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Evaluation of the Efficacy of Five Chemical Insecticides in the Protection of Maize against the Moth *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae) in Burkina Faso

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Abstract

Maize production in Burkina Faso faces a number of constraints, the main one being attacks by insect pests. One of these insects is the fall armyworm (*Spodoptera frugiperda* J.E. Smith). Control of this insect began with the application of chemical insecticides, which are ineffective in the long term and give resistance problems. This study aims to evaluate the efficacy of five insecticides in order to determine the level of resistance of *Spodoptera frugiperda* to these insecticides. The effectiveness of insecticides was evaluated in the field using a Fisher block experimental design with five repetitions and six treatments. The parameters evaluated concerned the number of larvae at all stages and the damage observed on maize plants and cobs. The work was carried out at the Farako-Bâ station during the rainy season of 2023-2024 and at the Bama station during the dry season of 2023-2024. The results obtained in the rainy season showed that Chlorantraniliprole and Indoxacarb were more effective than the untreated control and the other insecticides tested. The rate of plants and cobs attacked was 0.59% and 32.34% respectively in plots treated with Chlorantraniliprole. However, the rate of plants and cobs attacked was 1.52% and 44% respectively for the plots treated with Indoxacarb. In the dry season, Chlorantraniliprole, Indoxacarb and Emamectin benzoate were the most effective. The rate of plant attack in plots treated with Chlorantraniliprole was 0.52%, while the rate of cob attack was 1.35%. The plots treated with Indoxacarb had 1.92% and 5.96% of plants and cobs attacked respectively. The plots treated with Emamectin benzoate had 0.63% and 7.95% of plants and cobs attacked respectively. These results show that these insecticides can be used to manage this pest.

Subject Areas

Agricultural Sciences, Entomology

Keywords

Spodoptera frugiperda, Chemical Insecticides, Maize, Resistance, Burkina Faso

1. Introduction

In Burkina Faso, the rural sector occupies a predominant role in the national economy and agriculture contributes 25% [1] [2]. Agricultural production is dominated by cereals (sorghum, millet, maize, rice and fonio), which occupy more than 70% of the area sown annually [2]. Among cereals, maize is the most widely grown and consumed. It is the leading cereal crop in terms of production, with an estimated production of 2,053,927 tonnes in 2023, followed by sorghum and millet [3]. Maize production could be more profitable if certain constraints, mainly damage caused by crop pests, were removed in Burkina Faso. Indeed, since 2017, maize production has been facing the invasion of a new pest called the fall armyworm [4]. It is an insect pest that attacks a diversity of plant species belonging to the order Lepidoptera and the family Noctuidae [5]. The damage caused by this caterpillar concerns all parts of the maize plant with a capacity for continuous reproduction in favorable conditions [6] [7]. In fact, when environmental conditions are favorable, 4 to 6 generations of the caterpillar can develop in one year [6]. This explains the damage of this pest on maize plants, which can lead to yield losses of 15% to 73% when 55% to 100% of maize plants are infested [8]. To deal with this pest, the use of chemical pesticides is the most widely used solution. Indeed, in 2018, the Burkinabè state made approximately 15,000 liters of pesticides available to producers to fight against this pest [9]. However, long-term use of these pesticides could lead to their ineffectiveness and also resistance problems [10]. Thus, it is necessary to know the level of sensitivity of *Spodoptera frugiperda* to chemical insecticides frequently used in its management. In Burkina Faso, the insecticides frequently used to combat armyworm mainly concern the family of pyrethroids, organophosphates, indoxacarb and avermectins [11]-[13]. This is what led us to choose insecticides belonging to these families of insecticides (Deltamethrin, Emamectin benzoate, Indoxacarb, Chlorantraniliprole and Profénofos) to carry out our study. These insecticides are of the neurotoxic type for the Deltamethrin, Emamectin Benzoate, Indoxacarb and Profenofos, and muscle contraction inhibitor type for the Chlorantraniliprole which are used in the control of leaf-eating caterpillars [14] [15]. The objective of this study is to evaluate the effectiveness of five chemical insecticides for the protection of maize plants against *S. frugiperda*.

2. Materials and Methods

2.1. Study Area

The study was conducted at the Institute of Environment and Agricultural Research (INERA) of Farako-Bâ during the rainy season 2023/2024 (July to October 2023). INERA of Farako-Bâ is located at 10 km from Bobo-Dioulasso in Burkina Faso (04˚20'W, 11˚06'N). The climate of the area is South Sudanian and the soils are sandy-silty on the surface and clayey-sandy at depth [16]-[18]. In dry season (January to May 2024), the study was carried out at the branch of the Regional Direction of Environmental and Agricultural Research of the West (DRREA-O) of INERA located in the commune of Bama (N11˚22'58.8", W004˚23'05.3"). The commune of Bama is located in the province of Houët (Hauts-Bassins region), about 30 kilometers from the city of Bobo-Dioulasso. The climate of Bama is Sudano-Guinean and the soils are clayey, silty, clay-silty, sandy-clay-silty, sandy-clay and sandy-silty [19] [20].

2.2. Materials

2.2.1. Plant Material

The plant material used for the conduct of the experiments is the espoir variety of maize. It is an intermediate variety rich in protein with a yellow to orange-yellow colour. The potential yield of this variety is 6.5 tonnes per hectare for a cycle of 97 days.

2.2.2. Insecticides Used

Table 1 presents the characteristics of insecticides used in the field. The insecticides tested were: Deltamethrin, Emamectin benzoate, Indoxacarb, Chlorantraniliprole and Profenofos. Chlorpyriphos-ethyl 250 g/kg + thiram 250 g/kg was used to treat the seed before sowing.

Table 1. Characteristics of the insecticides used.

Active ingredients	Dose	Amount of water used	Period user
Chlorpyriphos-ethyl 250 g/kg + thiram 250 g/kg	4 g/kg of seed		Sowing
Deltamethrin	0.5 l/ha	300 l/ha	Vegetative phase, flowering and fruiting
Emamectin benzoate	0.5 l/ha	300 l/ha	Vegetative phase, flowering and fruiting
Indoxacarb	170 ml/ha	300 l/ha	Vegetative phase, flowering and fruiting
Chlorantraniliprole	100 ml/ha	300 l/ha	Vegetative phase, flowering and fruiting
Profenofos	1 l/ha	300 l/ha	Vegetative phase, flowering and fruiting

2.3. Method for Evaluating the Efficacy of Insecticides on *S. frugiperda* Larvae

2.3.1. Experimental Device

The experimental device used was a Fisher block with five repetitions and six treatments (Figure 1):

- T0: Plots without treatment;
- T1: Plots treated with Deltamethrin 25 g/l at a dose of 0.5 l/ha (12.5 g of active ingredient/ha);
- T2: Plots treated with Emamectin benzoate 19 g/l at a dose of 0.5 l/ha (9.5 g active ingredient/ha);
- T3: Plots treated with Indoxacarb 150 g/l at a dose of 170 ml/ha (25.5 g active ingredient/ha);
- T4: Plots treated with Chlorantraniliprole 200 g/l at a dose of 100 ml/ha (20 g of active ingredient/ha);
- T5: Plots treated with Profenofos 500 g/l at a dose of 1 l/ha, (500 g of active ingredient/ha).

Deltamethrin, Emamectin benzoate, Indoxacarb, Chlorantraniliprole and Profenofos were compared with each other through an experimental set-up with 30 elementary plots (EP). Each EP is composed of 8 lines, two of which are border. The spacing between the lines is 0.80 m. The length of the elementary plot is 5.6 m and the width is 4.4 m, giving a surface area of 24.64 m^2. A strip of 2 m separates the individual plots as well as the repeats. The total area of the test is: ((5.6 m × 6 + 2 m × 5) × (4.4 m × 5 + 2 m × 4)) = 43.6 m × 30 m = 1308 m^2.

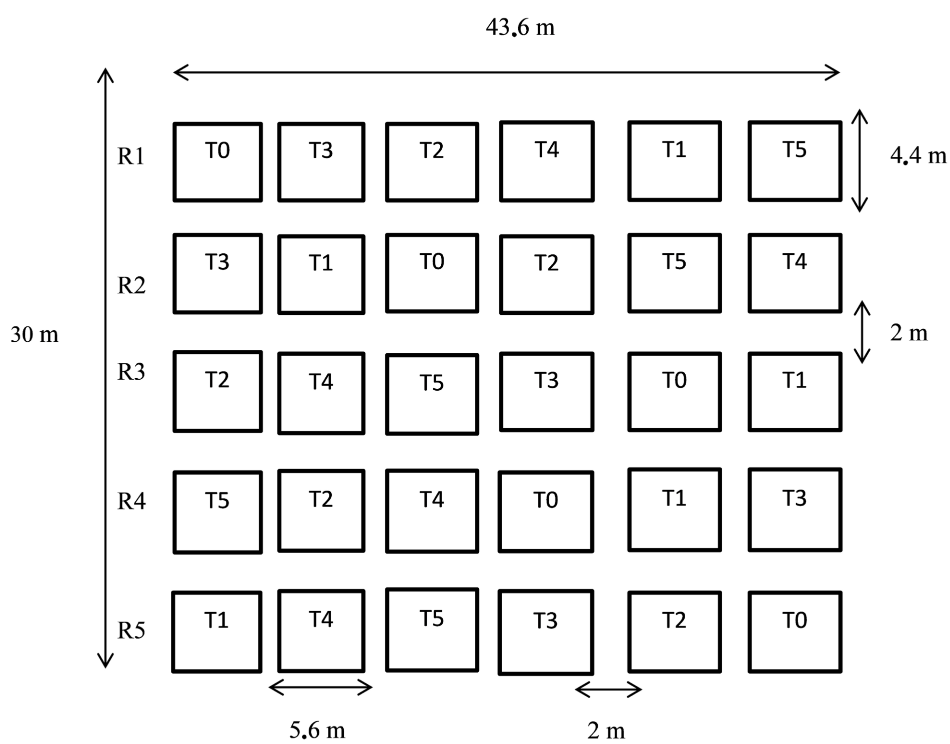

Figure 1. Experimental device (Fisher Block Test Plan).

2.3.2. Crop Management

- Sowing, fertilizing and maintaining the crop

The experimental plots were ploughed and harrowed with a tractor. Sowing was carried out manually at 3 maize grains per pocket. At emergence, the demarriage was done at 2 plants per pocket. For fertilization, NPK fertilizer was applied 14 days after sowing (DAS) at a dose of 200 kg/ha. Two doses of urea were applied at 30 and 45 DAS, 100 kg/ha and 50 kg/ha respectively. The second dose (45 DAS) of urea was carried out at the same time as earthing up. Three weedings were carried out on request in order to keep the plots clean.

- Plant protection

Insecticide applications were made between 7 and 14 days when the rate of new plants attacked per elementary plots was greater than or equal to 5% with the presence of 25 - 36 larvae/100 maize plants of different growth stages [5] [21]. Three foliar treatments were carried out at 28, 42 and 56 DAS. These sprays were carried out by an operator using a pressure device with a capacity of 16 liters.

- Observations

The evaluation of the efficacy of the insecticides tested was done before and after the application of the insecticides in the field.

Before application of insecticides

Eight DAS, we proceeded to search eggs and/or larvae of *S. frugiperda*. This was done twice a week. When larval attacks began, the number of larvae and plants attacked by EP in the field was counted.

After application of insecticides

After insecticides application, the following parameters were evaluated:

- The rate of plants and/or cobs infested by larvae:

It consisted of counting the number of plants and/or cobs per EP. The attacked plants or cobs were marked with a red woolen thread to avoid recount them next time. Observations were made every 3, 7 and 14 days on the maize plants and every 7 days on the maize cobs. Equation (1) shows the formula used to calculate percentage of plants and/or cobs attacked (IP = Infested Plants, IC = Infested Cobs).

$$\text{IP/IC} = \frac{\text{Number of plants and/or cobs attacked by } S.frugiperda}{\text{Total number of plants and/or cobs observed}} \times 100 \quad (1)$$

- Average number of live larvae: This was determined by counting the number of live larvae in each EP.
- Severity of damage to maize plants and/or cobs:

The severity of damage caused by fall armyworms to maize plants and/or cobs was evaluated using the severity scale developed by [22]. The scale developed by [22] is a scale for assessing damage to maize leaves and cobs due to the armyworm. It consists of rating each maize plant or cob on a scale of 1 to 9 where very resistant maize plants or cobs are rated 1 (no visible damage) and very sensitive maize plants or cobs are rated 9 (completely damaged). The evaluation was made on the plants and cobs of the two central lines of each EP. The leaves were evaluated once every

2 weeks. However, the cobs were evaluated at harvest. Equation (2) shows the formula used to calculate damage severity (DS) on maize plants and cobs.

$$\text{SD} = \frac{\text{Sum of scores for plants and/or cobs showing attack}}{\text{total number of plants and/or cobs evaluated}} \tag{2}$$

- Grain yield of maize:

It consisted of harvesting the cobs from the four central lines and counting the number of infested cobs. All the cobs were then dried and dehulled to determine the grain yield of the maize. Equation (3) shows the formula used for calculating grain yield of maize.

$$\text{Yield}\left(\frac{\text{Kg}}{\text{ha}}\right) = \frac{\text{dry weight of grains}(\text{kg}) \times 10000\left(\text{m}^2\right)}{\text{surface area of useful plot}\left(\text{m}^2\right)} \tag{3}$$

2.3.3. Statistical Analysis

The statistical analysis of the data was carried out using XLSTAT software (2016). Means were compared using the test of Newmann-Keuls at 5% probability threshold to check for significant differences. Items marked with an "a" in the results tables and figures are those of greatest interest.

3. Results

3.1. Rate of Plants Attacked by *S. frugiperda*

Table 2 and Table 3 show the rate of maize plants attacked by *S. frugiperda* in rainy and dry seasons. In rainy season, from 14 to 28 DAS, periods before the first insecticide application, statistical analysis of the rate of plants attacked by *S. frugiperda* showed that there was no significant difference (P = 0.481 at 14 DAS, P = 0.987 at 21 DAS and P = 0.981 at 28 DAS) between the insecticides tested and the control without treatment at the 5% threshold. During these periods of evaluation, the attack rate was highest at 28 DAS, period corresponding to the first insecticide application. In fact, 5.73% to 8.07% of plants were attacked. At 35 DAS, seven days after the first insecticide application, statistical analysis of the rate of plants attacked showed that treated plots were not significantly different from untreated plots at the 5% threshold (P = 0.121). At 42 and 49 DAS, periods corresponding respectively to the dates of the second foliar application and seven days after the second foliar application, statistical analysis showed that treated plots had significantly fewer larvae than untreated plots at the 5% threshold (P = 0.003 at 42 DAS and P = 0.001 at 49 DAS). At both evaluation periods, the insecticides tested were equivalent to each other and were more effective than the untreated control. At 56 DAS, date of the third foliar application, statistical analysis showed that there was no significant difference between treatments at the 5% threshold (P = 0.520). However, seven days after the third foliar application (63 DAS), statistical analysis of the rate of plants attacked revealed that the treated plots were significantly different from the untreated plots at the 5% threshold (P = 0.01). Plots treated with Chlorantraniliprole (0.58% attack) harboured fewer larvae than other treated plots and the plot without treatment.

Table 2. Rate of maize plants attacked by *S. frugiperda* larvae in rainy season.

Treatments	Rate of maize plants attacked by *S. frugiperda* (%) (Mean ± SD)							
	14 DAS	21 DAS	28 DAS	35 DAS	42 DAS	49 DAS	56 DAS	63 DAS
Without treatment	4.56 ± 2.08	6.43 ± 5.01	8.07 ± 3.41	12.98 ± 8.29	19.88 ± 11.97^{b}	10.87 ± 8.08^{b}	5.73 ± 9.87	3.5 ± 1.7^{b}
Deltamethrin	3.27 ± 3.42	5.61 ± 5.75	7.48 ± 4.72	3.74 ± 7.72	7.48 ± 6.06^{a}	2.45 ± 2.31^{a}	1.28 ± 2.56	2.33 ± 0.92^{ab}
Emamectin benzoate	1.05 ± 1.19	4.21 ± 6.45	5.73 ± 3.13	7.71 ± 7.48	2.22 ± 2.59^{a}	0.58 ± 1.3^{a}	1.63 ± 3.66	2.1 ± 1.28^{ab}
Indoxacarb	4.32 ± 3.82	6.19 ± 7.19	7.83 ± 6.78	1.98 ± 4.44	5.14 ± 6.26^{a}	0.00 ± 0^{a}	1.98 ± 2.46	1.52 ± 0.88^{ab}
Chlorantraniliprole	2.57 ± 3.54	4.67 ± 6.7	6.43 ± 5.23	2.57 ± 3.61	6.55 ± 5.08^{a}	1.17 ± 2.61^{a}	0.58 ± 1.3	0.59 ± 0.58^{a}
Profenofos	4.56 ± 4.3	6.31 ± 4.77	7.6 ± 7.62	7.25 ± 7.13	2.57 ± 2.82^{a}	1.87 ± 2.84^{a}	0.7 ± 1.26	1.4 ± 1.06^{ab}
P	0.481	0.987	0.981	0.121	0.003	0.001	0.520	0.01
Sign	NS	NS	NS	NS	HS	HS	NS	S

SD = standard deviation; DAS: days after sowing; Means ± SD marked with the same letter in the same column are not statistically different at the 5% threshold; NS = not significant; S = significant; HS = highly significant.

Table 3. Rate of maize plants attacked by *S. frugiperda* larvae in dry season.

Treatments	Rate of maize plants attacked by *S. frugiperda* (%) (Mean ± SD)						
	21 DAS	28 DAS	35 DAS	42 DAS	49 DAS	56 DAS	63 DAS
Without treatment	4.91 ± 6.44	7.90 ± 10.58	12.23 ± 4.82^{b}	35.00 ± 8.02^{b}	6.95 ± 4.65^{b}	9.50 ± 6.80	3.35 ± 1.31^{b}
Deltamethrin	4.93 ± 3.67	6.45 ± 5.57	5.18 ± 5.70^{ab}	26.35 ± 6.74^{b}	2.00 ± 1.12^{a}	11.38 ± 5.07	1.16 ± 0.94^{a}
Emamectin benzoate	8.81 ± 9.3	14.00 ± 11.27	1.36 ± 1.71^{a}	27.01 ± 6.93^{b}	1.75 ± 0.95^{a}	9.77 ± 5.93	0.63 ± 0.32^{a}
Indoxacarb	1.82 ± 2.5	9.45 ± 2.37	8.40 ± 6.76^{ab}	30.69 ± 11.16^{b}	1.25 ± 0.87^{a}	11.59 ± 9.33	1.92 ± 1.11^{a}
Chlorantraniliprole	4.42 ± 3.54	7.82 ± 8.59	2.27 ± 1.79^{ab}	11.93 ± 1.89^{a}	2.03 ± 1.48^{a}	5.78 ± 1.66	0.52 ± 0.36^{a}
Profenofos	5.43 ± 6.12	6.74 ± 7.32	6.74 ± 6.21^{ab}	31.64 ± 6.67^{b}	1.94 ± 1.45^{a}	12.61 ± 7.25	1.03 ± 1.19^{a}
P	0.587	0.752	0.02	0.001	0.004	0.627	0.001
Sign	NS	NS	S	HS	HS	NS	HS

SD = standard deviation; DAS: days after sowing; Means ± SD marked with the same letter in the same column are not statistically different at the 5% threshold; NS = not significant; S = significant; HS = highly significant.

In dry season, from the 21st to the 28th DAS, the rate of plants attacked by *S. frugiperda* showed that there was no significant difference between the different treatments at the 5% threshold (P = 0.587 at 21 DAS and P = 0.752 at 28 DAS). At 28 DAS, date at the first foliar application, the rate of attack on plants ranged from 6.45% to 14%. At 35 DAS, seven days after the first foliar application, statistical analysis indicated that the rates of attacked plants in treated plots were significantly different from those without treatment at the 5% threshold (P = 0.02). Plots treated with Emamectin benzoate showed significantly fewer attacks (1.36% attack) than the other treated plots and the untreated control. At 42 and 49 DAS, period corresponding respectively to the dates of the second foliar application and seven days after the second foliar application, the statistical analysis of the rate of plants attacked revealed a significant difference between the treatments at the 5% threshold (P = 0.001 and 0.004 respectively). At 42 DAS, Chlorantraniliprole was more effective. At 49 DAS, the rates of attacked plants of insecticides tested were equivalent to each other and more effective than the untreated control. At 56 DAS, the period of the third foliar application, statistical analysis revealed no significant difference between rates of attacked plants of all treatments at the 5% threshold (P = 0.627). However, at 63 DAS, the rates of attacked plants of treated plots were significantly different from the untreated plots at the 5% threshold (P = 0.001).

3.2. Density of *S. frugiperda* Larvae

Table 4 and Table 5 show density of *S. frugiperda* larvae per treatment in rainy and dry seasons. In rainy season, statistical analysis of larvae density revealed that there was no significant difference between treatments at 14, 21 and 28 DAS at the 5% threshold (P = 0.636 at 14 DAS, P = 0.386 at 21 DAS and P = 0.681 at 28 DAS). During these periods of observations, larvae density was highest at 28 DAS, date of first foliar application. The larvae density was between 0.8 and 2.6 at this date. At 35 DAS, seven days after the first foliar application, statistical analysis revealed that density of larvae were significantly different in treated plots than untreated plots at the 5% threshold (P = 0.014). However, density of larvae in the different treated plots were equally effective. At 42 DAS, the period corresponding to the second foliar application, statistical analysis of density of larvae showed that there was a significant difference between treatments at the 5% threshold (P = 0.039). At this date, the treated plots were equally effective. At 49 DAS, seven days after the second foliar application, statistical analysis showed that treated plots had significantly fewer larvae than untreated plots at the 5% threshold (P = 0.002). However, the different plots treated were equally effective. At 56 DAS, dated at the third foliar application, statistical analysis of the density of larvae revealed no significant difference between treatments at the 5% threshold (P = 0.098). However, seven days after the third foliar application (63 DAS), statistical analysis showed that the density of larvae in treated plots was significantly different from untreated plots at the 5% threshold (P = 0.012). Plots treated with Chlorantraniliprole and Indoxacarb had the lowest densities.

In dry season, from the 21st to the 28th DAS, the statistical analysis of larvae density showed that there is no significant difference between the treatments at the 5% threshold (P = 0.085 at 21 DAS and P = 0.274 at 28 DAS). However, at 28th DAS, the larvae density was higher and corresponded to the date of the first foliar application. The larvae density was between 1.8 and 6.2 at this date. Seven days after the first foliar application (35 DAS), the density of larvae of treated plots was equivalent and significantly different from untreated plots at the 5% threshold (P = 0.001). At 42 and 56 DAS, periods corresponding to the second and third foliar applications respectively, statistical analysis of larvae density showed that there was no significant difference between treatments at the 5% threshold (P = 0.494 at 42 DAS and P = 0.515 at 56 DAS). Seven days after the second and the third foliar application (49 DAS and 63 DAS respectively), statistical analysis showed that larvae density of treated plots was significantly different from the control plots at the 5% threshold (P = 0.000 at 49 DAS, P = 0.004 at 63 DAS). Larvae density of treated plots was equivalent to each other at these two dates.

Table 4. Density of *S. frugiperda* larvae per treatment in rainy season.

Treatments	Larval densities of *S. frugiperda* (Mean ± SD)							
	14 DAS	21 DAS	28 DAS	35 DAS	42 DAS	49 DAS	56 DAS	63 DAS
Without treatment	0.2 ± 0.44	1.2 ± 1.09	1.2 ± 1.09	12.20 ± 12.73[b]	40.2 ± 29.44[b]	27.6 ± 26.5[b]	11.4 ± 14.7	3.6 ± 1.51[b]
Deltamethrin	0.8 ± 1.3	1.6 ± 1.14	2.4 ± 1.14	3.4 ± 4.09[a]	26.4 ± 14.04[a]	1.6 ± 1.14[a]	3.6 ± 2.30	2.6 ± 3.20[ab]
Emamectin benzoate	1.4 ± 1.51	1.6 ± 1.14	2.6 ± 3.64	0.4 ± 0.54[a]	9 ± 5.83[a]	0.0 ± 0.0[a]	1.2 ± 1.30	1.2 ± 1.64[ab]
Indoxacarb	1.2 ± 2.16	0.4 ± 0.89	0.8 ± 0.83	0.2 ± 0.44[a]	14.2 ± 16.69[a]	0.6 ± 1.1[a]	1.2 ± 1.30	0.0 ± 0[a]
Chlorantraniliprole	0.6 ± 1.34	2.2 ± 1.92	1.6 ± 1.81	1.2 ± 2.16[a]	7.8 ± 10.80[a]	0.6 ± 0.89[a]	1.8 ± 1.92	0.2 ± 0.44[a]
Profenofos	0.2 ± 0.44	1.4 ± 1.14	2 ± 1.87	0.2 ± 0.44[a]	11.8 ± 14.85[a]	0.6 ± 0.89[a]	1.2 ± 0.83	0.8 ± 0.83[ab]
P	0.636	0.386	0.681	0.014	0.039	0.002	0.098	0.012
Sign	NS	NS	NS	S	S	HS	NS	S

SD = standard deviation; DAS: days after sowing; Means ± SD marked with the same letter in the same column are not statistically different at the 5% threshold; NS = not significant; S = significant; HS = highly significant.

Table 5. Density of *S. frugiperda* larvae per treatment in dry season.

Treatments	Larval densities of *S. frugiperda* (Mean ± SD)						
	21 DAS	28 DAS	35 DAS	42 DAS	49 DAS	56 DAS	63 DAS
Without treatment	0.0 ± 0.0	4.6 ± 4.92	11.2 ± 7.46[b]	16.2 ± 9.31	26.4 ± 14.17[b]	10.0 ± 8.86	9.8 ± 7.69[b]
Deltamethrin	0.0 ± 0.0	1.8 ± 2.68	2.8 ± 1.64[a]	10.6 ± 6.34	6.2 ± 2.48[a]	7.8 ± 3.83	1.6 ± 1.81[a]
Emamectin benzoate	0.6 ± 0.89	7.4 ± 5.17	0.4 ± 0.89[a]	10.0 ± 10.83	3.0 ± 2.44[a]	12.4 ± 12.77	1.6 ± 0.89[a]
Indoxacarb	0.0 ± 0.0	4.0 ± 4.79	0.6 ± 0.89[a]	14.2 ± 9.62	3.4 ± 1.81[a]	10.2 ± 10.35	1.6 ± 1.14[a]
Chlorantraniliprole	0.0 ± 0.0	2.0 ± 3.93	0.2 ± 0.44[a]	6.0 ± 6.55	0.0 ± 0.0[a]	2.0 ± 2.82	0.8 ± 1.09[a]
Profenofos	2.6 ± 3.71	6.2 ± 3.63	5.6 ± 4.93[a]	7.6 ± 10.71	8.2 ± 6.64[a]	6.8 ± 8.87	2.6 ± 2.60[a]
P	0.085	0.274	0.001	0.494	0.000	0.515	0.004
Sign	NS	NS	HS	NS	THS	NS	HS

SD = standard deviation; DAS: days after sowing; Means ± SD marked with the same letter in the same column are not statistically different at the 5% threshold; NS = not significant; HS = highly significant, THS = very highly significant.

3.3. Rate of Attacked Cobs

Analysis of the rate of cobs attacked by *S. frugiperda* showed that the plots treated with Chlorantraniliprole had fewer attacked cobs at the 5% threshold (32.64%) in rainy season (P = 0.045) (Figure 2). On the other hand, in dry season, statistical analysis indicated that the plots treated with Emamectin benzoate, Indoxacarb and Chlorantraniliprole were equivalent in terms of the rate of cobs attack at the 5% threshold. The rate of cobs attacked by these treatments was superior to the Deltamethrin, Profenofos treatments and the untreated control (P < 0.0001) (Figure 3).

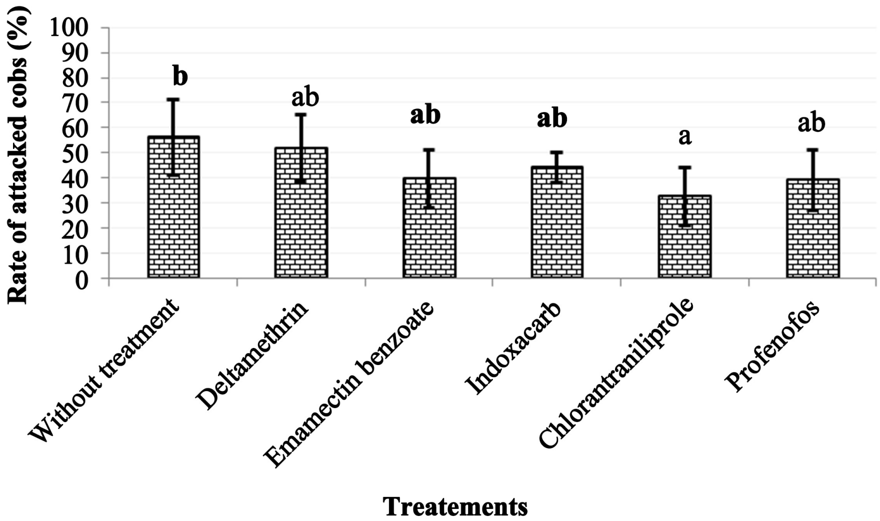

Figure 2. Rate of cobs attacked in rainy season. The letters that look similar in the figure indicate that the values at these letters do not differ statistically at the 5% threshold.

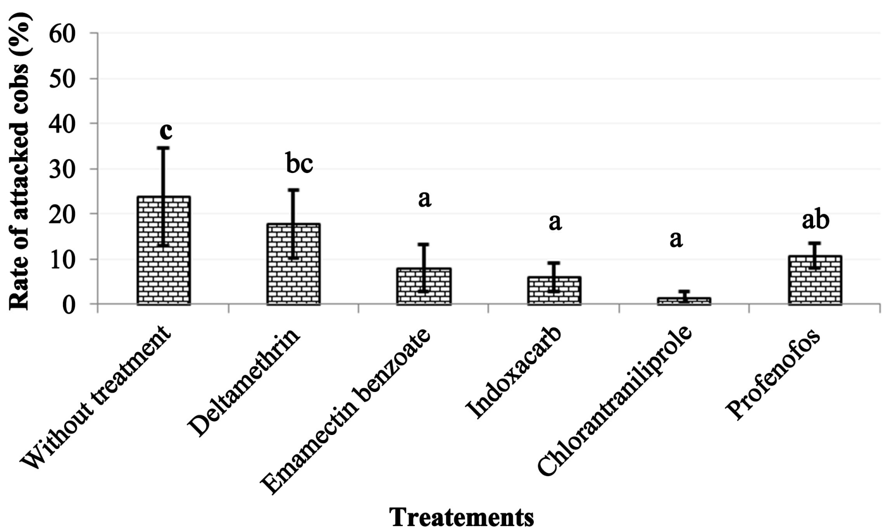

Figure 3. Rate of cobs attacked in dry season. The letters that look similar in the figure indicate that the values at these letters do not differ statistically at the 5% threshold.

3.4. Severity of Damage to Plants

Table 6 and Table 7 show the average damage scores caused by *S. frugiperda* larvae to maize plants in rainy and dry seasons.

Table 6. Severity of damage to plants in rainy season.

Treatments	Average plant damage scores (Mean ± SD)		
	28 DAS	42 DAS	56 DAS
Without treatment	2.05 ± 0.71[b]	2.83 ± 1.02[b]	2.88 ± 1.08[c]
Deltamethrin	1.77 ± 0.61[a]	2.12 ± 0.65[b]	1.95 ± 0.70[b]
Emamectin benzoate	1.75 ± 0.57[a]	1.82 ± 0.72[c]	1.51 ± 0.64[a]
Indoxacarb	1.83 ± 0.57[a]	1.98 ± 0.77[bc]	1.58 ± 0.64[a]
Chlorantraniliprole	1.88 ± 0.48[a]	1.68 ± 0.65[a]	1.83 ± 0.67[b]
Profenofos	1.85 ± 0.50[a]	1.95 ± 0.71[c]	1.81 ± 0.63[b]
P	<0.0001	<0.0001	<0.0001
Sign	THS	THS	THS

SD = standard deviation; DAS: days after sowing; Means ± SD marked with the same letter in the same column are not statistically different at the 5% threshold; THS = very highly significant.

Table 7. Severity of damage to plants in dry season.

Treatments	Average plant damage scores (Mean ± SD)		
	28 DAS	42 DAS	56 DAS
Without treatment	5.74 ± 1.76[c]	5.63 ± 2.21[c]	4.50 ± 2.07[c]
Deltamethrin	2.70 ± 1.26[b]	3.04 ± 1.59[b]	2.74 ± 1.32[b]
Emamectin benzoate	2.55 ± 1.82[b]	2.41 ± 1.89[b]	1.78 ± 1.03[b]
Indoxacarb	2.68 ± 1.66[b]	1.81 ± 1.16[b]	2.17 ± 1.42[b]
Chlorantraniliprole	1.71 ± 1.60[a]	1.50 ± 0.89[a]	1.49 ± 0.85[a]
Profenofos	2.58 ± 1.79[b]	2.39 ± 1.58[b]	2.13 ± 1.34[b]
P	<0.0001	<0.0001	<0.0001
Sign	THS	THS	THS

SD = standard deviation; DAS: days after sowing; Means ± SD marked with the same letter in the same column are not statistically different at the 5% threshold; THS = very highly significant.

In rainy season, the analysis showed that the average damage scores of treated plots were significantly different from the untreated plots at 28, 42 and 56 DAS at the 5% threshold ($P < 0.0001$). At 28 DAS, the average severity of damage was the same in all treated plots except for the untreated plots. However, at 42 DAS, Chlorantraniliprole showed the lowest average severity of damage (1.68). At 56 DAS, Emamectin benzoate and Indoxacarb showed the lowest average severity of damage (1.51 and 1.58 respectively).

In dry season, the analysis showed that treated plots showed significantly lower severity of attack than untreated plots at 28, 42 and 56 DAS at the 5% threshold ($P < 0.0001$). Chlorantraniliprole had the lowest average plant damage score at 28, 42 and 56 DAS (1.71, 1.50 and 1.49 respectively at 28, 42 and 56 DAS).

3.5. Severity of Damage to Cobs

Table 8 shows the mean scores for damage caused by *S. frugiperda* larvae to maize cobs in rainy and dry seasons. Statistical analysis revealed that treated plots showed significantly less cobs damage than untreated plots in rainy and dry seasons at the 5% threshold ($P < 0.0001$). Thus, the plots treated with Chlorantraniliprole showed the lowest score for cobs damage in both seasons (1.40 in rainy season and 1.12 in dry season).

Table 8. Severity of damage to cobs in rainy and dry seasons.

Treatments	Average score for damage to cobs (Mean ± SD)	
	Rainy season	Dry season
Without treatment	1.90 ± 1.02^{c}	1.79 ± 1.21^{c}
Deltamethrin	2.04 ± 0.90^{c}	1.53 ± 0.79^{b}
Emamectin benzoate	1.52 ± 0.77^{b}	1.37 ± 0.72^{b}
Indoxacarb	1.63 ± 0.83^{b}	1.49 ± 1.03^{b}
Chlorantraniliprole	1.40 ± 0.67^{a}	1.12 ± 0.50^{a}
Profenofos	1.79 ± 0.96^{b}	1.37 ± 0.94^{b}
P	<0.0001	<0.0001
Sign	THS	THS

SD = standard deviation; DAS: days after sowing; Means ± SD marked with the same letter in the same column are not statistically different at the 5% threshold; THS = very highly significant.

3.6. Grain Yield of Maize

In terms of grain yield, statistical analysis of the data showed no significant difference between treatments in rainy and dry seasons at the 5% threshold ($P = 0.270$, 0.298 respectively) (Table 9).

Table 9. Grain yield of maize in rainy and dry seasons.

Treatements	Grain yield kg/ha (Mean ± SD)	
	Rainy season	Dry season
Without treatment	3768.93 ± 923.96	2064.39 ± 537.35
Deltamethrin	4696.97 ± 788.32	2386.36 ± 677.59
Emamectin benzoate	5000 ± 1255.22	2500 ± 296.44
Indoxacarb	5037.87 ± 1025.17	2196.97 ± 545.63
Chlorantraniliprole	4905.30 ± 706.74	2613.63 ± 589.86
Profenofos	4602.27 ± 538.19	2784.09 ± 393.87
P	0.270	0.298
Sign	NS	NS

SD = standard deviation; Means ± SD marked with the same letter in the same column are not statistically different at the 5% threshold; NS: not significant.

4. Discussion

The efficacy of five insecticides with different modes of action on *S. frugiperda* larvae was evaluated during the rainy and dry cropping seasons 2023-2024 in field. These experiments demonstrated the efficacy of some of these insecticides on *S. frugiperda* population.

The results showed that in the rainy season, plots treated with insecticides harboured significantly fewer larvae than untreated plots after three foliar treatments. In this respect, Indoxacarb and Chlorantraniliprole were the most effective. The efficacy of these insecticides could be explained by their modes of action on *S. frugiperda* and by the fact that the larval population present in the field did not undergo selection pressure with respect to these insecticides. These results corroborate those of [23] who reported that these insecticides reduce the number of *S. frugiperda* larvae in the field. However, Deltamethrin, Emamectin benzoate and Profenofos were equivalent and less effective than Indoxacarb and Chlorantraniliprole. This could be explained by the fact that the population of larvae with which we had to deal was subject to selection pressure with regard to these insecticides. These results are in contradiction with those obtained by [24] who tested the sensitivity of *S. frugiperda* larvae to Delthamethrin and Emamectin benzoate and found that these insecticides were effective against *S. frugiperda*. However, [25] [26] found respectively that Profenofos and Deltamethrin were ineffective on *S. frugiperda* larvae.

In dry season, the five insecticides tested showed the same efficacy after three foliar treatments. This could be explained by the fact that Bama larvae are still sensitive to the various insecticides tested despite the recurrent use of these insecticides to control *S. frugiperda* in Burkina Faso [11]-[13]. These results are in agreement with those of [27] [28] who found that these insecticides reduce *S. frugiperda* larvae.

The significant reduction in the number of larvae by Chlorantraniliprole compared with the other treatments also explains its reducing effect on the rate of plants attacked by *S. frugiperda* larvae in rainy season. Thus, it was the most effective after the three foliar treatments in the rainy season. These results are similar to those of [29], who reported that this insecticide reduced *S. frugiperda* damage in sorghum.

In dry season, all the insecticides tested showed the same efficacy after the three foliar treatments. These results are in line with those obtained by [29]-[31] who found respectively that Chlorantraniliprole, Deltamethine and Emamectin benzoate reduced *S. frugiperda* damage. These results are also in line with those of [32], [33] who showed that Profenofos and Indoxacarb reduced the damage caused by *Helicoverpa armigera* on cotton and tomato respectively.

Also, the estimation of foliar damage showed a low average severity of damage for the treatments Chlorantraniliprole, Indoxacarb and Emamectin benzoate in rainy season, while in dry season Chlorantraniliprole showed the lowest average severity of damage. These results demonstrate the effectiveness of these insecticides on the population of *S. frugiperda* larvae, thus reducing their damage on maize plants. Our results are in agreement with those obtained by [29] [31] who showed in their studies that Chlorantraniliprole and Emamectin benzoate reduce the damage of *S. frugiperda*. Similarly, [33] found that Indoxacarb also reduces the damage of *Helicoverpa armigera* on tomato crops.

As for the rate of cobs attacked by *Spodoptera frugiperda* larvae, in rainy season, Chlorantraniliprole was the most effective while in dry season Chlorantraniliprole, Indoxacarb and Emamectin benzoate were the most effective. These results are in line with those of [34]. Indeed, these authors found that these three insecticides were effective both in controlling the *S. frugiperda* population and reducing its damage in the field compared to the insecticides Thiamethoxam 25 WG, Lambda cyhalothrin 2.5% EC, Spinosad 45 SC, Profenophos 50 EC, Cypermethrin 10 EC, Verticillium lecani 1.15 WP and Neem oil 3%. Thus, these three insecticides produced the maximum yield and the highest cost-benefit ratio compared to the other insecticides tested.

Regarding the estimation of *S. frugiperda* damage on maize cobs, the results of our experiments showed that plots treated with Chlorantraniliprole recorded the lowest mean damage scores on cobs during both seasons. These results corroborate those obtained by [35] who used this insecticide as a seed and foliar treatments in the protection of maize and found that it resulted in less damage from *S. frugiperda* on maize cobs.

However, it should be emphasized that long-term use of insecticides can have negative effects on biodiversity, the environment and soil. This observation was made by [36] who determined the effect of Permethrin and Cypermethrin on bacteria, cultivated and uncultured fungi and on soil enzymatic activity. Indeed, they found that these two chemical insecticides inhibit the growth of fungi by 31.7% and the enzymatic activity of the soil, thus reducing the biochemical fertility index. Also, studies carried out by [37] [38] show that the use of pesticides leads to harmful effects on beneficial insects such as pollinators and natural enemies of insect pests. Likewise, the investigations carried out by [39] [40] respectively on cotton and tomatoes show that the use of chemical insecticides can have negative impacts on the health of producers and consumers. In addition to these negative impacts, the long-term use of insecticides can also be the cause of the creation of resistant insect strains leading to the ineffectiveness of the insecticides used [41]. Also, there are biological, genetic and environmental factors (wind, humidity) that lead to the ineffectiveness of the insecticides used [41]-[43]. Indeed, environmental factors influence the distribution, persistence and degradation of chemical insecticides in the environment. Which makes pest control ineffective [42] [43]. In view of the negative impact of insecticides on the environment, biodiversity and health, we recommend the use of biological insecticides and control techniques to attract the natural enemies of pests for a more environmentally friendly fight.

5. Conclusion

The objective of this study was to evaluate the effectiveness of five insecticides

(Deltamethrin, Emamectin benzoate, Indoxacarb, Chlorantraniliprole and Profenofos) on *S. frugiperda* larvae in the field in Burkina Faso. The results of the experiments showed that in rainy season, Chlorantraniliprole was the most effective, and followed by Indoxacarb. In dry season, Chlorantraniliprole, Indoxacarb and Emamectin benzoate were the most effective with a reduction in the damage of this insect on the maize plant. These results will be used in the implementation of control programs for this maize pest in Burkina Faso.

Conflicts of Interest

The authors declare no conflicts of interest.

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