JOURNAL OF THE CAMEROON ACADEMY OF SCIENCES Vol. 20 No. 3 (AUGUST 2024)

*Research Article*

# Alternative control methods for Fall army worm in some agroecologies in Cameroon

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## Abstract

Maize cultivation in Cameroon faces threats from the fall armyworm (Spodoptera frugiperda), significantly reducing crop yields. This study explores eco-friendly, safe, and accessible pest control methods. Trials were conducted in Garoua (zone I), Foumbot (zone III), and Ntui (zone V) using six treatments: Control, Emamectin (RAPAX), Bacillus thuringiensis, Soap, A. indica oil (neem), and Bacillus thuringiensis + Emamectin. All treatments showed insecticidal effects compared to the control, with Emamectin, Bacillus thuringiensis + Emamectin, A. indica oil, and Bacillus thuringiensis being most effective. High incidence rates were found in zones I and III (55.82% and 44.17%) versus zone V (34.72%). Significant positive correlations existed between attack severity and incidence (r=0.801), larval numbers with incidence (r=0.639) and severity (r=0.420), while grain yield had significant negative correlations with incidence (r= -0.736), severity (r= -0.931), and larval numbers (r= -0.690). Yield analysis showed significant effects (P<0.05) from all treatments compared to control. Emamectin yielded 2950kg/ha, followed by Emamectin + Bacillus thuringiensis (2783kg/ha). Control treatments yielded 1100kg, while soap, A. indica, and Bacillus thuringiensis yielded 2257kg/ha, 2607kg/ha, and 2750kg/ha respectively. No significant zone effect was noted. The study emphasizes balancing economic and efficacy factors in pest control method selection, with neem oil, emamectin benzoate, and RAPAX suitable for various pest pressures and environmental conditions.

## Résumé

La culture du maïs au Cameroun est menacée par la légionnaire d'automne (Spodoptera frugiperda), réduisant considérablement les rendements des cultures. Cette étude explore des méthodes de lutte contre les ravageurs respectueuses de l'environnement, sûres et accessibles. Des essais ont été menés à Garoua (zone I), Foumbot (zone III) et Ntui (zone V) en utilisant six traitements : Témoin, Emamectine (RAPAX), Bacillus thuringiensis, Savon, Huile d'A. indica (neem) et Bacillus thuringiensis + Emamectine. Tous les traitements ont montré des effets insecticides par rapport au témoin, l'Emamectine, Bacillus thuringiensis + Emamectine, l'huile d'A. indica et Bacillus thuringiensis étant les plus efficaces. Des taux d'incidence élevés ont été trouvés dans les zones I et III (55,82 % et 44,17 %) par rapport à la zone

Received: 15/04/2024
Accepted: 03/07/2024
DOI: https://dx.doi.org/10.4314/jcas.v20i3.1

V (34,72 %). Des corrélations positives significatives existaient entre la gravité de l'attaque et l'incidence (r=0,801), le nombre de larves avec l'incidence (r=0,639) et la gravité (r=0,420), tandis que le rendement en grain avait des corrélations négatives significatives avec l'incidence (r= -0,736), la gravité (r= -0,931) et le nombre de larves (r= -0,690). L'analyse des rendements a montré des effets significatifs (P<0,05) de tous les traitements par rapport au témoin. L'Emamectine a produit 2950 kg/ha, suivie de l'Emamectine + Bacillus thuringiensis (2783 kg/ha). Les traitements témoins ont produit 1100 kg, tandis que le savon, l'huile d'A. indica et Bacillus thuringiensis ont produit respectivement 2257 kg/ha, 2607 kg/ha et 2750 kg/ha. Aucun effet significatif de la zone n'a été noté. L'étude met en avant l'importance de l'équilibre entre les facteurs économiques et l'efficacité dans le choix des méthodes de lutte contre les ravageurs, l'huile de neem, l'emamectine benzoate et le RAPAX étant adaptés à diverses pressions de ravageurs et conditions environnementales.

**Key words:** Fall Armyworm, Agroecological zone, Cameroon, Maize

## Introduction

Maize, or corn (*Zea mays L.*), stands as the foremost cereal crop globally, surpassing both wheat and rice in production. It represents 41% of the world's total cereal production, cultivated on approximately 170 million hectares and yielding an estimated 867 million tons. This equates to an average yield of 5 tons per hectare (AGPM, 2013). As a crucial carbohydrate source, maize is pivotal to the diet in Sub-Saharan Africa (FAO, 2017).

Cameroon, located in Central Africa, is characterized by diverse agroecological zones due to its varied topography, climate, and soil types. These zones are essential for understanding agricultural practices, crop suitability, and environmental sustainability. Cameroon is typically divided into five main agroecological zones: Sudano-Sahelian Zone covering regions like the Far North and parts of the North having Semi-arid climate with a short rainy season (June to September) and a long dry season. It has Sparse vegetation, mainly savannas and dry forests. The High Guinea Savannah Zone covering parts of the Adamawa region and having a tropical savanna climate with distinct wet (April to October) and dry (November to March) seasons. It has Grasslands with scattered trees and shrubs. The Western Highlands Zone covering the North West and South West regions having an Equatorial climate with abundant rainfall throughout the year, although more concentrated between March and November. It has dense forests and montane vegetation. The Humid Forest Zone with Monomodal Rainfall covering South West and Littoral regions having an Equatorial climate with one long rainy season (March to November) and a short dry season. It has dense tropical rainforests. The Humid Forest Zone with Bimodal Rainfall covering Central, East, and parts of the South regions having an Equatorial climate with two rainy seasons (March to June and September to November) and two dry seasons and dense tropical rainforests.

Each of these zones supports different types of agriculture and has distinct environmental characteristics that influence land use and farming practices. Understanding these zones is crucial for effective agricultural planning, sustainable development, and environmental conservation in Cameroon.

In Cameroon, cereals like maize constitute about 60% of a household's spending – a considerable portion of the average budget (INS, 2018). Despite an annual national demand of 1.5 million tons in 2009, local production fell short by

120,000 tons. The gap led to importing 22,600 tons of maize by 2016 (FAO, 2017). Moreover, in early 2020 Cameroon spent CFA 190 billion on food imports that could be locally produced (MINADER, 2020), with maize and its derivatives alone accounting for CFA 150 billion annually. Unfortunately, as food and feed demands have continued to rise, so has the production deficit—escalating to 350,000 tons and even reaching a peak of 600,000 tons in 2019 (MINADER, 2019). Without significant initiatives to enhance production capabilities, this deficit is likely to worsen alongside climbing demand.

Cameroon's food crop yields are severely hampered by a range of challenges, including biotic and abiotic factors. Of particular concern in recent times is the fall armyworm (FAW), which has garnered significant scientific interest due to its destructive impact on maize. This pest targets every stage of the maize lifecycle and all parts of the plant above ground, leading to considerable crop damage and yield loss without intervention (Ahissou *et al.,* 2021). The impact of FAW includes compromised photosynthesis due to foliage loss, lodging, stunted growth, and destruction of key reproductive parts like the whorl, panicle, and ears (Chimweta *et al.,* 2020). Aniwanou et al., (2021) noted that in 2016, FAW devastated over 38,000 hectares of maize in northern Benin. The resultant yield reductions can vary widely from 15% to as much as 73%, depending on several factors such as the maize's stage of growth when attacked, its variety, and farming practices (Assefa & Ayalew, 2019).

Africa suffers from significant crop losses estimated at $16 billion annually due to the Fall Armyworm, scientifically known as *Spodoptera frugiperda* (Harrison *et al.,* 2019). This devastating impact has led farmers in several nations to increasingly rely on chemical pesticides for pest management. Unfortunately, such intensive use is accelerating the development of resistance in the pest (Ndiaye *et al.,* 2022). The first incidents of Fall Armyworm damage were recorded in Cameroon in December 2015 (MINADER, 2019), and by 2017, it had spread to six out of the ten regions of the country, inflicting substantial damage on a variety of crops. Known as one of the most challenging pests for maize farming, the Fall Armyworm can lead to total crop destruction if not effectively managed. Despite efforts to combat this pest, existing control strategies, which heavily depend on synthetic pesticides, remain insufficient.

The rampant use of synthetic pesticides has resulted in significant issues like environmental contamination, pesticide resistance, and unforeseen health complications. The World Health Organization estimates that these substances are directly responsible for the deaths of 200,000 people annually (Belmain *et al.,* 2013). The United Nations Environment Programme highlights that, in sub-Saharan Africa alone, the cost of addressing pesticide-induced illnesses could soar to US$ 90 billion from 2005 to 2020 (UNEP, 2011). These challenges have spurred focused research into and development of natural pesticides.

Natural pesticides confer a twofold advantage: they not only support environmental sustainability but also control pests effectively (Mkenda *et al.,* 2015). These biological pesticides degrade swiftly in nature, reducing environmental impact and offering an eco-friendly solution for pest control. Compared to synthetic pesticides, their impact on beneficial organisms and non-target species is minimal (Mkenda *et al.,* 2015; Amoabeng *et al.,* 2013), and they provide a cost-efficient option (Mkenda *et al.,* 2015). Recent research by Dzokou et al. (2022) highlights the insect-fighting capabilities of *L. camara's* ethanolic extract against armyworms. In Cameroon, studies by Kammo *et al.,* (2019) indicate that *A. indica* is highly potent in combating fall armyworms. Research in Cote d'Ivoire assessed the effectiveness of a *B. thuringiensis*-based pesticide against three major pests—*Helicoverpa armigera, Pectinophora gossypiella,* and *Jacobiella fascialis* with positive results (Kouadio *et al.,* 2022). Rapax AS is a biological pesticide designed to target lepidopteran larvae, leveraging the bacterium *Bacillus thuringiensis* (Bt), specifically the subspecies kurstaki strain EG 2348. This strain is known for its effectiveness in controlling various pest species while being environmentally benign, making it a popular choice in integrated pest management (IPM) programs.

Emamectin-benzoate is a semi-synthetic derivative of the natural avermectin family. It is widely utilized in agricultural practices for the control of lepidopteran pests. With a high efficacy and low toxicity to non-target organisms, Emamectin-benzoate has gained popularity among farmers and agronomists. The insecticide is effective at low application rates, which minimizes environmental impact and reduces the risk of resistance development among pest populations.

Tomislav Curkovic (2016) has also confirmed the biopesticidal efficacy of soap against various crop pathogens. Despite the limited commercial success of these products, they hold significant potential for smallholder farmers in Cameroon, yet this potential is currently underutilized. The goal of this study was to assess alternate pest control agents in the battle against the Fall Armyworm (FAW) within the Agro-ecological zones I, III, and V of Cameroon.

## Materials and methods

### Study sites

In 2023, research was carried out across three distinct agro-ecological regions of Cameroon during the primary planting season. The first site was the Garoua Multipurpose Research Station at Sanguere Njoï, situated in an area spanning from 8°36" to 12°54" North in latitude and 12°30" to 15°42" East in longitude, with an elevation of 290 meters with an annual rainfall of 997.4 mm. The second location was the Foumbot site at the IRAD station, nestled in the Western Highlands. This site is perched at an altitude of 1010 meters, positioned at 5°28'37" North latitude and 10°33'50" East longitude. Its volcanic soil receives an annual rainfall of 1,538.8 mm, with the heaviest downpours occurring from July to September, and temperatures oscillating between 20°C and 24°C. The third and final site of study was the bimodal rainforest zone, specifically in the Ntui district of the Mbam and Nkim division, at the IRAD's substation. This substation stands at an altitude of 485 meters, located at 4°28'58" North latitude and 11°38'29" East longitude. The region experiences annual rainfall ranging from 1,500 to 2,000 mm, split into two separate rainy seasons that are conducive to dual cropping cycles and a diversified farming schedule. Here, temperatures vary from 20°C to 25°C. These zones were selected for their significance within Cameroon's various agro-ecological areas and their status as prominent maize-producing regions ( Fig 1).

### Maize variety

The maize variety used in this work is CMS 8704. It is a yellow open pollinated variety. The yield ranges between 3-4 t/ha with a cycle of 110 to 120 days. It is suited to agro-ecological zones I, III, IV and V. The choice of this maize variety is strongly influenced by producers and populations in these two zones.

### Botanical Insecticide

The neem seeds were collected from neem trees at IRAD Garoua, washed in tap water, dried in shade and then crushed. The crushed material was made into powder, sieved and then stored in dark, hermetically sealed bottles. Then 4 kg of powder

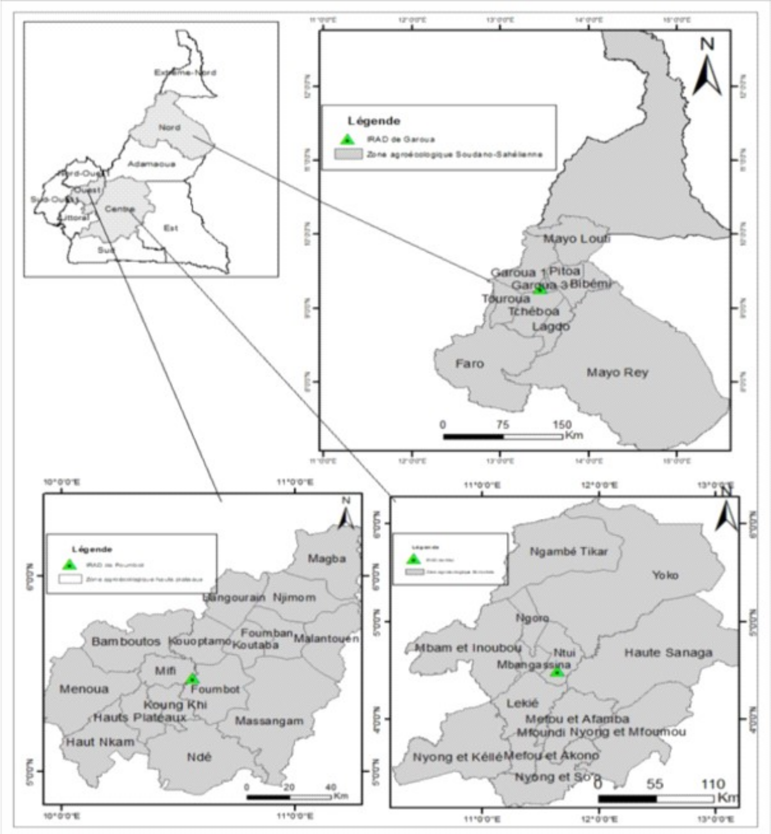

Fig 1: map of sites

was mixed with 0.5 L of hot water. The mixture was stirred into a paste and oil obtained later. Three doses were evaluated (3L/Ha, 5L/Ha and 7L/ha) for 400 L of water.

Neem seeds were collected from neem trees, washed in tap water, and dried in the shade. The dried seeds were crushed to produce a coarse powder, which was then sieved and stored in dark, hermetically sealed bottles to prevent oxidation and degradation of the oil.

Three doses of neem oil (3L/Ha, 5L/Ha, and 7L/Ha) were evaluated for effectiveness. Each dose was mixed with 400 L of water and applied to agricultural fields. The effectiveness of each dose was assessed based on pest control efficiency and crop health.

**Biological insecticide**

Rapax AS is formulated with *Bacillus thuringiensis* subspecies kurstaki strain EG 2348, an aqueous suspension concentrate. This specific strain was selected for its high efficacy against a broad spectrum of lepidopteran pests. The pesticide is marketed and distributed by Biogard, which highlights its innovative liquid formulation and broad-spectrum activity.

The European Food Safety Authority (EFSA) has conducted peer reviews of the pesticide risk assessment for Bacillus thuringiensis subspecies kurstaki strain EG 2348, affirming its safety and efficacy for use in agricultural settings. Application rate was 2 liters per hectare (dilution rate of 15 grams of product per 10 liters of water).

**Synthetic Insecticide**

Emamectin-benzoate is available in various formulations, with a common concentration being 50 g/kg. This formulation is typically presented as a wettable granule or soluble granular form, making it easy to apply in agricultural settings.

Emamectin-benzoate is distributed by Syngenta in Cameroon.

The safety and efficacy of Emamectin-benzoate have been extensively reviewed by regulatory agencies such as the European Food Safety Authority (EFSA) and the United States Environmental Protection Agency (EPA). These reviews confirm that when used as directed, Emamectin-benzoate poses minimal risk to human health and the environment

### Soap insecticide

Pure liquid soap without additives, fragrances, or detergent was used. It was dissolved in warm tap water. 1 tablespoon (15 ml) of pure liquid soap was mixed with 1 L of warm water. The mixture was shaken well before use. The application was done early in the morning or late afternoon to minimize leaf burn using a clean sprayer, ensuring thorough coverage of the plants, including the undersides of leaves.

## Methods

### Experimental design

Experiments were conducted across three distinct regions during the primary agricultural season of 2023, which coincided with late planting times and peak Fall Armyworm (FAW) infestations as reported by Djomo et al. in 2022. The experimental setup (fig 2) involved planting the maize variety CMS 8704 using a completely randomized block design, with each of the three blocks containing six plots measuring 250 square meters, summing up to a collective area of 18 plots. There were six different treatments applied: **Soap, the bacterial insecticide** *Bacillus thuringiensis*, *A. indica* oil, Emamectin, a combination of *Bacillus thuringiensis* and Emamectin, and a control treatment that received no treatment. Initially, three seeds were planted in each plot, but after two weeks, the seedlings were thinned to ensure a consistent density of two plants per hill. Plots were spaced 50 centimeters apart, while rows of sowing were maintained at 75 centimeters apart. Each plot comprised 13 rows that were each 25 meters long, with a 4-meter buffer between each block. The spacing between individual experimental units was set at 2 meters. In total, the area used for the trials spanned 6,250 square meters.

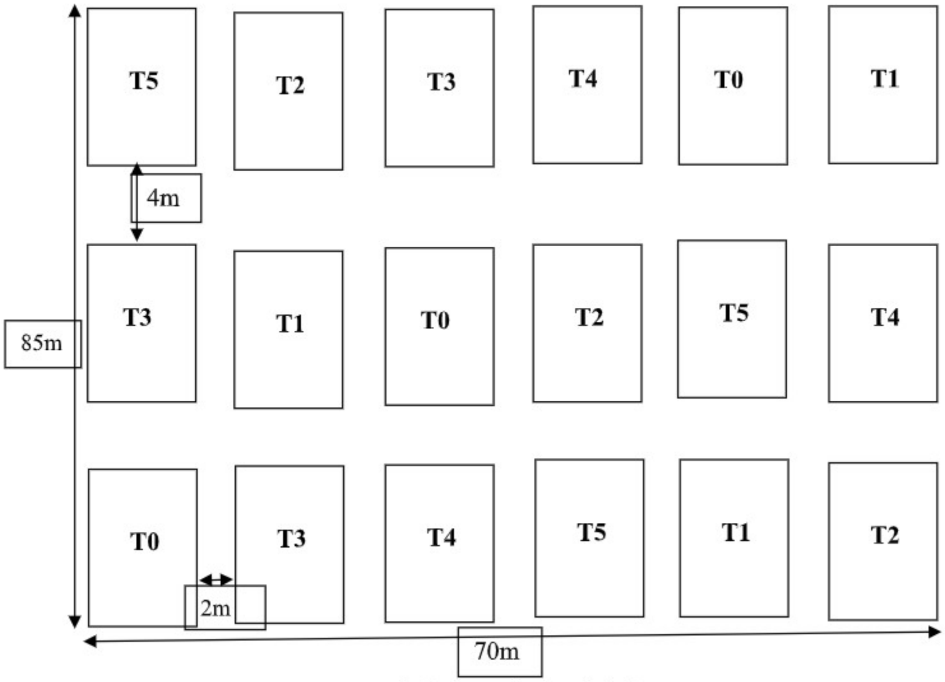

Fig 2. Experimental design

### Establishment of the trial

After sowing, two manual weeding operations were carried out at 15-day intervals. Mineral basal fertilizer (NPK 14-23-14) was applied at sowing at a quantity of 300 kg/ha (Kambale et *al.,* 2023), Then, 100 kg/ha of urea (46% nitrogen) was applied 4 weeks after sowing as a final fertilizer (Neba *et al.,* 2015).

### Data collected

The Fall Armyworm infestations in the trial was evaluated regularly. The data were

Collected weekly from 21 days after sowing on 20 randomly selected and marked plants in the middle of each experimental unit.

### Assessment of pest incidence

Incidence was assessed using the ratio of the number of plants attacked in each experimental plot to the total number of plants inspected in the sub-plot, multiplied by 100 (I = Y/X×100) (Fajinmi *et al.,* 2012).

Percentage of attack reduction (%) = 100 - (Treatment Incidence)/ control incidence*100

### Assessment of pest severity

Severity is assessed visually using the rating scale defined by (Notteghem *et al.,* 1980). Scores were assigned and each number corresponds to percentage of diseased area as seen in table 1.

Table 1 : Diseased leaf area codes

| score | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|
| DLA (%) | 0 | 0,05 | 0,5 | 1,5 | 3,5 | 7,5 | 17,5 | 37,5 | 62,5 | 87,5 |

DLA: Diseased leaf area

The severity index was calculated using the following formula: IS= (“Xi. Ni/Nt) ×100; IS: severity of attack index, Xi: severity of attack (Note), Ni: Number of plants with severity i, Nt: Total number of plants observed.

The number of larvae was assessed by weekly counts. Maize plants are generally more susceptible and infected at the beginning of their life cycle.

### Grain yields (kg/ha)

The ears harvested per treatment on 07 lines in the middle of the 13 lines/treatment are counted. After dehulling, the grains were dried to moisture content of 13%. The grains are weighed using a sensitive balance and grain yields are calculated and reported per hectare according to (Guibert *et al.,* 2016): Rdt (kg/ha)= (10,000 m2/SE)*PSG. Rdt: Yield, DGS: Dry Grain Weight, SE: Unit Area in m2.

### Data analysis

Data on the incidence and severity of each locality in the different ZAEs were subjected to analysis of variance using the generalized linear model (GLM) of the Genstat and JMP version 8 software (SAS, 2007). The mean values of the various parameters were separated using Tukey’s HDS test at the 5 % probability threshold (Tukey, 1953).

### Results

The ANOVA analysis revealed that the treatments had a significant effect on the incidence of FAW across all three agroecological zones. Different treatments resulted in varying levels of FAW suppression. The incidence of FAW varied significantly across the three agroecological zones. The interaction effect between treatments and zones was also significant, indicating that the effectiveness of a given treatment varied depending on the agro-ecological context.

(Table 2).

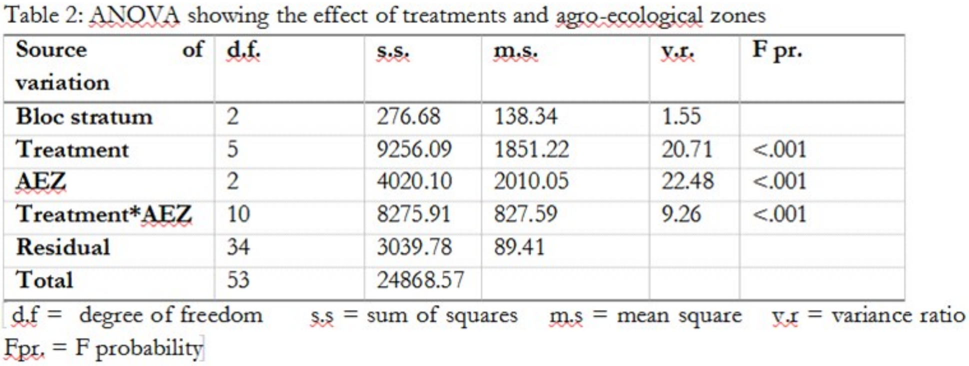

Table 2: ANOVA showing the effect of treatments and agro-ecological zones

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| **Bloc stratum** | 2 | 276.68 | 138.34 | 1.55 | |
| **Treatment** | 5 | 9256.09 | 1851.22 | 20.71 | <.001 |
| **AEZ** | 2 | 4020.10 | 2010.05 | 22.48 | <.001 |
| **Treatment*AEZ** | 10 | 8275.91 | 827.59 | 9.26 | <.001 |
| **Residual** | 34 | 3039.78 | 89.41 | | |
| **Total** | 53 | 24868.57 | | | |

d.f = degree of freedom s.s = sum of squares m.s = mean square v.r = variance ratio

Fpr. = F probability

Table 2 shows the incidence of FAW as a function of treatment and agroecological zone during all phases of maize growth. This analysis reveals a significant effect (P<0.05) of the different treatments applied on the incidence of FAW, from day 21 after sowing to day 42. The-Emamectin, Emamectin + *Bacillus thuringiensis*, Neem and *Bacillus thuringiensis* treatments significantly reduced the incidence of FAW on plants compared with the control in all three study areas.

**Table 3**: Incidence of FAW according to treatments and agro-ecological zone

| AEZ | Traitements | 21 DAS | 28 DAS | 35 DAS | 42 DAS |
|---|---|---|---|---|---|
| **V** | **Control** | 66,66 ± 5,77 a | 83,33 ± 11,54 a | 96,67 ± 5,77 a | 96,67 ± 5,77 a |
| | Soap | 33,33 ± 5,77 b | 36,67 ± 5,77 b | 33,33 ± 5,77 b | 33,33 ± 5,77 b |
| | *B.thuringiensis* | 26,67 ± 5,77 bc | 36,67 ± 5,77 b | 23,33 ± 5,77 c | 23,33 ± 5,77 c |
| | *A.indica* | 26,67 ± 5,77 bc | 26,67 ± 5,77 bc | 20.00± 0,00 c | 20 ± 0,00 c |
| | Emamectin | 23,33 ± 5,77 bc | 26,67 ± 5,77 bc | 16,67 ± 5,77 c | 16,67 ± 5,77 c |
| | *B.thuringiensis* + Emamectin | 16,67 ± 5,77c | 16,67 ± 11,54 c | 16,67 ± 5,77 c | 16,67 ± 5,77 c |
| | **Means** | **32,22 ± 5,57 c** | **37,78 ± 6,73 a** | **37,11 ± 4,80 b** | **37,11 ± 4,80 b** |
| **I** | Control | 63,3±0,0a | 66,7±1,3a | 78,9 ± 2,1 a | 83,3 ± 2,7 a |
| | Soap | 65,6±1,9a | 64,4±1,2a | 76,7 ± 2,2 a | 78,9 ± 7,7 ab |
| | *B.thuringiensis* | 34,4±1,9b | 32,2±3,2bc | 31,1 ± 3,3 b | 21,1 ± 9,5 c |
| | *A.indica* | 35,6±1,9b | 38,9±6,1b | 33,3 ± 4,0 b | 25,6 ± 10,9b c |
| | Emamectin | 27,8±1,9c | 24,4±5,9c | 18,9 ± 15,5 d | 15,6 ± 14,2 d |
| | *B.thuringiensis* + Emamectin | 30,0±3,3bc | 32,2±3,2bc | 28,9 ± 5,3b c | 23,3 ± 5,3 c |
| | **Means** | **42,8±1,81 a** | **43,1±3,48 a** | **44,6±5,4 a** | **41,1±8,38 a** |
| **III** | Control | 56,67 ± 7,63 a | 81,67 ± 2,89 a | 98,33 ± 2,89 a | 98,33 ± 2,89 a |
| | Soap | 38,33 ± 5,77 b | 41,67 ± 2,89 b | 50 ± 5,00 b | 53,33 ± 2,89 b |
| | *B.thuringiensis* | 36,67 ± 2,88 bc | 43,33 ± 2,89 bc | 43,33 ± 5,78 bc | 43,33 ± 2,89 c |
| | *A.indica* | 30 ± 0,00 cd | 36,67 ± 2,89 cd | 43,33 ± 2,89 bc | 40 ± 0,00 cd |
| | Emamectin | 26,67 ± 2,89 d | 33,33 ± 2,89 de | 36,67 ± 2,89 c | 33,33 ± 5,78 d |
| | *B.thuringiensis* + Emamectin | 23,33 ± 2,89 d | 30 ± 5,00 e | 23,33 ± 5,78 d | 18,33 ± 5,78 e |
| | **Means** | **35,28±3,68 d** | **44,46±3,24 b** | **40,83±4,21 c** | **47,78±3,37 a** |

| **Source** | Degree of freedom | Sum of squares | Mean square | Variance | Prob. > F |
|---|---|---|---|---|---|
| **Treatment** | 5 | 11227,778 | 2245,56 | 146,9818 | <,0001* |
| **Residual** | 12 | 183,333 | 15,28 | | |
| **Total** | 17 | 11411,111 | | | |

For each parameter and each zone, means followed by the same letter are not significantly different (Tukey's HSD test, P=0.05). DAS: Day after sowing

The incidence of FAW on crops according to agroecological zone is shown in Fig. 3, which shows that the Sudano-Sahelian agroecological zone (I) and the Western High land zone (III) are more susceptible to FAW proliferation (55.82 and 44.17%), compared with the bimodal rainforest zone (V) (34.7%).

Table 4 shows that the different treatments applied had a significant effect (P<0.05) on the severity of FAW in the three agroecological zones. However, it also shows that there were differences between the agroecological zones and even the interaction between the treatments and the agroecological zones.

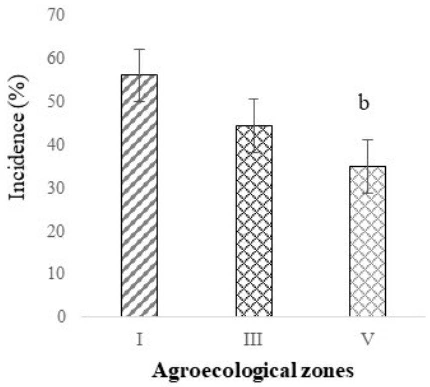

Fig. 3: Incidence of FAW according to the different Agroecological zone.

Table 4: ANOVA showing the effect of treatments and agroecological zones on the severity of FAW

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| **Bloc stratum** | 2 | 0.0521 | 0.0261 | 0.12 | |
| **Treatment** | 5 | 147.0700 | 29.4140 | 131.15 | <.001 |
| **AEZ** | 2 | 21.5991 | 10.7996 | 48.15 | <.001 |
| **Treatment*AEZ** | 10 | 30.3761 | 3.0376 | 13.54 | <.001 |
| **Residual** | 34 | 7.6256 | 0.2243 | | |
| **Total** | 53 | 206.7231 | | | |

d.f = degree of freedom s.s = sum of squares m.s = mean square v.r = variance ratio
Fpr. = F probability

The analysis of variance carried out on the severity of FAW attack on maize plants (Table 5) showed that all the treatments applied had a significant effect on the degree of FAW attack in the trials, from day 21 after sowing to day 42. The Emacmetin, *B. thuringiensis* + Emacmetin, *A. indica* and *B. thuringiensis* treatments respectively had a significant effect (P<0.05) on the severity of FAW attack. In the Sudano-Sahelian zone, severity was significantly higher on the 28th day after sowing (4.4±1.6) than on the 21st, 35th and 42nd days after sowing respectively (4.1; 4.0; 4.1)

Table 5: Severity of FAW according to treatments and agro-ecological zones

| AEZ | Treatments | 21 DAS | 28 DAS | 35 DAS | 42 DAS |
|---|---|---|---|---|---|
| V | Control | 6,67 ± 2,08 a | 7,67 ± 0,67 a | 8,33 ± 0,57 a | 8,33 ± 0,57 a |
| | Soap | 2,67 ± 1,52 b | 3 ± 0,57 b | 1,33 ± 0,57 b | 1,33 ± 0,57 b |
| | *B. thuringiensis* | 2,33 ± 0,57 b | 2 ± 0,57 bc | 2 ± 0,00 bc | 2 ± 0,00 bc |
| | *A. indica* | 2 ± 1,00 b | 2 ± 0,57 bc | 1,33 ± 0,57 bc | 1,33 ± 0,57 bc |
| | Emacmetin | 1,67 ± 0,57 b | 1,33 ± 0,33 c | 1 ± 0,00 c | 1 ± 0,00 c |
| | *B. thuringiensis* + Emacmetin | 1 ± 0,00 b | 1 ± 0,00 c | 1 ± 0,00 c | 1 ± 0,00 c |
| | **Means** | **2,72 ± 0,95 a** | **2,77 ± 0,45 a** | **2,49 ± 0,29 a** | **2,49 ± 0,29 a** |
| I | Control | 5,6 ± 0,3a | 6,4 ± 1,5a | 6,1 ± 0,3a | 6,3 ± 0,3a |
| | Soap | 5,4 ± 0,3a | 6,3 ± 0,4a | 6,0 ± 0,4a | 6,3 ± 0,4a |
| | *B. thuringiensis* | 3,5 ± 0,5b | 3,8 ± 0,4b | 3,5 ± 0,4b | 3,5 ± 0,5b |
| | *A. indica* | 3,5 ± 0,7b | 3,8 ± 0,4b | 3,9 ± 0,3b | 3,6 ± 0,4b |
| | Emacmetin | 3,2 ± 0,2b | 2,6 ± 0,4c | 2,1 ± 0,7c | 2,3 ± 0,6c |
| | *B. thuringiensis* + Emacmetin | 3,5 ± 1,3b | 3,5 ± 0,1bc | 2,3 ± 0,3c | 2,4 ± 0,2c |
| | **Means** | **4,1±1,1 b** | **4,4±1,6 a** | **4,0±1,7 c** | **4,1±1,8 b** |
| III | Control | 5,33 ± 0,38 a | 6,67 ± 0,58 a | 7,33 ± 0,58 a | 8 ± 0,00 a |
| | Soap | 3,33 ± 0,38 b | 3 ± 0,00 bc | 3,33 ± 0,58 bc | 3 ± 1,00 b |
| | *B. thuringiensis* | 3 ± 0,00 bc | 3,67 ± 0,57 b | 4 ± 1,00 b | 1,67 ± 0,58 c |
| | *A. indica* | 3 ± 0,00 bc | 2,67 ± 0,58 cd | 1,67 ± 0,58 de | 1,33 ± 0,58 c |
| | Emacmetin | 2,33 ± 0,38 c | 1,67 ± 0,00 e | 1 ± 0,00 e | 1,33 ± 0,58 c |
| | *B. thuringiensis* + Emacmetin | 2,33 ± 0,38 c | 2 ± 0,00 de | 2,33 ± 0,58 cd | 1,67 ± 0,58 c |
| | **Means** | **3,22±0,25 a** | **3,28±0,29 a** | **3,28±0,55 a** | **2,83±0,55 a** |

| Source | Degree of freedom | Sum of squares | Mean square | Variation F | Prob. > F |
|---|---|---|---|---|---|
| **Treatment** | 5 | 101,83333 | 20,3667 | 52,3714 | <,0001* |
| **Residual** | 12 | 4,66667 | 0,3889 | | |
| **Total** | 17 | 106,5 | | | |

For each parameter and each zone, means followed by the same letter are not significantly different (Tukey's HSD test, P=0.05). DAS: Day after sowing

Fig. 4 and 5 show the severity according to agro-ecological zone. It can be seen from this graph that the severity is significantly higher in the Sudano-Sahelian agro ecological zone (I) and the Western Highlands zone (III) (4.16 and 3.15) than in the bimodal rainforest zone (V) (2.6).

The analysis of variance on larvae reveals that the different treatments applied had a significant effect (P<0.05) on larvae in the three agroecological zones. However, it also shows that there are differences between the agroecological zones and even the interaction between the treatments and the agroecological zones.

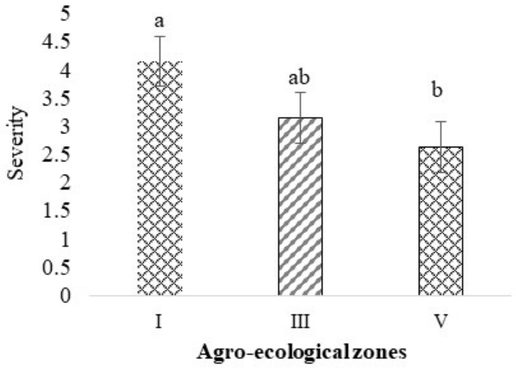

Fig. 4: Severity of FAW according to different agroecological zone.

**Fig 5.** Experimental field (a) with damage caused by FAW(a)and larvae(c)

Table 6: Larva as a function of treatments and agroecological zones

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| **Bloc stratum** | 2 | 1.9479 | 0.9739 | 1.04 | |
| **Treatment** | 5 | 85.9876 | 17.1975 | 18.37 | <.001 |
| **AEZ** | 2 | 20.3981 | 10.1991 | 10.89 | <.001 |
| **Treatment*AEZ** | 10 | 25.9196 | 2.5920 | 2.77 | 0.013 |
| **Residual** | 34 | 31.8288 | 0.9361 | | |

d.f = degree of freedom s.s = sum of squares m.s = mean square v.r = variance ratio Fpr. = F probability

Table 6 shows the number of larvae present on the plants as a function of the different treatments applied and the agroecological zones. It shows that, from the 21st to the 42nd day after sowing, the treatments applied had a significant effect ($P<0.05$) on the average number of larvae present on the plants. In the humid forest zone (V), the Emamectin, *A. indica* and *B.thuringiensis* + Emamectin treatments significantly reduced the number of larvae present on maize plants on the 28th day after sowing (2; 2 and 1.33) compared with the control (6). In the Sudano-Sahelian zone, the Emamectin treatment reduced the number of larvae on maize plants to 0 from 28 to 42 days after sowing (0.3, 0, 0 and 0), followed by the *A. indica*, *B.thuringiensis* + Emamectin and *B.thuringiensis* treatments.

Table 7: Average number of larvae according to treatment and agroecological zone

| AEZ | Treatments | 21 DAS | 28 DAS | 35 DAS | 42 DAS |
|---|---|---|---|---|---|
| **V** | Control | 4,33 ± 0,57 a | 6 ± 1,00 a | 7 ± 1,00 a | 7 ± 1,00 a |
| | Soap | 4 ± 1,00 a | 3,33 ± 0,57 b | 2,67 ± 0,57 bc | 2,67 ± 0,57 bc |
| | *B. thuringiensis* | 3,67 ± 0,57 ab | 3 ± 0,00 b | 3,33 ± 0,57 b | 3,33 ± 0,57 b |
| | *A. indica* | 2,67 ± 0,57 bc | 2 ± 0,00 c | 1,67 ± 0,57 cd | 1,67 ± 0,57 cd |
| | Emacmetin | 2,33 ± 0,57 c | 2 ± 0,00 c | 2,33 ± 0,57 bcd | 2,33 ± 0,57 bcd |
| | *B. thuringiensis* + Emacmetin | 2 ± 0,00 c | 1,33 ± 0,57 c | 1,33 ± 0,57 d | 1,33 ± 0,57 d |
| | Means | **3,17 ± 0,54 a** | **2,94 ± 0,36 a** | **3,06 ± 0,64 a** | **3,06 ± 0,64 a** |
| **I** | Control | 4,7 ± 2,5 a | 3,0 ± 2,4 a | 1,3 ± 0,3 a | 9,0 ± 0,9 a |
| | 3,7±3,0 ab | 2,7 ± 0,2 ab | 2,0 ± 1,2 ab | 3,7 ± 0,5 b | 3,7 ± 0,5 b |
| | 2,0±0,8 bc | 1,0 ± 1,6 | 0,7 ± 1,5 c | 1,0 ± 0,01 c | 1,0 ± 0,01 c |
| | 0,3±1,0 d | 0,0 ± 0,0 d | 0,0 ± 0,0 d | 0,0 ± 0 d | 0,0 ± 0,0 d |
| | 1,7±0,5 c | 2,0 ± 1,0 bc | 1,3 ± 1,5 b | 2,7 ± 1,4 bc | 2,7 ± 1,4 bc |
| | 1,7±0,9 c | 0,3 ± 0,7 c | 0,7 ± 0,3 c | 0,0 ± 0 d | 0,0 ± 0,0 d |
| | **Means** | **2,35 ± 1,6 a** | **1,5 ± 1,1 b** | **1±0,7 b** | **2,73±0,46 a** |
| **III** | Control | 3,33 ± 0,58 a | 3,33 ± 0,58 a | 6 ± 1,00 a | 6,33 ± 0,58 a |
| | Soap | 2 ± 0,00 b | 2 ± 0,00 b | 3,67 ± 0,58 b | 3 ± 0,00 b |
| | *B. thuringiensis* | 2 ± 0,00 b | 2 ± 0,00 b | 3 ± 1,00 bc | 2,33 ± 0,58 bc |
| | Emacmetin | 1,33 ± 0,58 bc | 1,33 ± 0,58 bc | 1,67 ± 0,58 d | 1 ± 0,00 d |
| | *A. indica* | 1,67 ± 0,58 bc | 1,67 ± 0,58 bc | 2,33 ± 0,58 cd | 2 ± 0,00 c |
| | *B. thuringiensis* + Emacmetin | 1 ± 0,00 c | 1 ± 0,00 c | 2 ± 0,00 cd | 1,67± 0,58 cd |
| | **Means** | **1,89±0,29 a** | **1,89±0,29 a** | **3,11±0,62 a** | **2,72±0,29 a** |

Fig 5 and Table 7 show the number of larvae as a function of agroecological zone. This graph shows that the number of larvae present on the plants is significantly higher in the humid forest zone with bimodal rainfall (3.05) and the western highlands zone (III) (2.41), compared with that observed in the Sudano-Sahelian zone (I) (1.55).

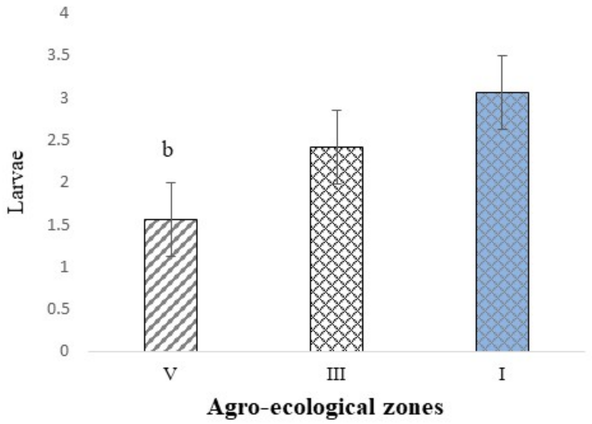

Fig. 5: Number of larvae as a function of treatments and agroecological zones

Table 8: Grain yields by treatment and agroecological zone

| AEZ | Treatments | Yield (t/ha) | Zone effect |
|---|---|---|---|
| **V** | Control | 1,07 ± 0,04 e | **2,52 ± 0,67 a** |
| | *A.indica* | 2,64 ± 0,02 c | |
| | soap | 2,45 ± 0,01 d | |
| | *B.thuringiensis* | 2,85 ± 0,02 b | |
| | Emamectin | 2,95 ± 0,02 a | |
| | *B. thuringiensis* + Emamectin | 2,79 ± 0,01 b | |
| | **Means** | **2,26±0,02 c** | |
| **I** | Control | 1,24 ± 0,14 f | **2,29 ± 0,52 a** |
| | *A.indica* | 2,48±0.06 d | |
| | soap | 1,65±0.03 e | |
| | *B.thuringiensis* | 2,58 ± 0,06 c | |
| | Emamectin | 2,98 ± 0,07 a | |
| | *B. thuringiensis* + Emamectin | 2,80 ± 0,05 b | |
| | **Means** | **2,29±0,09 a** | |
| **III** | Control | 1,02 ± 0,02 e | **2,48±0,68 a** |
| | *A.indica* | 2,70 ± 0,03 d | |
| | soap | 2,67 ± 0,01 d | |
| | *B.thuringiensis* | 2,82 ± 0,02 b | |
| | emamectin | 2,92 ± 0,03 a | |
| | *B. thuringiensis* + Emamectin | 2,76 ± 0,02 c | |
| | **Means** | **2,48±0,02 a** | |

| Source | **Degree of freedom** | **Sum of squares** | **Mean squares** | **Variance ratio** | **Prob. > F** |
|---|---|---|---|---|---|
| Treatment | 5 | 4,343,628 | 0,868726 | 734,726 | <,0001 * |
| Factors | 12 | 0,1418856 | 0,011824 | | |
| Total | 17 | 44,855,136 | | | |

Table 9 : Cost analysis of treatments

| Treatment | Yield (kg) | Chemical treatment Cost/ha $ | Sales $ ( at 0.8$/Kg) | Benefit (Sales-Cost) $ |
|---|---|---|---|---|
| **Control** | 1110 | 0 | 888 | 888 |
| **A.indica** | 2607 | 50 | 2085.6 | 2035.6 |
| **Soap** | 2257 | 20 | 1805.6 | 1785.6 |
| **B. thuringiensis** | 2750 | 70 | 2200 | 2130 |
| **Emamectin** | 2950 | 230 | 2360 | 2130 |
| **Emamectin + B.T** | 2783 | 200 | 2226.4 | 2026.4 |

As seen in table 9, the cost of neem oil application is typically around $50 per hectare while the cost of emamectin benzoate application is approximately $200 per hectare. The cost of RAPAX ( *B.thuringiensis*) and soap are approximately $70 and $20 per hectare respectively. The cost analysis involved calculating the total expenditure for each treatment per hectare, considering both the cost of the product and application expenses. Effectiveness was measured in terms of pest control efficiency and the resultant increase in maize yields. The cost of soap and neem oil applications were found to be the lowest among the treatments. Despite its lower cost, neem oil demonstrated significant efficacy in controlling pests and improving maize yields. However, its effectiveness may vary based on pest pressure and environmental conditions. Emamectin benzoate, with a cost of $200 per hectare, was the most expensive treatment apart from when it was combined with *B.thuringiensis*. Its high cost is offset by its superior efficacy and residual activity, leading to substantial yield improvements. This makes it a preferred choice for farmers facing severe pest infestations. RAPAX ( *B. thuringiensis*), costing about $70 per hectare, offers a balanced approach with moderate costs and good efficacy against lepidopteran pests. Its use is particularly advantageous in integrated pest management (IPM) strategies due to its minimal environmental impact. The cost-benefit analysis revealed that while neem oil is the most cost-effective option, emamectin benzoate provides the highest yield benefits, justifying its higher cost in cases of severe infestations. RAPAX serves as an effective middle ground, offering both economic and environmental benefits.

Table 10: Pearson Correlation

| | Incidence (%) | Severity | Larvae | |
|---|---|---|---|---|
| **Incidence (%)** | 1 | | | |
| **Severity** | ,801$^{**}$ | 1 | | |
| **Larva** | ,420$^{**}$ | ,639$^{**}$ | 1 | |
| **Yield (t/ha)** | -,736$^{**}$ | -,931$^{**}$ | -,690$^{**}$ | 1 |

**. Correlation is significant at the 0.01 level (2-tailed).

Analysis of the correlation between the parameters measured and evaluated (table 10) shows that all these variables are significantly correlated. Incidence was positively and highly significantly correlated (r=0, .801**) with the severity of the attack. The number of larvae was positively and highly significantly correlated (r=0, .420**) with incidence (r=0, .639**) and severity. Grain yield was negatively and highly significantly correlated (r= -0.736**) with incidence, (-0.931**) with severity and (r= -0.690**) with the number of larvae present on the plant.

## Discussion

The heightened vulnerability of maize to Fall Armyworm (FAW) infestation, particularly evident from 21 to 35 days after planting, can be attributed to the tender, less lignified cell walls of young maize, which are more easily compromised by FAW. Tindo et al. (2017) have observed that FAW can target maize throughout its growth, with the most destructive impact on the younger plants.

In our study, the application of Emamectin benzoate demonstrated a marked reduction in FAW occurrence across the three agroecological zones, with the combined *B. thuringiensis* and Emamectin benzoate treatment, along with *A. indica* and *B. thuringiensis* treatments, also showing effectiveness. The efficacy of Emamectin benzoate aligns with findings from Nboyine et al. (2022) and Phambala et al. (2020), who reported similar outcomes when pitted against *A. indica* and other synthetic agents. *A. indica* oil, recognized for its safety to humans and animals, proves detrimental to fungi and insects, primarily due to its azadirachtin content, which disrupts insect feeding behavior and physiological function, leading to their demise (Bidiga, 2014; Ch., 2013).

Compounds such as azadirachtin, nimbidinin, solanine, deacetylazadirchtinol, and melantriol, isolated from *A. indica* seed oil, are noted for their biological activity (Diedhou, 2017). Particularly, azadirachtin has been acknowledged as a potent insect growth inhibitor since 1972, with Schmutterer and Rembold (1980) verifying its insecticidal and repellent actions against over 200 insect species (Faye, 2010).

Our analysis revealed a statistically significant correlation among all variables studied, indicating a complex interplay among FAW incidence, severity, larval presence, and crop yield. The various treatments, namely Emamectin benzoate, *B. thuringiensis* with Emamectin benzoate, *A. indica*, and *B. thuringiensis* on their own, significantly mitigated larval damage compared to the control, with foliage applications deterring larval consumption of maize leaves and the insecticidal properties of the treatments, such as *A. indica* oil, exterminating the feeding larvae. These outcomes parallel the findings of Patricia et al. (2010) and Estefania et al. (2016), who noted the significant efficacy of *A. indica* extracts against wheat aphids. The mode of action of *B. thuringiensis* involves the ingestion of the bacterium by the larvae, which then produce toxins that disrupt the gut cells, ultimately leading to the pest's death. This biological control method is highly specific to target pests, minimizing the impact on non-target species and beneficial insects. Rapax AS, with its active ingredient Bacillus thuringiensis subspecies kurstaki strain EG 2348, represents a reliable and eco-friendly solution for pest control in agriculture. Its targeted action against lepidopteran larvae and minimal impact on non-target species make it an integral part of sustainable agricultural practices. The active ingredient of Emamectin benzoate works by targeting the nervous system of the pests, leading to paralysis and death.

The reduced larval presence on maize from 21 to 42 days post-sowing in all treatments (excluding the control) is attributable to the high effectiveness of the plant extracts, which blocked larval feeding on different plant sections. Kammo et al. (2019) similarly discovered that, after 75 days post-sowing, there were no larvae on maize treated with these extracts, whereas untreated (control) plants were infested.

In terms of grain yield, all treatments significantly outperformed the control in all three study areas, with the synthetic insecticide yielding the highest output, followed by the combined *B. thuringiensis* and Emacmetin treatment, *A. indica*, and *B. thuringiensis* alone. This is consistent with results from Nboyine et al. (2022) in Ghana.

The Sudano-Sahelian Agroecological zone proved most prone to FAW in terms of incidence, severity, and larval count, followed by the Western Highlands zone, both primary maize-producing regions in Cameroon. This may be partly due to the excessive use of chemical pesticides in these zones, potentially fostering pest resistance, specifically in fall armyworms, and also because of the trial sites' proximity to market-garden fields, which Kasongo et al. (2021) identified as more susceptible to armyworms, with an average incidence of 52±17% compared to fields bordered by alternate vegetation.

## Conclusion

The study at hand, with the goal of evaluating the bio-efficacy of biological products against armyworms in agroecological zones I, III, and V, has demonstrated that *A. indica* (neem) and B. thuringiensis possess highly effective insecticidal properties. The findings indicate that zones I and III are more vulnerable to Fall Armyworm (FAW) infestations compared to zone V. Considering the outcomes, the use of *A. indica* extract and Thuringiensis offer promising sustainable alternatives to synthetic insecticides for the control of fall armyworms in agricultural practices. This shift towards using these bio pesticides can contribute to integrated pest management (IPM) strategies that emphasize environmental sustainability, reduced pesticide resistance, and minimized negative impact on non-target organisms, including pollinators and natural pest predators. Additionally, it aligns with the growing demand for organic farming practices and the need to ensure food security without compromising human health and the ecosystem. The study highlights the importance of considering both economic and efficacy factors when selecting pest control methods for maize fields. Neem oil, emamectin benzoate, and RAPAX each have their strengths and are suitable for different scenarios based on pest pressure and environmental considerations. Farmers should weigh the costs against the expected benefits to make informed decisions that optimize both yield and profitability.

## Acknowledgement

The authors are grateful to FAO for financing this study under grant TCP/INT/3705.
Gratitude also goes to the TAAT Clearing house for supporting the publication fees.

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