synthetic insecticides against fall armyworm in maize. Randomized complete block design was used having six (06) treatment including control via Chlorantranilrole 18.5% SC Spinosad 45% SC, Spinetoram 11.7% SC, Flubendiamide 39.35% SC and Chlorpyrifos 40% EC replicated three (03) times. The variety sown was Azam. After both the spray application, Spinosad (1.04, 0.52) and Chlorantraniliprole (1.07, 0.61) significantly lowered the mean density of fall armyworm and were found non-significant with each other while the control plot showed highest mean density of fall armyworm ((2.48, 2.88). The findings also indicated that Spinosad resulted in highest maize yield (9777.8 $kgha^{-1}$) and cost benefit ratio (15.82) followed by Spinetoram (9481.5 $kgha^{-1}$) and (14.62). The lowest yield was observed in control (6222.2 $kgha^{-1}$) and lower cost benefit ratio was noted in Flubendiamide (8.61). The above study concluded the effectiveness of Spinetoram 11.7% SC and Spinosad 45% SC treatments against fall armyworm infestation and ensuring profitability in maize production. So, these insecticides are recommended for best management of the insect pest.

Keywords: Fall armyworm, Maize, Synthetic insecticides, Azam, Swat.

Introduction
Maize (Zea mays L.) holds the distinction of being the most extensively cultivated crop globally, ranked 3rd after wheat and rice. It is an extremely important cereal crop consumed by birds, cattle's and human being worldwide. Maize holds a prominent position in industrial sector for its use in manufacturing of bioproducts like starch, alcohlmand oil (Khalid et al., 2023). It was cultivated 1st in South America, then distributed globally and originated to Pacific Island, India, China, Africa, Mexico, Canada, Europe and Russia (Manjunath et al., 2016). According to Food and Agriculture Organization (FAO-Stat, 2021), the area under maize cultivation was about 197 million hectares with production of 1137 million tons globally in 2020-21. In Pakistan during 2020, the area under maize cultivation was 1.41 million ha with production of 7.24 tons. Its stake in value added agriculture and GDP was 2.9% and 0.6% respectively (GOP, 2020). Khyber Pakhtunkhwa holds a pivotal role in the cultivation of maize, contributing over 50 percent of the country's maize production followed by Punjab (29%), whereas Baluchistan and Sindh collectively contribute 5% (GOP, 2022). Maize production

faces an annual decline attributed to multiple biotic and abiotic challenges, leading to yield reductions of up to 75% (Gondal et al., 2022). Among the biotic challenges, Insect pests, numbering around 40 species, attack maize during various developmental stages (Kasim et al., 2016). These insect pests of maize such as stem borers, shoot flies, cutworms, and other lepidopterans, coupled with microorganisms, pose significant threats to maize cultivation globally, spanning regions like Vietnam, India, Indonesia, Africa, Thailand, Brazil, Nepal, China, Philippines and Pakistan (Kim et al., 2020). These pests' impact both the vegetative and reproductive stages of maize (Khan et al., 2016). The Fall Armyworm (Spodoptera frugiperda) is a significant pest of maize originating from America and now a major threat in tropical regions. FAW targets over 80 plant species, including peanut, millet, rice, cotton, sorghum, and maize (Bakry and Abdel-Baky, 2023). Maize plants are exposed to the attack of FAW at all the growth stages, causes substantial damage to leaves, affecting reproduction, growth, photosynthesis, and grain yield (Chimweta et al., 2019). The female deposits their eggs in groups (150- 200 eggs/ group) on lower and upper leaf surfaces covered with fine brownish hairs in clusters. Newly emerge larva start attack on leaves, rupture the chlorophyll, resulting in an elongated white spot. At the beginning, the larva feed on leaf tissue from one side, leaving the other side intact. Thus, loaded the whorls from the feeding waste. The larva can be destructive both at flowering and vegetative stage. It also bore into the cob, ears and stem of the plant. The full-grown larva can be identified by their head having inverted Y shape cap and 8^{th} abdominal segment having 4 black spots (Shylesha et al., 2018). The adult caterpillar bore into the cob and reduce the crop quality, disrupt pollination and fertilization (Anjorin et al., 2022). The caterpillar is destructive when became 42-56 days old (Dhar et al., 2019). The adult female mostly prefers young plant for its egg-laying having 30-60 cm height. The caterpillar feed on the young leaves, resulting in hollowing of leaves (Belay, 2011). Ful grown larva become more destructive and cause defoliation, left only the stalk and ribs of corn while excessive feeding may also lead to tearing of the newly developed plants (Capinera, 2017). The adult moth under eco-friendly conditions may live for 14 days and can occupy new trains in subtropical and tropical areas (Du Plessis et al., 2020). It is important to evaluate pesticide performance against FAW in open field settings since repeated insecticide exposure can result in resistance (Khatri et al., 2020; Gahatraj et al., 2020). The need for a robust management approach arises from the growing threat this species poses to Pakistan's food security. The Current study was designed with the aim to evaluate the performance of insecticides against this nocturnal pest, contributing the enormous crop losses and their and usefulness of insecticides as an effective tool. Prior to this investigation, there was a lack of studies on this specific pest in Pakistan, making our research a foundational baseline for future inquiries. The outcomes of our study are expected to be beneficial for future researchers and applicable at the farm level.

Methodology

The study was scheduled to take place in a farmer's field in the Swat district of Khyber Pakhtunkhwa. The selected Azam variety was acquired from a seed company and sowning on last week of July 2023.

Study Area and Experimental Design

Throughout the study's duration, standard agronomic practices, including cultural, physical, and mechanical aspects, was thoroughly observed. The primary aim of the experiment was to assess the effectiveness of various insecticides against the Spodoptera frugiperda. The research design was involving a Randomized Complete Block Design (RCBD) featuring five distinct treatments and a control. The experiment was replicated three times. Standard agronomic practices were applied to all the treatments. Each sub-plot was comprising six rows, each row with 5 meters in length, with a row spacing of 0.75 meters and a plant-to-plant distance of 0.25 meters and total plot size was 22.5 meter^2. The following treatments were applied.

Table 1. Insecticides used against fall armyworm management in maize field.

SN	Common name	Formulation	Trade name	Dose/lit water
1	Chlorantraniliprole	18.5% SC	Coragen	0.4 ml
2	Spinosad	45% SC	Tracer	0.3 ml
3	Spinetoram	11.7% SC	Delegate	0.3 ml
4	Flubendiamide	39.35% SC	Belt	1.5ml
5	Chlorpyrifos	40%EC	Chopat	10 ml
6	Control	--	--	--

Data collections

All plants on each plot were visually observed for symptoms of FAW larval damage on leaves. The number of larva and damaged plant was counted from randomly selected plants before as well as 1, 3, 7, 10 and 14 days after each application. The second application was applied fifteen days after the first spray application. The number of damaged cobs was also recorded at harvest from each plot. Three randomly selected sites of one-meter row length in each treatment were observed, excluding border rows, to gather comprehensive information on the efficacy of the different treatments against FAW.

Mean density of Spodoptera frugiperda larvae plant^{-1}

Mean number of larvae per plants was calculated as follows:

$$\text{Mean Number of FAW larvae} = \frac{(\text{Number of larvae per plants})}{(\text{Total number of plants})}$$

% cobs damage

The number of FAW larvae infested cobs and total number of cobs per plot was counted. FAW damage cobs was taken, based on the larvae present on the maize cob and then converted into percent damage of cobs.

$$\text{\% of cob infested with FAW} = \frac{(\text{Number of cobs infested per plot})}{(\text{Total number of cobs plot})} \text{ x } 100$$

Yield kg/ha

For recording grain yield, six rows were harvested in sub plot with the help of sickle. Ears was removed from the harvest plants, was dry, thresh and weighed with the help of electric balance and data was then convert in kg /ha. In each treatment the weight of cobs (Kg) was recorded after each picking. It was then be converted into Kg/ha with method used by Hussain et al. (2022).

$$\text{Yield kg per ha} = \frac{\text{cobs weight (kg)}}{\text{Area harvested (m2)}} \text{ x } 10000$$

The parameters via cobs plant^{-1}, size of cobs, number of cob/plot and weight of cobs was also be calculated.

Cost benefit ratio

Cost of control in relation to its benefit was determined using the approach developed by Usman et al. (2015), to determine the most effective treatments in terms of cost benefit ratio using the formula.

$$C.\,B.\,R. = \frac{\text{Estimated Net Benefit}}{\text{Total Expenditure}}$$

Statistical Analysis

Statistix 8.1 was used to analyze different parameters through ANOVA and LSD test was applied for separating the means that were significantly different 5% level of significance.

Results

Mean density of fall armyworm larvae plant $^{-1}$ before and after 1st spray application

Table 2 illustrates the progression of mean density of fall armyworm larvae plant $^{-1}$ measurements before and after spray applications. Initially, before the first spray application, the mean density values were comparable across all plots. Across various days' post-spray application, the lowest mean density fall armyworm appeared in plots treated with Spinosad, Chlorantraniliprole and Spinetoram with values of 1.04, 1.07 and 1.15 respectively, which were statistically non-significant with each other, followed by chlorpyrifos (1.30). The control plots exhibited the highest mean density fall army worm with a value of 2.48.

Table 2. Mean density of fall armyworm larvae plant $^{-1}$ after first spray application of different treatments.

Fall armyworm larvae plant $^{-1}$ after first spray application							
Treatments	**DBT**	**1DAT**	**3 DAT**	**7DAT**	**10DAT**	**14DAT**	**Mean**
Flubendiamide	2.01a	1.81ab	1.82b	1.75b	1.64b	1.42b	1.74b
Chlorpyrifos	2.03a	1.51b	1.32c	1.15c	0.52c	1.24bc	1.30c
Spinetoram	1.92a	1.68ab	0.97cd	0.58d	0.45c	1.31b	1.15cd
Chlorantraniliprole	1.99a	1.52b	0.89d	0.58d	0.51c	0.95cd	1.07d
Spinosad	1.98a	1.45b	0.92cd	0.64d	0.40c	0.82d	1.04d
Control	2.21a	2.05a	2.49a	2.57a	2.72a	2.85a	2.48a
CV	8.03	12.33	15.98	14.06	12.94	11.62	7.00

Mean followed by different letters in rows are significantly different at 0.05 level of probability followed by LSD test.

*DBT= Day before treatment

DAT= Day after treatment

Mean density of fall armyworm larvae plant $^{-1}$ After 2nd spray application

Table 3 presents the mean density fall armyworm larvae plant $^{-1}$ variations before and after the second spray application. Day Before treatment after 2nd spray application the lowest mean density of fall armyworm was recorded in plot treated with Spinosad (0.82) which was found similar with Chlorantraniliprole (0.95), followed by Chlorpyrifos (1.24). The highest mean density was noted in untreated plot (2.85). After different days of spray application, the lowest mean density of fall armyworm larvae plant $^{-1}$ was recorded in plot treated with Spinosad (0.52) and Chlorantraniliprole (0.61) which was statistically non-significant with each other. Followed by Chlorpyrifos (0.90), Spinetoram (0.98), and exhibited significantly non-significant with each other. While the highest mean densities of fall armyworm larvae plant $^{-1}$ was recorded in untreated plot (2.88).

Table 3. Mean density of fall armyworm larvae plant $^{-1}$ after Second spray application of different insecticides.

Fall armyworm larvae plant $^{-1}$ after Second spray application							
Treatments	**DBT**	**1DAT**	**3 DAT**	**7DAT**	**10DAT**	**14DAT**	**Mean**
Flubendiamide	1.42b	1.19b	1.07cd	1.82b	1.67b	1.58b	1.46b
Chlorpyrifos	1.24bc	1.13b	1.24bc	0.88c	0.45cd	0.46c	0.90c
Spinetoram	1.31b	1.20b	1.48b	0.83c	0.65c	0.44c	0.98c
Chlorantraniliprole	0.95cd	0.92bc	1.09bcd	0.40d	0.21d	0.07d	0.61d
Spinosad	0.82d	0.72c	0.82d	0.44d	0.24d	0.10d	0.52d
Control	2.85a	2.86a	2.86a	2.87a	2.92a	2.93a	2.88a
CV	11.62	11.61	15.60	16.71	14.08	16.19	10.20

Mean followed by different letters in rows are significantly different at 0.05 level of probability followed by LSD test.

Effect of different treatment on various aspects of maize production

The table 4 provides a detailed comparison of different treatments' effects on various aspects of maize production. Spinetoram treatment resulted in the highest fresh weight of cobs, with an average of 41.08 grams per cob. This was closely followed by Spinosad, which yielded cobs weighing 39.73 grams on average. In contrast, the Control group had the lowest fresh cob weight at 27.53 grams, indicating significantly inferior growth under natural conditions without treatment. The longest cobs, measuring an average of 25.08cm, were likewise displayed by Spinetoram. Plants treated with Spinosad yielded cobs that measured an average of 22.73 cm in length. The Control group, on the other hand had the shortest cobs, measuring an average of just 16.19cm. The treatments that produced the most cobs per plant on average were Spinetoram and Spinosad; each treatment produced an average of three cobs per plant. As a result of low output in the absence of treatments, the Control group had the lowest cobs per plant, an average of just 1.33 cobs per plant. With the lowest percentage of infested cobs (14.33%), spinetoram was found to be beneficial in reducing pest infestations. Good pest control was also demonstrated by the Spinosad treatment, with an infestation rate of 17%. On the other hand, the Control group's 85.67% infestation rate was noticeably greater, emphasizing how vulnerable untreated plants are to pests.

Table 4. Effect of different treatment on the maize fresh weight cobs (g), cobs length (cm), cobs per plant, and infested cobs

Treatment	Fresh weight cobs (g)	Cobs length (cm)	Cobs per plant	% infested cobs
Flubendiamide	37.47b	22.14b	2.67a	19.33bc
Chlorpyrifos	36.53b	24.19ab	2.67a	23.67b
Spinetoram	41.08a	25.08a	3.00a	14.33c
Chlorantraniliprole	37.25b	21.49b	2.67a	16.00c
Spinosad	39.73a	22.73ab	3.00a	17.00c
Control	27.53c	16.19c	1.33b	85.67a
CV	6.24	7.27	17.01	10.25

Mean followed by different letters in rows are significantly different at 0.05 level of probability followed by LSD test.

Cost benefit Ratio of different Treatments

Table 5 present the cost-benefit ratio (CBR) of various treatments employed for managing fall armyworm infestation. It was observed that all tested treatments yielded profitability with positive CBR values. Notably, Spinosad exhibited the highest profitability with a (CBR: 15.82), followed closely by Spinetoram (CBR: 14.62), Chlorantraniliprole (CBR: 13.18), and Chlorpyrifos (CBR: 12.83) respectively. Conversely, Flubendiamide showed the least profitability with a (CBR: 8.61). Yield data indicated that Spinosad was found superior with maximum yield of 9777.8 kg/ha followed by spinetoram 9481.5 kg/ha, while the lowest yield was noted in control 6222.2 kg/ha.

Table 5. Cost benefit ratio of different chemical insecticides against fall army worm.

Treatments	Yield kg/ha. A	Gross income Rs. B	Cost of control C	Return over Control D	Estimated net Benefit. (Rs. ha^{-1}) E=(D-C)	C: B F=(E/C)
Flubendiamide	8148.1	325924	8945	77036	68090.33	8.61
Chlorpyrifos	8888.9	355556	8316	106668	98351.1	12.83
Spinetoram	9481.5	379260	8918	130372	121453.1	14.62
Chlorantraniliprole	9185.2	367408	8991	118520	109528.8	13.18
Spinosad	9777.8	391112	8992	142224	133231.7	15.82
Control	6222.2	248888				

Kg=40Pkr

Discussion

The study was conducted on the effect of different chemical control against fall armyworm in maize crop at District Swat, Khyber Pakhtunkhwa in field. The present study showed significant effect on chemical insecticides against fall army worm in maize crop. Across various days of different spray application, plots treated with Spinosad, Spinetoram, Chlorantraniliprole, and Chlorpyrifos consistently displayed the lowest mean density of fall armyworm larvae plant^{-1} was observed. On the other hand, control plots consistently had the highest mean density of fall armyworm larvae plant-1, whereas flubendiamide consistently displayed higher mean densities of the same. This outcome is aligned with the findings of Ali et al. (2023). Furthermore, when compared to other insecticides, Chlorantraniliprole 20% SC performed better, providing effective control against FAW larvae within 3 days of application, as reported by Ahmed et al. (2022) and Susanto et al. (2021) using 38% Chlorantraniliprole in a laboratory setting. After the second round of spraying, the Chlorantraniliprole-treated plot showed the lowest mean density of fall armyworm larvae plant-1. This result supports the study by Boukouvala and Kavallieratos (2021), which shown that the WG formulation of chlorantraniliprole was more effective than the SC formulation at controlling pests in maize. Research by Sisay et al. (2019), Kong et al. (2021), Ahmed et al. (2022), and Altaf et al. (2022) has repeatedly shown that chlorantraniliprole is a potential choice for suppressing Spodoptera spp. Mumtaz et al. (2022) reported similar results indicating the efficacy of chlorantraniliprole and chlorpyrifos. It is recommended that these artificial pesticides be essential parts of integrated management plans for S. frugiperda in Pakistan. Merely 14.33% of cobs were impacted by the chemical pesticide Spinetoram, indicating significant success in lowering cob infestation. With a 17.00% pest infestation rate, spinosad treatment was found to be effective as well. Conversely, the untreated Control group had a noticeably greater infestation rate of 85.67%, highlighting the fact that untreated plants are more vulnerable to pests. The results of Hardke et al. (2011) are consistent with these findings. Furthermore, with a damage percentage of 29.64%, Chlorantraniliprole, Spinosad, and Spinetoram proved to be an efficient combination for regulating FAW in maize. Similar outcomes were noted in the research project carried out by Bajracharya et al. (2020). The treatment of spinosad produced the maximum amount of maize, averaging 9777.8 kgha-1. Closely after, the application of Spinetoram produced a notable yield of 9481.5 kgha-1. The lowest yield, 6222.20 kgha-1, was shown by the Control group, indicating the critical importance that effective pest management plays in maximising crop productivity. Similar results of increased yields in maize fields treated with spinosad were reported by Srujana et al. (2021). Additionally, Nonci et al. (2021) found that fields treated with spinetoram and spinosad produced higher maize yields than those treated with chlorantraniliprole. On the other hand, research by Sharma et al. (2023), Deshmukh et al. (2020), and Bajracharya et al. (2020) consistently showed that the lowest yields were recorded in control areas.

Conclusion

The study highlights the efficiency of synthetic insecticides in controlling S. frugiperda infestations, including Spinetoram 11.7% SC, Spinosad 45% SC, and Chlorantraniliprole 18.5% SC. These pesticides were effective instruments for reducing infestations in maize crops because they quickly reduced S. frugiperda larvae impacts and shown high toxicity in field settings. However, it is crucial to combine chemical management with an Integrated Pest Management (IPM) strategy in order to reduce the likelihood that S. frugiperda will become resistant to pesticides.

Recommendations

1) Include treatments for spinosad and spinetoram in insect pest management plans.
2) Continue tracking of pest populations in order to take prompt action.

3) Further investigations should be carried out to evaluate the durability of treatments.
4) Educate farmers on efficient insect pest control techniques.

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