RESEARCH

Field Efficacy of Different Insecticides Against Fall Armyworm (*Spodoptera frugiperda* J.E. Smith) in Spring Maize (*Zea mays* L.)

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Abstract

An experiment was conducted from February to June 2022 to determine the effectiveness of different insecticides in controlling fall armyworm (*Spodoptera frugiperda*: FA) under field conditions. The experiment followed a randomized complete block design (RCBD) with 5 treatments and 4 replications. Insecticides were applied three times at 7-day intervals. The treatments included: T1 - untreated or control (water spray), T2 - Cypermethrin 5% + Chlorpyriphos 50% EC, T3 - Chlorantraniliprole 18.5% SC, T4 - Emamectin Benzoate 5% SG, and T5 - Spinetoram 11.7% SC. Data were collected for the number of live larvae, damage to the top four leaves and whorls, and yield attributes. The results showed that the lowest FA infestation was observed in the plots treated with Chlorantraniliprole 18.5% SC, while the highest infestation was observed in the control group. The highest yield (7.52 t/ha) was obtained from the Emamectin Benzoate treatment, while the lowest yield (5.74 t/ha) was recorded in the control group. Among the different control measures, spraying Chlorantraniliprole 18.5% SC at 7-day intervals was found to be the most effective method to control FA in spring maize variety TX-369, achieving 100% efficacy. These results provide valuable guidance to growers in selecting effective insecticides for FA control. This study addresses the challenge of FA management in maize crops while aligning with multiple Sustainable Development Goals (SDGs).

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Statement of Sustainability: By evaluating the efficacy of different insecticides, this work contributes to SDG 2: Zero Hunger by reducing crop losses and improving food security. It also aims to support SDG 1: No Poverty, by safeguarding the livelihoods of farmers. In addition, this research aligns with SDG 15: Life on Land by considering the environmental impact of insecticide use and promoting sustainable pest management practices. By integrating insecticides into an integrated pest management (IPM) framework, this work contributes to SDG 14: Life Below Water and SDG 15: Life on Land by reducing reliance on chemical control methods and conserving biodiversity. In addition, current research supports SDG 12: Responsible Consumption and Production by guiding farmers in the targeted use of insecticides, minimizing environmental and health impacts, and addressing pesticide resistance. Overall, our research aims to achieve multiple SDGs, including zero hunger, zero poverty, life on land, life underwater, responsible consumption, and production.

1. Introduction

The maize (*Zea mays* L.), a member of the Poaceae family, is an important cereal crop grown extensively in temperate, subtropical, and tropical regions of the world (Sangle et al., 2020). In Nepal, maize occupies a prominent position as the second most cultivated crop after rice in terms of both area and production, with an annual growth rate of 5% from the previous year. Maize accounts for approximately 25.02% of the total cereal production in Nepal (Govind et al., 2018). Globally, maize accounts for 12% of primary crop production, with a total production of 1.2 billion tons in 2020 (FAO, 2021). In Nepal, maize production is about 2,997,733 tons, spread over an area of 979,776 hectares, with an

average productivity of 3.06 tons per hectare (MoALD, 2022). Maize cultivation is suitable for altitudes ranging from 800 meters to 2500 meters, where the climate is hot and dry, with minimum and maximum temperatures ranging from 20 to 27 °C. Optimal maize growth requires well-drained, fertile soils with high water-holding capacity and a pH range of 5.5 to 8, although soil fertility should be low to moderate (Sidar et al., 2017). Maize production in Nepal faces several challenges, especially in the Terai region, where various pests cause significant economic losses. Among these challenges, insect pest infestation is a common problem that poses a threat to maize crops from sowing to harvesting and storage.

According to Bhandari and Koirala (2021), maize crops in Nepal are attacked by 53 different pest species, of which 12 to 15 are particularly active and destructive. The major pests observed in different ecological regions of Nepal include white grubs (*Phyllophaga* spp. and *Cyclocephala* spp.), stem borers (*Chilo partellus*), armyworms (*Spodoptera* spp. and *Mythimna* spp.), cutworms (*Agrotis* spp.), blister beetles, maize aphids, wireworms, maize shoot fly, flea beetles, and field crickets. Among these pests, the fall armyworm (FA), scientifically known as *Spodoptera frugiperda* (J.E. Smith), has emerged as a significant threat to corn production. The first outbreak of FA in Nepal was recorded in Nawalparasi district on May 9, 2019 (Bajracharya et al., 2019). FAs are polyphagous and can attack more than 180 plant species belonging to 42 different families (Chhetri, 2019). They are globally recognized as economically important pests that pose a serious threat to food security (GC et al., 2019). The migratory nature of FAs, covering a distance of 100 km per night, combined with their ability to cause extensive damage in a short period, results in significant yield losses in maize production (Chhetri, 2019; K. Bhusal and Bhattarai, 2019). As a result, Nepal is becoming increasingly dependent on and demanding maize from other countries (Bista et al., 2020).

In Argentina, FA infestation results in the highest yield loss (15-73%) in maize production (Bista et al., 2020). Two strains of FA have been identified, each with different host plant preferences. The corn/maize strain (C-strain) feeds primarily on maize, cotton, and sorghum, while the rice strain (R-strain) targets rice and pasture grasses. These strains differ in pheromone composition, mating behavior, and host range (Prasanna et al., 2018). They also have different biological characteristics, such as varying resistance to pesticides or genetically modified (GM) maize due to genetic exchange (Cock et al., 2017; CABI, 2019). FA eggs are typically laid in clusters, with each cluster containing approximately 100-200 eggs. Eggs are usually found on the upper or lower side of the leaves, stem, or funnel of maize plants (CABI, 2017). They can be white or gray and are often covered with a tuft of hair on the female's anal region, although they can sometimes be hairless (Firake et al., 2019). Eggs are generally spherical (Bista et al., 2020). After hatching, newly emerged FA caterpillars exhibit a green coloration during the 1st to 2nd instars, which later turns brown to black during the 3rd to 6th instars (CABI, 2017). Mature larvae reach a length of 3 to 4 cm and have a white inverted "Y" shaped mark on their dark blackheads and four black spots arranged in a square pattern on the 8th abdominal segment (Bhandari and Koirala, 2021).

FA larvae have three white dorsal lines and bright lateral lines running along the body (Bista et al., 2020). The pupal stage is characterized by a loose cocoon enclosed in an earthen cell that measures 1.3 to 1.7 cm and is glossy brown (GC et al., 2019). Adult FA moths are gray-brown (CABI, 2017). Kandel and Poudel (2020) noted that male moths are smaller than females and have triangular white spots on the tip and center of their wings, along with a mottled appearance on the forewings. As voracious feeders, FAs can cause damage to nearly all stages of potential host plants. Larvae are commonly found on young leaves, leaf whorls, tassels, or cobs (Assefa and Ayalew, 2019). During feeding, young larvae consume green tissue from the lower surface of maize leaves, resulting in elongated, papery, window-like damage symptoms (Lamsal et al., 2020). Third, fourth, and fifth instar larvae create holes and scratches on the leaf surface, causing damage to the whorls. Sixth-instar larvae defoliate heavily and leave a significant amount of fecal matter in the leaf whorl (Suby et al., 2020).

FA infestation can cause cessation of plant growth and development, failing cob or tassel formation (Sagar et al., 2020). Damage symptoms caused by FA include loss of photosynthetic area, reduced reproduction, lodging (stem breakage), and structural damage to the whorls of the maize plant (Harrison et al., 2019). In Nepal, FA, if left unchecked, can cause maize yield losses of approximately 20-25%, which has a significant impact on farmers and the economy of maize farming (Pradhan, 2022). Currently, FA control is primarily achieved using synthetic insecticides. However, this method is associated with high costs, the potential for environmental contamination, the development of chemical resistance, and the risk of pest resurgence (Assefa and Ayalew, 2019). Previous studies have demonstrated the

effectiveness of certain chemical insecticides, such as spinosad, Spinetoram, and Chlorantraniliprole, in controlling FA. However, there is a lack of research specifically evaluating the efficacy of these insecticides in combination with other commonly used chemicals, including Emamectin Benzoate, Chlorpyrifos, Cypermethrin, Lambda-cyhalothrin, Deltamethrin, Betacycflatherin, and Betacycflatherin, which are widely used by growers but are reported to be less effective against FA. In addition, there is a need to determine the economic threshold for the use of chemical insecticides in FA management.

Therefore, this research aims to address these research gaps by evaluating the efficacy of different chemical insecticides, including those commonly used by farmers, against FA infestation in maize.

2. Material and Methods

The field research was conducted from the third week of February to the third week of June 2022. Below are further details regarding the materials and methods used in the experiment.

2.1. Research Site

The experiment was conducted in a farmer's field in Ward No. 6 of Jhapa Rural Municipality, Jhapa District, which is about 38 km west of Bhadrapur, the district headquarters of Jhapa. This area is located in the inner Terai region of Nepal. The geographical coordinates of the field are approximately 26°32'46.6" N latitude and 87°53'23.15" E longitude. The altitude of the field is approximately 92 meters above sea level. The region experiences an annual rainfall of about 2000 mm and the maximum temperature reaches 42°C in summer and drops to 10°C in winter. The soils in the area are predominantly within the highly acidic to neutral pH range of 5.5–7.5, which is highly suitable for corn production.

2.2. Plant Material

The research trial was conducted using the TX-369 hybrid, one of the most popular spring maize varieties in tropical areas. A popular hybrid variety like TX-369 was used in this research because it is more directly applicable to farmers in the target region. The variety was provided by the National Agriculture Research Council, Nepal.

2.3. Field Preparation

The field was prepared for planting by plowing with a disk harrow, followed by two rounds of rotavator to properly cultivate the main field. The final rotavator pass was made one day before planting to coincide with the final layout of the experiment. During this process, all plant debris and weeds were removed from the field, ensuring a clean environment for the experiment.

2.4. Fertilizer Application

Before plowing, the field received a uniform application of farmyard manure (10 t/ha) spread evenly over the entire area. Chemical fertilizers including diammonium phosphate (DAP), potassium ammonium phosphate (MOP), and urea were also applied. Following the general recommendation of 150:60:40 kg NPK/ha, the first split dose of urea (7.25 kg), the full dose of DAP (6.87 kg), and MOP (3.52 kg) were applied. The second and third doses of urea were then side dressed during the first irrigation and grounding phases, respectively. This fertilization plan was implemented to provide the necessary nutrients for the corn crop.

2.5. Planting and Plant Establishment

Seeds of the hybrid variety of Tx-369 were sown on February 16, 2022, maintaining the spacing of 60 × 25 cm (R-R × P-P). Two seeds per hill were sown at a depth of 3–5 cm. There were four rows in each plot and the total number of plants in each row was sixteen.

2.6. Intercultural Operation

2.6.1. Weed Management

After three weeks of sowing, the plants were thinned, leaving only one plant per hill. This thinning process helps maintain proper plant spacing and reduces competition between plants. The first weeding was done manually 25 days after sowing (DAS) to remove any competing weeds that could hinder the growth of the maize plants. The second weeding and grounding were done at 40 DAS and 55 DAS, respectively.

2.6.2. Irrigation

The irrigation was done using a water motor pump set. Four irrigations were carried out throughout the research at different stages which include: the seedling stage, knee height stage, tasseling stage, and grain filling stage.

2.6.3. Insecticidal Application

The decision to apply a standard insecticide was based on three specific criteria: the number of adult insects caught in pheromone traps, the percentage of plants with pinhole damage (10–20%), and the number of plants with shothole damage (10–20%). A knapsack sprayer was used to ensure uniform distribution of insecticide throughout the field. Precautions were taken to prevent spray from drifting onto adjacent plots. During spraying, efforts were made to prevent the coalescence and runoff of spray droplets into the soil and to ensure that the entire crop was thoroughly covered with the spray material. After applying each insecticide at the labeled rate, the sprayer was properly washed and cleaned. Before each application, the sprayer was calibrated to deliver the correct dose to the plants and avoid unnecessary waste of insecticide. This calibration process included determining the amount of water needed for each plot. The first spray was made on March 23, 2022, followed by the second spray on March 30, and the third spray on April 6, 2022. These sprays were applied according to the established schedule to effectively control the target pests and mitigate any potential damage to the corn crop.

2.6.4. Harvesting and Threshing

The maize crop was harvested manually on June 17, 2022. During the harvest, the moisture content of the maize grains was measured using a moisture meter to ensure proper drying and storage conditions. After harvesting, the next step was threshing, which was done using a hand-held device called a corn sheller. This device helps to separate the grains from the cobs. Once the grains were separated, the next task was to clean them. Winnowing, a process of tossing the grains in the air to allow the lighter chaff and debris to be carried away by the wind, was used for cleaning purposes. Finally, the weight of the harvested maize grains was measured using an electronic scale. This step helps determine the yield of the crop and provides accurate measurements for further analysis and record-keeping.

2.7. Experimental Design

On June 17, 2022, the maize crop was harvested manually. During the harvesting process, the moisture content of the maize grains was measured using a moisture meter. This measurement is important for determining the optimal drying and storage conditions for the harvested grains. The next step, which took place on June 18, 2022, was to thresh the harvested maize. A hand-held device called a corn sheller was used to separate the grains from the cobs. This device simplifies the process and ensures efficient grain separation. After threshing, the separated grains underwent a cleaning process. Winnowing, a traditional method of separating the grain from any remaining chaff or debris, was used. This technique involves tossing the grains in the air, allowing the lighter chaff to be carried away by the wind while the kernels fall back to the ground or into a container.

2.7.1. Treatment Details

There were five treatments for pest control, which are organized in the following way:

Table 1. List of treatments with formulations, rates, and trade names.

Treatments	Formulations	Doses	Trade Name
Control plot (water spray)	-	-	-
Cypermethrin + Chlorpyrifos	5% EC+ 50% EC	1.5 mL/L	Dada 505
Chlorantraniliprole	18.5 % SC	0.4 mL/L	Cover
Emamectin Benzoate	5 % SG	0.4 g/L	Volga
Spinetoram	11.7 % SC	0.3 mL/L	Largo

T: Treatment; SC: Suspension concentrate; EC: Emulsifiable concentrate; Soluble granules.

2.8. Observation and Data Collection

Data were collected from 12 randomly tagged plants per plot using the Davis scoring scale from 0 to 5. Observations were recorded three times with a 7-day interval between each recording. Observations focused on the presence or absence of live larvae and the presence or absence of foliar damage on the upper four leaves and the whorl of the plants. Yield data was then the subject of recording. The parameters for which data were recorded included:

2.8.1. Damage on Upper Four Leaves and Whorls

Foliar damage on the upper four leaves and whorls was recorded from the selected 12 plants. Data was taken 24 h before each spray and 24 h, on the 2nd day, 4th day, and 6th day after each spray. A total of 3 sprays were done.

2.8.2. Number of Live Fall Armyworm (*S. frugiperda*) Larva

The number of live larvae was recorded from 12 randomly selected plants from each plot before each spray and 24 h, 2nd, 4th, and 6th day after each spray. Data was recorded at a 7-day interval.

2.8.3. Yield

The total grain weight from each plot was recorded at the time of harvesting. 1000 g weight per plot and moisture percent of the grains were also recorded. Grain yield was calculated using the formula provided by (Ngoune and Mutengwa, 2019).

$$\text{Grain yield (t/ha)} = \frac{\text{FW (kg/plot)} \times (100 - \text{HMP}) \times \text{S} \times 10000}{(100 - \text{DMP}) \times \text{NPA} \times 1000}$$

Where, FW: Fresh weight of ear; HMP: grain moisture percentage at harvest; DMP: desired moisture percentage i.e., 15%; NPA: net harvest plot area, m^2; S: Shelling coefficient, i.e., 0.8.

2.8.4. Scoring Scale for Foliar Damage by Fall Armyworm (*S. frugiperda*)

Scoring of foliar damage on upper leaves and whorl was done from twelve randomly selected plants based on the scoring scale given below:

Table 2. Scoring scale (0-5) for assessment of foliar damage due to FA.

Score	Damage Symptoms/Description
0	No visible feeding symptoms on upper leaves and whorl
1	Papery window damage symptoms on upper leaves and whorl
2	Few small holes on the upper leaves and whorl
3	Ragged holes on upper leaves and partially whorl damage
4	Whorl and upper leaves extensively damaged
5	Whorl completely destroyed and plant dying due to extreme defoliation

8.5. Calculation

The population reduction over control (PROC) percentage was calculated by using the Modified Abbots formula given by Fleming and Retnakaran (1985):

$$\text{PROC (\%)} = \left(1 - \frac{T_a \times C_b}{T_b \times C_a}\right) \times 100$$

Where, T_a: Population of insects after treatment application; T_b: Population of insects before treatment application; C_a: Population of insects in control after treatment application; C_b: Population of insects in control before treatment application.

$$\text{Increase or Decrease of Yield over Control (\%)} = \frac{X2 - X1}{X2} \times 100$$

Where, X1 is the yield from untreated control; X2 is the yield obtained from the respective treatment plot.

2.9 Statistical Data Analysis

The recorded data were then entered and organized in a Microsoft Excel 2013 (Microsoft Corporation, Redmond, Washington, United States). GenStat software (15th edition, VSN International Ltd., Hemel Hempstead, United Kingdom) was used to analyze the tabulated data and account for variance errors. To normalize the data and minimize variance, all population data were square root transformed using the formula √(X+0.5). A comprehensive analysis of variance (ANOVA) was performed on the transformed data, followed by Duncan's multiple range test (DMRT) to separate means and identify significant differences between treatments or groups.

3. Results

3.1. Monitoring of Adult Fall Armyworm (*S. frugiperda*) Moths

The adult FA moths were detected in the FA trap approximately 10 days after the emergence of the maize plants (Figure 1). During this early stage, maize seedlings are highly vulnerable to pest damage and can be killed by the larvae (Taylor et al., 2012). Initially, three moths were observed in the trap, which increased to 11 moths within a week, and then to 23 moths within an 11-day interval. Based on the criterion of 10% or 20% of plants showing pinhole-type damage, the need for pest control arose 24 days after plant emergence. Consequently, the first insecticidal treatment was administered the day following the capture of 23 moths in the pheromone trap. Up to this point, a total of 42 moths had been captured, with 23 moths captured on the day before the insecticidal application. The larval population at the time of the insecticidal treatment was likely relatively high and consisted primarily of susceptible early-stage larvae. Before the second spray, a cumulative total of 20 moths were captured, and during the third spray at a 7-day interval, nine adult moths were observed in the trap. The graph also illustrates the presence of other armyworm species in the trap, with seven adult moths of *Mythimna separata* observed before both the first and second sprays, while no moths were observed before the third spray in the FA trap.
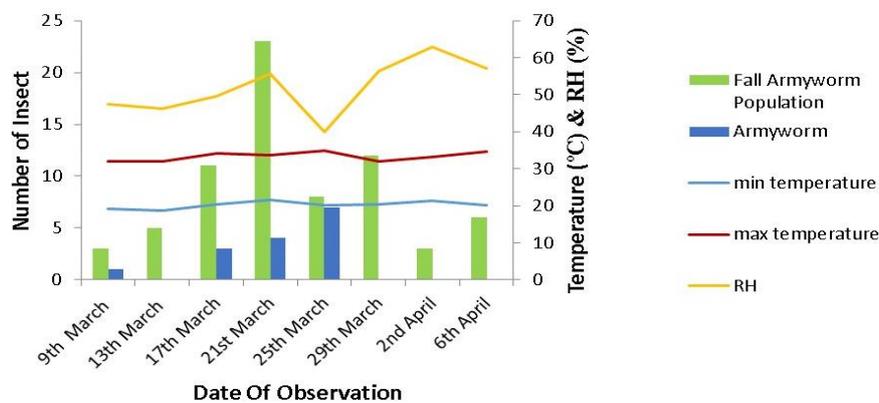

Figure 1. Graphical diagram showing the number of insect populations captured in FA trap on different dates of monitoring.

3.2. Damage on Upper Leaves and Whorls

The percentage of plants with symptoms of damage by FA larvae on the upper leaves and whorls, with their average damage score, is given in Table 3. Based on damage symptoms on the whorl and upper four leaves, Chlorantraniliprole was found to be superior to all other treatments. Damage symptoms were recorded in 20.83 percent of the maize plants after the first spray, which was reduced to less than 10.41 percent and 2.08 percent after the second and third sprays, respectively.

Table 3. The percentage of plants with fall armyworm larvae damage symptoms on upper leaves and whorls with their average foliar damage score.

Insecticides	Percent Plant with Whorl Average Foliar Damage Score					
	Damage Symptoms			Scoring		
	AFS	ASS*	ATS*	AFS	ASS	ATS
Chlorantraniliprole	20.83[a]	10.41[a]	2.08[a]	2-3	1	1
Spinetoram	27.08[a]	18.75[ab]	2.08[a]	1-2	1	1
Emamectin Benzoate	37.50[a]	31.24[bc]	10.41[a]	3	2	2
Cypermethrin + Chlorpyrifos	47.83[ab]	39.58[c]	45.83[b]	2-3	1-2	2
Control	68.75[b]	81.25[d]	87.50[c]	4	4	4
F-test	*	**	**			
LSD$_{0.05}$	26.33	18.27	19.52			
CV (%)	43.2%	33.4%	56.5%			
SEM (±)	8.73	6.06	6.45			

AFS: After the first spray, ASS: After the second spray, ATS: After the third spray, *Significant at 5% level of significance, **Significant at 1% level of significance, CV: Coefficient of variance, LSD: Least Significant Difference, SEM: Standard error of the mean.

The average foliar damage score was 1-3 with few papery window damage symptoms and ragged holes on upper leaves. Spinetoram was found to be the second most effective insecticide based on damage symptoms in the whorl and

upper leaves. Around 27.08 percent of maize plants in Spinetoram treated plots were found damaged by FA larvae after the first spray which reduced to 18.75 and 2.08 percent after the second and third spray respectively. The average damage scoring scale ranged between 1-2 with papery windows and few holes in leaves and whorl. Cent percent of maize plants were found damaged in control plots and the damage score was 4 showing extensive damage in whorl and upper leaves. Similarly, there was a slow reduction in the damage symptoms in the Emamectin Benzoate-treated plots with the average damage scoring scale ranging from 2-3 (few small and ragged holes on upper leaves and whorl). However, the performance of Cypermethrin+Chlorpyrifos was not consistent after the first and second sprays.

3.3. Effect on Population Reduction of Fall Armyworm (*S. frugiperda*)

The mean number of insect populations per treatment and percentage of reduction over control after spraying different insecticides at different time intervals during spring in maize is presented here:

3.3.1. First spray

The results of the study indicated that initially, the insect population per plant did not show any significant differences, suggesting an even distribution of infestation across the plants before spraying. However, the data collected on the effects of different insecticides on the number of FA larvae at various time intervals revealed significant differences among the treatments. All the treatments were found to be significantly more effective than the untreated control in reducing the larval population of FA at 24 h, 2 days, 4 days, and 6 days after spraying (Table 4). Specifically, the data recorded at 24 h after spraying showed significant differences among the treatments. The percentage of reduction in the larval population varied among the treatments, ranging from 37.14 to 93.49%. Chlorantraniliprole exhibited the lowest population of FA larvae and demonstrated a substantial reduction compared to the control, with a reduction rate of 93.49%. Emamectin Benzoate and Spinetoram also showed significant reductions in larval populations, with rates of 72.62 and 63.50%, respectively. On the other hand, the Cypermethrin + Chlorpyrifos treatment exhibited the lowest reduction in larval population at 37.14%.

Table 4. Effect of different treatments on the number of FA larvae in different time intervals after the first spray.

Treatments	Insect Population Per Plant	24 h	PROC	2 Days	PROC	4 Days	PROC
Emamectin Benzoate	0.62^a (1.02)	0.18^b	72.62%	0.04^a (0.73)	92.90%	0.02^a (0.72)	96.45%
Chlorantraniliprole	0.29^a (0.88)	0.02^a	93.49%	0.04^a (0.70)	84.82%	0.02^a (0.70)	92.41%
Spinetoram	0.27^a (0.87)	0.24^{bc}	63.50%	0.04^a (0.70)	83.70%	0.02^a (0.70)	91.85%
Cypermethrin + Chlorpyrifos	0.24^a (0.86)	0.16^b	37.14%	0.08^a (0.76)	63.33%	0.08^a (0.76)	63.33%
Control	0.33^a (0.91)	0.35^c	-	0.30^b (0.89)	-	0.30^b (0.89)	-
F-test	NS	**		**		**	
LSD$_{0.05}$	0.47	0.10		0.12		0.13	
CV (%)	14.8%	5.3%		6.5%		6.9%	
SEM (±)	0.15	0.03		0.04		0.04	

PROC: Percentage of reduction over control, ^{NS}Non-significant, **Significant at 1% level of significance, CV: Coefficient of variance, LSD: Least significant difference, SEM: Standard error of the mean.

The treatment Emamectin Benzoate outperformed among rest of the treatments on the 2nd and 4th days with 92.90% and 96.45% reduction, which was statistically at par with Chlorantraniliprole (92.41%) and Spinetoram (91.85%) reduction. However, the reduction percentage remained consistent on both the 2nd and 4th day in Cypermethrin + Chlorpyrifos treated plot (63.33%). The incidence activity of the pest reappeared on the 6th day after spraying so, a second spraying was done.

3.3.2. Second Spray

The data in Table 5 indicate that initially the lowest population was recorded in Chlorantraniliprole (0.14; mean no. of live larvae) treated plot which was at par with Spinetoram (0.16) and Emamectin Benzoate (0.16) treated plot. The highest larval population was recorded in treatment second (0.22). The experimental result presented in Table 5 shows that the maximum reduction was recorded in the treatment of Chlorantraniliprole (100% reduction) followed by Spinetoram and Emamectin Benzoate (70.83%). The lowest reduction was observed in the treatment Cypermethrin + Chlorpyrifos (57.57%). Results presented in Table 5 revealed that the percentage reduction over control ranged from 23.19-100% and 14.33-100% on the 2nd and 4th day after treatment application. Apart from the treatment of Chlorantraniliprole, at this time interval, Spinetoram (100%) reached the highest reduction percent followed by Emamectin Benzoate (69.82%-83.17%). The treatment Cypermethrin + Chlorpyrifos caused the least reduction (23.19-

14.33%) among all the treatments on the 2nd and 4th day respectively. The larval population was observed on 6th day after spraying, so a third spraying was performed.

Table 5. Effect of different treatments on the number of FA larvae in different time intervals after the second spray.

Treatments	Insect Population Per Plant	24 h	PROC	2 Days	PROC	4 Days	PROC
Chlorantraniliprole	0.14[a] (0.91)	0.00[a]	100%	0.00[a] (0.70)	100%	0.00[a] (0.87)	100%
Spinetoram	0.16[a] (0.85)	0.04[a]	70.83%	0.00[a] (0.70)	100%	0.00[a] (0.80)	100%
Emamectin Benzoate	0.16[a] (0.80)	0.04[a]	70.83%	0.04[a] (0.73)	69.82%	0.02[a] (0.70)	83.17%
Cypermethrin+ Chlorpyrifos	0.22[ab] (0.81)	0.08[a]	57.57%	0.14[ab] (0.80)	23.19%	0.14[b] (0.72)	14.33%
Control	0.35[b] (0.81)	0.30[b]	-	0.29[b] (0.88)	-	0.26[b] (0.70)	-
F-test	NS	**		**	-	**	-
LSD$_{0.05}$	0.14	0.10		0.148		0.08	
CV (%)	6.90	5.60		7.50		4.30	
SEM (±)	0.0491	0.03		0.049		0.03	

PROC: Percentage of reduction over control, NSNon-significant, **Significant at 1% level of significance, CV: Coefficient of variance, LSD: Least significant difference, SEM: Standard error of the mean.

3.3.3. Third spray

The data presented in Table 6 demonstrate that initially, the lowest population of FA larvae was observed in the plot treated with Chlorantraniliprole (0.04 mean number of live larvae), which was comparable to the plots treated with Spinetoram (0.12) and Emamectin Benzoate (0.10). On the other hand, the highest larval population was recorded in the plot treated with Cypermethrin + Chlorpyrifos (0.26). Furthermore, the data collected on the effects of different insecticides on the number of FA larvae at various time intervals showed that all the treatments were significantly more effective than the untreated control in reducing the larval population of FA at 24 h, 2 days, 4 days, and 6 days after spraying. Specifically, the treatment with Chlorantraniliprole exhibited the highest PROC value (percent reduction of larvae) at 100%, indicating the most effective reduction in the larval population after 24 h of spray. This was followed by Spinetoram (79.62%) and Emamectin Benzoate (75.55%), showing significant reductions in the larval population. The treatment with Cypermethrin + Chlorpyrifos demonstrated the least reduction in larval population at 62.39% after 24 h of spray.

All three treatments Chlorantraniliprole, Spinetoram, and Emamectin Benzoate are at par with 100% reduction in larval population over the untreated plots at all 2nds, 4th and 6th days after spray. However, the treatment Cypermethrin + Chlorpyrifos recorded 68.26% and 89.42% reduction on the 2nd and 4th days after spray respectively.

Table 6. Effect of different treatments on the number of FA larvae in different time intervals after the third spray.

Treatments	Insect Pest Population Per Plant	24 h	PROC	2 Days	PROC	4 Days	PROC
Chlorantraniliprole	0.04[a] (0.85)	0.04[a]	100	0.00[a] (0.70)	100	0.00[a] (0.70)	100
Spinetoram	0.12[a] (0.87)	0.12[a]	79.62	0.00[a] (0.70)	100	0.00[a] (0.70)	100
Emamectin Benzoate	0.10[a] (0.73)	0.10[a]	75.55	0.00[a] (0.70)	100	0.00[a] (0.70)	100
Cypermethrin+ Chlorpyrifos	0.26[b] (0.77)	0..26[b]	62.39	0.06[a] (0.74)	68.26	0.02[a] (0.72)	89.42
Control	0.22[b] (0.78)	0.22[b]	-	0.16[a] (0.81)	-	0.16[a] (0.81)	-
F-test	**	**		**		**	
LSD$_{0.05}$	0.10	0.08		0.05		0.54	
CV (%)	5.3%	4.60		3.10		3.10	
SEM (±)	0.03	0.02		0.01		0.01	

PROC: Percentage of reduction over control, **Significant at 1% level of significance, CV: Coefficient of Variance, LSD: Least Significant Difference, SEM: Standard Error of Mean

3.4. Yield (ton/ha) of Maize

Among the tested insecticides, it was observed that the highest yield was obtained from the plot treated with Emamectin Benzoate (7.52 t/ha), which was comparable to the yield from the Chlorantraniliprole treatment (7.42 t/ha). The next best-performing treatments were Spinetoram (6.66 t/ha) and Cypermethrin + Chlorpyriphos (6.07 t/ha). The lowest yield was recorded in the untreated control plot, with a yield of 5.74 t/ha. In terms of the increase in yield compared to the control, the Emamectin Benzoate treatment showed the highest improvement, with a 30.80% increase over the control plot. On the other hand, the Cypermethrin + Chlorpyrifos treatment had the lowest increase in yield, with a 5.69% improvement over the control plot.
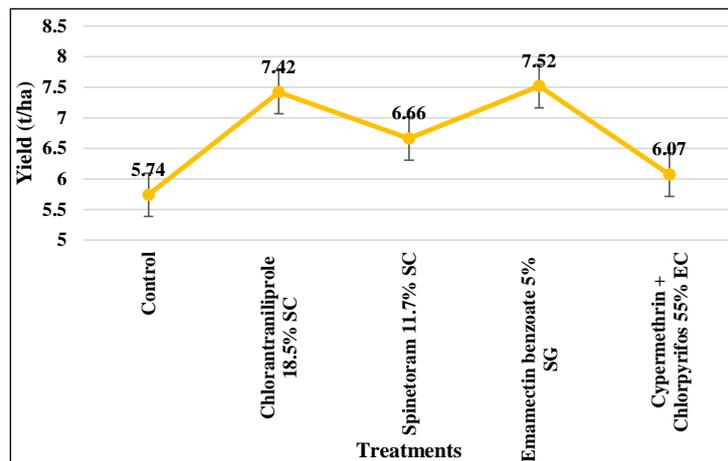
Figure 2. Graphical representation of the effect of different insecticides on the yield of maize.

4. Discussion

There were significant differences observed among the treatments in terms of reducing FA larvae populations at various time intervals after treatment application (Kumar, 2021). This aligns with the study conducted by Bharadwaj et al. (2020), which also reported significant reductions in the populations of FA larvae with the application of different insecticides. Our study builds upon these findings and provides additional evidence for the effectiveness of insecticides in controlling FAs. Notably, after the third spray, live larvae were not found in the maize plants treated with Chlorantraniliprole, Spinetoram, and Emamectin Benzoate. These results are consistent with the promising outcomes reported by Dahal et al. (2022), who found that these insecticides were effective in reducing FA populations. The absence of live larvae indicates the successful control and suppression of the pest population in the treated plots. Based on the observed parameters of percent plant infestation, percent plants with foliar damage by larvae, and damage score, Chlorantraniliprole and Spinetoram emerged as the most effective insecticides in reducing FA infestation in our maize research field. These findings align with a greenhouse experiment conducted by Sisay et al. (2019), where Chlorantraniliprole and Spinetoram were found to be highly effective in reducing foliar damage in maize compared to the untreated control. The consistent results across different studies reinforce the notion that Chlorantraniliprole and Spinetoram are reliable options for managing FA infestations and minimizing crop damage.

In line with our results, several studies have highlighted the efficacy of Chlorantraniliprole and Spinetoram in controlling FA infestation. For instance, a study by Wang et al. (2023) demonstrated that Chlorantraniliprole effectively reduced FA populations in maize fields. Similarly, Spinetoram has shown promising results in reducing FA damage in the study conducted by Deshmukh et al. (2020). Comparing our findings with other studies, it is worth noting that the efficacy of insecticides can vary depending on factors such as geographic location, crop variety, and pest populations. For example, a study by Beuzelin et al. (2022) reported varying effectiveness of Chlorantraniliprole and Spinetoram against FA populations in different regions. They found that Chlorantraniliprole was highly effective in some regions but less so in others, indicating the importance of considering local conditions when selecting insecticides for FA management. In addition to Chlorantraniliprole and Spinetoram, other insecticides have also been studied for FA management. A study by Mallapur et al. (2019) highlighted the effectiveness of Emamectin Benzoate in reducing FA infestation and minimizing crop damage. Similarly, a study by Kushwaha (2022) reported the efficacy of Lambda-cyhalothrin in controlling FA populations in maize fields. Furthermore, some studies have explored the potential of biological control agents for FA management. For instance, a study by Thumar et al. (2020) investigated the efficacy of the entomopathogenic fungus *Beauveria bassiana* in reducing FA populations. They found that the application of *B. bassiana* significantly reduced larval populations and resulted in reduced crop damage. It is important to acknowledge that while our study contributes valuable insights, further research is needed to explore the long-term sustainability and potential ecological impacts of these insecticides. For instance, a study by Susanto et al. (2021) emphasized the need to evaluate the impact of insecticides on non-target organisms, such as beneficial insects and pollinators, to ensure the overall ecological balance in agricultural systems. Integrated pest management (IPM) approaches that combine cultural, biological, and chemical control methods should be considered for comprehensive fall armyworm management. A study

by Lunagariya et al. ([2020](#)) demonstrated the effectiveness of combining insecticides with cultural practices, such as planting resistant maize varieties and implementing proper crop rotation, in reducing fall armyworm infestation and minimizing the reliance on chemical control.

These comparisons highlight the efficacy of Chlorantraniliprole and Spinetoram across different studies, supporting their effectiveness in controlling fall armyworm infestation and reducing foliar damage in maize crops. The consistent findings across multiple studies provide robust evidence for the potential use of these insecticides as valuable tools in integrated pest management strategies for fall armyworm control. It is important to note that while our study focused on the specific geographic location and maize variety, further research is needed to validate these findings across different regions, crop varieties, and growing conditions. Additionally, future studies should consider the long-term sustainability and potential ecological impacts of these insecticides, including their effects on non-target organisms and the development of resistance in pest populations. Overall, the results obtained in our study, along with the comparison to other related studies, underscore the significance of Chlorantraniliprole and Spinetoram as effective options for fall armyworm management in maize cultivation. These findings contribute to the growing body of knowledge on integrated pest management strategies and provide valuable insights for farmers in their efforts to mitigate fall armyworm infestation and protect maize yields.

5. Conclusion

Fall armyworm (*S. frugiperda*) poses a significant threat to maize and other Poaceae crops, necessitating effective insect-pest management strategies. To address this issue, we conducted this research to determine the most effective insecticides for fall armyworm management under field conditions. Our study recorded data on live larvae presence, damage on upper leaves and whorls, and yield. Chlorantraniliprole consistently demonstrated superior performance in reducing live larvae populations, followed by Spinetoram and Emamectin Benzoate. Chlorantraniliprole achieved a reduction of 93.49% to 100% in live larvae after the third spray, while Emamectin Benzoate positively influenced yield performance with 7.52 tons/ha. Additionally, Chlorantraniliprole exhibited effectiveness in reducing damage symptoms in the whorl and upper leaves. The study highlights the significance of using chemical insecticides to decrease pest populations and mitigate infestation and damage. Based on our findings, we recommend Chlorantraniliprole 18.5% SC as the preferred insecticide for controlling fall armyworm in spring maize (TX-369) at Sarnamati, Jhapa. Despite the positive outcomes, it is essential to acknowledge certain limitations of our study. The research focused on a specific geographic location and maize variety, and further investigations are required to validate the findings across different regions and crop varieties. Moreover, the study primarily assessed short-term efficacy, warranting future research on long-term sustainability and potential ecological impacts.

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Institutional/Ethical Approval: Not applicable.

Data/Supplementary Information Availability: Not applicable.

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