



Response of bio-pesticides in the control of *Spodoptera frugiperda* (J.E.Smith) on maize in two agro-ecological zones of Cameroon

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Abstract

The fall armyworm (FAW) is a real threat to food security and nutrition in the tropics. Studies show that the damage caused by FAW is severe on maize, resulting in yield losses (15–73%). This work is a contribution to the search for alternatives to chemical control of FAW. The trials were conducted at two localities: Ntui and Foumbot, during the rainy (RS) and dry (DS) seasons (2022–2023) using a completely randomized block design with three replications. Treatments consisted of control (T-), Gremec050WG as a positive control (T+), tobacco, *Lantana camara*, neem and Rapax. The results showed that plant extracts had an insecticidal effect on FAW infestations compared to the control. Gremec, tobacco and neem significantly reduced the infestation rate of FAW in Foumbot (RS: 16.67%, 20% and 25%; DS: 24.33%, 28.67% and 29%) and Ntui (RS: 12.23%, 15% and 20%; DS: 15.67%, 24.33% and 25%). Treatments with Gremec, tobacco and neem had a significant insecticidal effect on FAW damage compared with the control in both localities. The DS was more sensitive to FAW infestations. Foumbot was more susceptible to FAW (3.92) than Ntui (2.72). In Foumbot, Gremec, tobacco and neem resulted in a significantly lower incidence of dead hearts than the control and other treatments in both the RS and DS. The highest gain yields (t/ha) were obtained with Gremec (2.93), tobacco (2.77) and neem (2.83). Tobacco and neem showed an insecticidal effect comparable to that observed with Gremec and can therefore constitute an alternative to chemical control and a sustainable management strategy for FAW.

Keywords Agro-ecological zones · Bio-pesticides · Control · Fall armyworm

1 Introduction

Maize (*Zea mays* L.) is one of the world's most widely grown cereals. It accounts for approximately 41% of global cereal production and its output was estimated at more than 843 million tons for the period 2013–2014 (OECD/FAO 2015). Maize is grown not only for human food and livestock

(large and small livestock), but also for numerous uses in the textile, pharmaceutical, alcoholic and non-alcoholic beverage, biodegradable plastic and biofuel production industries (Issa et al. 2011; Kaho et al. 2011; Useni et al. 2013; Temegne et al. 2020).

In Cameroon, 90% of households spend around 60% of their budgets on cereal consumption (INS 2018). It is the most widely grown cereal in the various agro-ecological zones (Mafouasson et al. 2020), with around 37% of production in the Sudano-Sahelian zone (Zone I), 13% in the Guinean savannah zone (Zone II), 25% in the Western highlands zone (Zone III), 15% in the monomodal rainforest zone (Zone IV) and 10% in the bimodal rainforest zone (Zone V) (DESA 2017). In 2009, annual national demand was estimated at 1,500,000 tons compared to a production of 1,380,000 tons, resulting in a deficit of 120,000 tons. In 2016, Cameroon imported 22,600 tons of maize (FAO 2017). Since then, demand for food and feed has been rising. In the absence of strong measures to boost production, the deficit has also kept growing with demand,

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reaching 350,000 tons and peaking at 600,000 tons in 2019 (MINADER 2019).

However, maize cultivation in Cameroon faces abiotic constraints such as water stress, soil acidity, soil poverty, climate change and biotic problems including fungal, bacterial or viral diseases and pests (Tanyi et al. 2020).

The fall armyworm (*Spodoptera frugiperda* (J.E. Smith)) is a nocturnal polyphagous pest native to sub-tropical and tropical regions of the Americas (Cokola et al. 2021; Kasoma et al. 2021; Kumar et al. 2021). Its voracity has been reported by several authors, as it attacks over 80 plant species (Sisay et al. 2018; Shobiya et al. 2021; Seutchueng et al. 2022). First detected in Africa in 2016 (IITA 2016; FAO 2017), this species is now reported in over 45 countries (Shobiya et al. 2021; Daudi et al. 2021; Dassou et al. 2021; Tambo et al. 2021; Tshaibukole et al. 2021). It attacks maize at all its stages of development (Ahiassou et al. 2021), causing foliar damage leading to major yield losses in the absence of control measures (Hruska 2019; Tshaibukole et al. 2021). Fall armyworm damage is characterized by loss of the photosynthetic zone, causing lodging of maize plants, stunted growth, deterioration of fresh seeds, and destruction of the whorl, panicle and ears (Chimweta et al. 2019). In Africa, the economic loss caused by fall armyworm is estimated at around \$16 billion (Harrison et al. 2019). Faced with this widespread damage, farmers in several countries are resorting to the intensive use of chemical pesticides to control the pest, leading to the development of resistance by the fall armyworm (Yu et al. 2003; Ndiaye et al. 2022).

This misuse of chemical pesticides by growers is not without consequences for human health. Furthermore, there are the harmful effects on the environment and animals (Toé 2010). Also, alongside chemical methods, there are other simple and accessible means such as bio-pesticides including with broad spectrums of action (repellent, stunner, larvicide, anti-appetent, etc.) and physical control but whose use remains limited due to a lack of awareness of their existence and the absence of standard recommendations (FAO 2018). FAO also specifies that studies on the use of plant leaves from the Meliaceae and Asteraceae families show effectiveness in the management of fall armyworm. Munoz et al. (2013) also showed that extracts of *Calceolaria talcana* act as a powerful bio-insecticide against *S. frugiperda* with a mortality rate of 95%. Ethanol fruit and seed extracts of *Cabralea canjerana* showed anti-appetizing and larvicidal activity against *S. frugiperda* (Magrini et al. 2015). Azadirachtin has also been cited in numerous studies for its efficacy against *S. frugiperda* (Gahukar 2014; Hernandez-Trejo et al. 2019). The aim of the present study is to contribute to the search for innovative alternatives to chemical control by exploring the potential of plant extracts for managing fall armyworm in Cameroon.

2 Materials and methods

2.1 Materials

2.1.1 Study sites

The trials were conducted in agro-ecological zones III, (Western Highlands zone) and V, (bimodal rainforest zone) in 2023, during the dry and rainy seasons. In the Western Highlands zone (AEZ III), the trial took place at the Foubot IRAD station, Foubot Sub-division, Mangoum village. This station is located at an altitude of 1,010 m at latitude 5°28'37"North and longitude 10°33'50"East. The soils are volcanic, annual rainfall is 1,538.8 mm and the rainiest periods of the year are between July and September. Temperatures fluctuate between 20 and 24 °C.

In the bimodal rainforest zone (AEZ V), the trial took place at the IRAD antenna in the Ntui Sub-division, Mbam and Kim Division. The antenna is located at an altitude of 485 m at latitude 4°28'58"North and longitude 11°38'29"East. Annual rainfall ranges from 1,500–2,000 mm, distributed over two distinct rainy seasons, which favor two crop cycles and a staggered agricultural calendar with asynchronous sowing and harvesting. The temperatures ranges are between 20 °C and 25 °C. The choice of these two zones was based on their representativeness of the different AEZ of Cameroon, as well as their significance in national maize production.

2.1.2 Maize variety

The maize variety used is CMS 8704, a yellow open-pollinated variety. Yield varies between 3–4 t.ha⁻¹, with a cycle of 110 to 120 days. The choice of this maize variety was largely influenced by farmers in these two zones. It is highly susceptible to armyworms. These cultivars are noted to be sweeter than the others. Insects are generally attracted to sugar (Buteme et al. 2020), and armyworm are no exception.

2.1.3 Botanical and bio-insecticides

Botanical insecticides (neem oil (*Azadirachta indica*), *Lantana camara* and tobacco (*Nicotina tabacum*)) were selected for their insecticidal properties and broad availability in the local environment. These plants have shown proven efficacy in controlling crop pests in Cameroon and elsewhere (Dzokou et al. 2022; Laminou et al. 2022). Their selection also stems from their accessibility to smallholder farmers, most of whom have limited financial resources.

The registered bio-pesticide used is Rapax AS, with the active ingredient *Bacillus subtilis thuringiensis*, sub-species *kurstaki* strain EG 2348 18.8% w/w. Registration No.:1106/18/IN/HOMO/CNHPCAT/CMR.

2.1.4 Chemical pesticide

The synthetic pesticide used was Emamectin-benzoate 50 g.kg⁻¹, Registration No. 1107/18/IN/HOMO/CNHPCAT/CMR, dose 160 g.pc⁻¹.ha⁻¹, obtained from the local market. No synthetic herbicide treatments were applied in either of the two seasons.

2.2 Methods

2.2.1 *Lantana camara* and *Nicotina tabacum* secondary metabolites extraction

Solvent extraction was used to obtain 20% extracts of *L. camara* and *N. tabacum*. Leaves were harvested early in the morning and thoroughly washed in distilled water to remove microorganisms and dust particles. The cleaned leaves were air-dried for two weeks. The dried leaves were ground in the laboratory using a mini electric Moulinex (800w) and the resulting powder was used for solvent extraction. Using a high-sensitivity balance (1000 g*0.1 g), 100 g of powder from each dried plant was placed in a beaker, and 1 L of 95% ethanol was added, and the mixture was stored for two days at room temperature (25 °C). Using filter paper and absorbent cotton, the mixture was filtered, then transferred to an open stainless-steel container and placed in a well-ventilated corner of the laboratory for 72 h, to evaporate the ethanol. After drying, the residual powder obtained was used to prepare 20% of extracts (Dzokou et al. 2022) by weighing 20 g of powder, to which 80 mL of distilled water and 10 mL liquid soap (Dzokou et al. 2022) were added for the ready-to-apply solution. Liquid soap (adjuvant) was added to enhance the effectiveness of the extracts by improving their adhesion to and dispersion on the leaf surface (Dzokou et al. 2022). From 21 days after sowing, the various treatments were applied at a rate of 6.5 L/ha every 7 days for 4 weeks, i.e. 260 mL/sprayer. Manual pressure sprayers with a capacity of 16 L (i.e. 320 L of water/ha) were used for this work. Treatments were applied directly to the horn of each plant, in the evening, to avoid the effect of the sun, which could adversely affect the chemistry of the extracts. Sprayers were thoroughly washed and rinsed between treatments.

2.2.2 Extraction of oil neem

The neem seeds were collected from under the neem trees in Ntui, washed with tap water, dried in the sun for seven days and then ground. The crushed material was separated

from the pulp and re-ground. The resulting powder was sieved and stored in dark, hermetically sealed bottles. Next, 4 kg of powder were mixed with 0.5 L of hot water at 40 °C. The mixture was stirred until the oil was obtained from the paste. The dose used for this work was 1.5 L.ha⁻¹. Treatment was carried out using two brand-name sprayers with a capacity of 16 L. Treatments were applied precisely at the horn of each plant, in the evening, to avoid the effect of the sun, which could adversely affect the chemistry of the extracts. Sprayers were thoroughly washed and rinsed between treatments.

2.2.3 Experimental set-up

The trials were set up in both zones in 2022 and 2023, at the start of the dry and rainy seasons (period when the FAW population in fields is abundant) (Dabrowski 1983). Infestation in the trials occurred naturally, with the dynamics of armyworms are much more amplified by dry periods. Rainy periods have a detrimental effect on their proliferation. Indeed, the rains washed the eggs deposited by the adults on the lower part of the leaf. The experimental design was a completely randomized block with one factor (treatments) and three (03) replications (blocks), comprising 06 units of 250 m² each per block, for a total of 18 units. The distance between two units was 2 m. The choice of this model was guided by the heterogeneous nature of the experimental site (heterogeneous fertility, relative humidity, pressure, etc.). It guarantees a balanced distribution between treatments and minimizes errors. Treatments applied were: Rapax; neem; tobacco; *L. camara*; Gremec and control. To avoid errors due to the influence of treatments from one sub-plot to another, the blocks were spaced 4 m apart. Also, the different treatments were applied in calm weather (absence of wind), with a surface area of 1,510 m² each/block. The trial covered a total area of 4,538 m². Three seeds of CMS8704 maize variety were sown per pocket. After two weeks of sowing, the removal of one plant was done to leave only two plants/pocket. The sowing density adopted for this work was 75*50 cm. Each experimental unit had 13 lines of 25 m each.

2.2.4 Monitoring and control 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⁻¹ (Kambale et al. 2023). Then, 100 kg/ha of urea (46% nitrogen) was applied 4 weeks after sowing as a final fertilizer (Neba 2015). Maintenance consisted of weeding and ridging.

2.2.5 Data collected

The infestation of the trial by armyworms was done without any human intervention (naturally). Data are collected weekly from 21 days after sowing on 20 randomly selected and marked plants in the middle of each experimental unit.

2.2.6 Armyworm impact assessment

Incidence of armyworm Incidence was assessed from the ratio of the plants attacked in each experimental unit to the total number of plants inspected and all, multiplied by 100 ($I = Y/X \times 100$) (Fajinmi et al. 2012). The percentage of attack reduction was calculated using the following formula

$$\text{Percent of attack reduction (\%)} = 100 - (\text{Treatment Incidence}) / \text{Control Incidence} * 100$$

Assessment of the proportion of dead heart The proportion of dead hearts was evaluated from the third week

$$\text{Proportion of dead heart (\%)} = (\text{number of plants with dead heart}) / (\text{total number of plant inspected}) * 100.$$

Grain yields (t.ha.⁻¹) The ears harvested per treatment, were counted. After destemming, the kernels were dried to a constant weight. The grains were weighed using a sensitive

$$\text{Yield (kg.ha}^{-1}\text{)} = \left(\frac{10,000 \text{ m}^2}{\text{EA}} \right) * \text{DGW} \quad \text{DGW : Dry Grain Weight, EA : Elementary Area in m}^2.$$

The elementary area (experimental unit) in the context of this work measured 250 m² each. Yield data were collected in each elementary area, i.e. 18 in total.

2.2.7 Data analysis

Data on FAW attack and grains yield of each locality (AEZ) were subjected to analysis of variance using the generalized linear model (GLM) of JMP version 8 software (SAS). The mean values of the different parameters were separated by Turkey's HSD test at the 5% probability threshold (Tukey 1953). The correlation test (Pearson, Kendall and Spearman) between all the studied parameters (all the treatments values) was done using R version 4.0.5 software (CI: 95%).

3 Results

3.1 Incidence of fall armyworm

Table 1 shows the incidence of fall armyworm attack in zones III and V over the two seasons. The incidence of

Severity of armyworm Severity was assessed visually using the rating scale defined by (Notteghem et al. 1980) scores were assigned, and each number corresponds to:

Note	0	1	2	3	4	5	6	7	8	9
SFM (%)	0	0.05	0.5	1.5	3.5	7.5	17.5	37.5	62.5	87.5

The severity index was calculated using the following formula: $DS = (\sum Xi. Ni/Nt) \times 100$; DS: Pest Severity, Xi: Pest severity notes, Ni: Number of plants with severity i, Nt: Total number of plants observed. The number of larvae and the number of dead hearts were assessed by weekly counts. Maize plants were generally more susceptible and infected early in their life cycle (Bua and Chelimo 2010).

at two weeks' interval in each plot using the following formula:

balance and grain yields were calculated and reported per hectare according to Guibert et al. (2016).

fall armyworm attack in all treatments was significantly ($P < 0.05$) reduced. The incidence of these legionary caterpillars was characterized by leaf lesions (especially on leaves located at the whorl of the maize plant) as well as damage to the stems. Emamectin benzoate, tobacco and neem respectively showed the lowest incidence compared with the control in both seasons, in zones III and V. During the dry season, the incidence of fall armyworm attack was significantly higher in Foubot and Ntui (48.06% and 43.56%, respectively) than the rainy season (31.67% and 28.06%, respectively). No significant effects of the interactions Treatment*Season and Treatment*AEZ were revealed.

3.2 Severity of fall armyworm

Table 2 shows that the various treatments applied had a highly significant insecticidal effect on the severity of armyworm attack compared with the control. Emamectin benzoate, tobacco, neem and *L. camara* were the most effective treatments against caterpillars. It also reveals a significant effect of season and AEZ on the severity of armyworm attack. The dry season (4.72 ± 0.49 ; 3.67

Table 1 Incidence of caterpillars according to treatment, season and zone

AEZ	Locality	Treatment	Incidence Rainy season	Incidence Dry season	AEZ Effect
III	Foumbot	Control (T-)	91.67 ± 2.89a	99 ± 1.74a	41.03 ± 4.11 A'
		<i>L. camara</i>	30 ± 2.14b	39 ± 1.16b	
		Rapax	30 ± 1.67b	34.33 ± 1.74c	
		Neem	25 ± 2.23c	29 ± 2.31d	
		Tobacco	20 ± 2.24d	28.67 ± 1.73d	
		Gremec (T +)	16.67 ± 2.88e	24.33 ± 1.15e	
		Mean season	31.67 ± 4.38 B	48.06 ± 5.67 A	
V	Ntui	Control (T-)	81.67 ± 2.89a	93.33 ± 2.89a	31.56 ± 3.26 A'
		<i>L. camara</i>	25 ± 1.03b	35 ± 2.43b	
		Rapax	25 ± 2.16b	34.33 ± 1.16b	
		Neem	20 ± 2.34c	25 ± 2.2c	
		Tobacco	15 ± 1.2d	24.33 ± 1.16c	
		Gremec (T +)	12.33 ± 2.51d	15.67 ± 1.16d	
		Mean season	28.06 ± 5.44 B	43.56 ± 5.07 A	
		Treatment	***	***	
		Season	*	*	
		AEZ	ns	ns	
		Treatment*Season	ns	ns	
		Treatment*AEZ	ns	ns	
		Treatment*Season*AEZ	ns	ns	

For each parameter and each zone, means followed by the same letter are not significantly different (Tukey's HSD test, $P = 0.05$). AEZ: agro-ecological zone. *, ** and ***: significant at the 0.05, 0.01 and 0.001 levels, respectively, ns: no significant difference at the 0.05 level

Table 2 Severity of caterpillar attack by treatment, season and zone

AEZ	Locality	Treatments	Severity Rainy season	Severity Dry season	AEZ Effect
III	Foumbot	Control (T-)	7.67 ± 0.57a	9 ± 0.61a	3.92 ± 0.37 A'
		Rapax	2.67 ± 0.57b	3.67 ± 0.57b	
		<i>L. camara</i>	2.33 ± 0.57bc	3.67 ± 0.57b	
		Neem	2.33 ± 0.57bc	2.67 ± 0.57c	
		Tobacco	2 ± 0.57bc	2.67 ± 0.57c	
		Gremec (T +)	1.67 ± 0.12c	2.33 ± 0.57c	
		Means season	3.11 ± 0.51 B	4.72 ± 0.49 A	
V	Ntui	Control (T-)	7 ± 0.21a	7.67 ± 0.57a	2.72 ± 0.30 B'
		Rapax	2 ± 0.31b	2.67 ± 0.57b	
		<i>L. camara</i>	1.33 ± 0.57c	2.67 ± 0.57b	
		Neem	1.33 ± 0.57c	2 ± 0.57bc	
		Tobacco	1 ± 0.01c	1.67 ± 0.21c	
		Gremec (T +)	1 ± 0.01c	1.33 ± 0.57c	
		Mean season	2.17 ± 0.46 B	3.67 ± 0.46 A	
		Treatment	***	***	
		Season	*	*	
		AEZ	*	*	
		Treatment*Season	ns	ns	
		Treatment*AEZ	ns	ns	
		Treatment*Season*AEZ	ns	ns	

For each parameter and each zone, means followed by the same letter are not significantly different (Tukey's HSD test, $P = 0.05$). AEZ: agro-ecological zone. *, ** and ***: significant at the 0.05, 0.01 and 0.001 levels, respectively, ns: no significant difference at the 0.05 level

Table 3 Incidence of dead hearts on maize plants as a function of different treatments, season and agro-ecological zones

AEZ	Locality	Treatment	N° of leaves Rainy season	N° of leaves Dry season	AEZ Effect
III	Foumbot	Control (T-)	71.67 ± 2.88a	86.67 ± 2.88a	36.94 ± 3.42 A'
		Rapax	26.67 ± 2.88c	35 ± 2.56c	
		<i>L. camara</i>	36.67 ± 2.88b	41.67 ± 2.88b	
		Neem	23.33 ± 2.88cd	28.33 ± 2.88d	
		Tobacco	21.67 ± 2.88cd	26.67 ± 2.88d	
		Gremec (T +)	18.33 ± 2.88d	26.67 ± 2.88d	
Mean season			33.05 ± 2.88 B	40.84 ± 2.82 A	
V	Ntui	Control (T-)	68.33 ± 2.88a	76.67 ± 1.66a	31.38 ± 3.25 A'
		Rapax	21.67 ± 2.88c	28.33 ± 1.66bc	
		<i>L. camara</i>	31.67 ± 2.88b	31.67 ± 1.66b	
		Neem	18.33 ± 2.88cd	23.33 ± 1.66cd	
		Tobacco	20 ± 2.65cd	18.33 ± 1.66d	
		Gremec (T +)	15 ± 1.23d	23.33 ± 1.66cd	
Mean season			29.16 ± 2.57 B	33.61 ± 1.66 A	
Treatment			***	***	
Season			***	***	
AEZ			***	***	
Treatment*Season			ns	ns	
Treatment*AEZ			ns	ns	
Treatment*Season*AEZ			ns	ns	

For each parameter and each zone, means followed by the same letter are not significantly different (Tukey's HSD test, $P = 0.05$). AEZ: agro-ecological zone. *, ** and ***: significant at the 0.05, 0.01 and 0.001 levels, respectively, ns: no significant difference at the 0.05 level

± 0.46) was more favorable to caterpillar infestation, with a significantly higher degree of attack in both zones compared with the rainy season (3.11 ± 0.51 ; 2.167 ± 0.46). Zone III was significantly more susceptible to caterpillars (3.92 ± 0.37) than Zone V (2.72 ± 0.30). No significant effect of the interactions Treatment*Season and Treatment*AEZ was found.

3.3 Incidence of dead hearts

The results show a significant effect of the different treatments and seasons on the incidence of dead hearts (Table 3). In zone III, the Emamectin benzoate, tobacco and neem treatments had a significantly lower incidence of dead hearts than the control and the other treatments in both the wet season (18.33%, 21.67% and 23.33%) and the dry season (26.67%, 26.67% and 28.33%). In zone V in the rainy season, the Emamectin benzoate, neem and tobacco treatments respectively had a significantly lower incidence of dead hearts (15%, 18.33% and 20%); in the dry season, the same observation was made. The incidence of dead hearts was significantly higher in the dry season (40.84% and 33.61%) than in the rainy season (33.05% and 29.16%) in both study zones. No significant zonal effect was observed.

3.4 Number of larvae

Table 4 shows the influence of the various treatments on larvae numbers in the different AEZs, revealing that all treatments significantly reduced larval numbers compared with the control (T-), depending on the season and zone. The dry season was significantly more sensitive to larvae proliferation in zones III and V respectively (2.61 ± 0.97 and 2.22 ± 0.19), compared with the rainy season (1.89 ± 0.83 and 1.61 ± 0.16). Zone III was more susceptible to larval proliferation (2.25 ± 0.16), compared with Zone V (1.78 ± 0.11). No significant interaction Treatment*Season and Treatment*AEZ was observed.

3.5 Grain yield

ANOVA table shows a highly significant ($P < 0.001$) effect of different treatments on maize grain yield, compared with the control, in both AEZ (Table 5). In zone III, Emamectin benzoate (2.92 and 2.82 t/ha) treatment had a significant effect in both seasons, followed by neem oil extract (2.82 and 2.79 t/ha) and tobacco (2.75 and 2.73 t/ha). The same observation was made in zone V. Significant seasonal and zonal effects were observed. No significant interaction Treatment*Season and Treatment*AEZ was observed.

Table 4 Number of larvae by treatment, season and zone

AEZ	Locality	Treatment	N° of larvae Rainy season	N° of larvae Dry season	AEZ Effect
III	Foumbot	Control (T-)	3.33 ±0.58a	4.33 ±0.58a	2.25 ±0.16 A'
		Rapax	2 ±0.65b	2.66 ±0.58b	
		<i>L. camara</i>	2 ±0.65b	2.33 ±0.58b	
		Neem	1.67 ±0.58bc	2.33 ±0.58b	
		Tobacco	1 ±0.1c	1.67 ±0.58b	
		Gremec (T +)	1.33 ±0.58bc	2.33 ±0.58b	
Mean season			1.89 ±0.83 B	2.61 ±0.97 A	
V	Ntui	Control (T-)	2.67 ±0.57a	3.33 ±0.58a	1.78 ±0.11 B'
		Rapax	1.67 ±0.58b	2.33 ±0.58ab	
		<i>L. camara</i>	1.33 ±0.58b	2 ±1b	
		Neem	1.33 ±0.58b	1.67 ±0.58b	
		Tobacco	1 ±0.21b	1.33 ±0.58b	
		Gremec (T +)	1.66 ±0.58b	2 ±1b	
Mean season			1.61 ±0.16 B	2.22 ±0.19 A	
Treatment			***	***	
Season			*	*	
AEZ			*	*	
Treatment*Season			ns	ns	
Treatment*AEZ			ns	ns	
Treatment*Season*AEZ			ns	ns	

For each parameter and each zone, means followed by the same letter are not significantly different (Tukey's HSD test, $P = 0.05$). AEZ: agro-ecological zone. *, ** and ***: significant at the 0.05, 0.01 and 0.001 levels, respectively, ns: no significant difference at the 0.05 level

Table 5 Grain yield ($\text{t} \cdot \text{ha}^{-1}$) by season and zone

AEZ	Locality	Treatment	Yield Rainy season	Yield Dry season	AEZ Effect
III	Foumbot	Control (T-)	1.02 ± 0.02e	0.92 ± 0.01d	2.45 ± 0.11 A'
		Rapax	2.67 ± 0.01d	2.62 ± 0.03c	
		<i>L. camara</i>	2.70 ± 0.03d	2.65 ± 0.03c	
		Neem	2.82 ± 0.02b	2.79 ± 0.04a	
		Tobacco	2.75 ± 0.02c	2.73 ± 0.03b	
		Gremec (T +)	2.92 ± 0.03a	2.82 ± 0.02a	
Mean season			2.48 ± 0.16a	2.41 ± 0.16a	2.49 ± 0.11 A'
V	Ntui	Control (T-)	1.07 ± 0.04e	0.98 ± 0.02e	
		Rapax	2.71 ± 0.01d	2.69 ± 0.02d	
		<i>L. camara</i>	2.74 ± 0.02d	2.68 ± 0.02d	
		Neem	2.85 ± 0.02b	2.83 ± 0.03b	
		Tobacco	2.79 ± 0.01c	2.77 ± 0.02c	
		Gremec (T +)	2.95 ± 0.02a	2.93 ± 0.03a	
Mean season			2.52 ± 0.16a	2.44 ± 0.17a	
Treatment			***	***	
Season			ns	ns	
AEZ			ns	ns	
Treatment*Season			ns	ns	
Treatment*AEZ			ns	ns	
Treatment*Season*AEZ			ns	ns	

For each parameter and each zone, means followed by the same letter are not significantly different (Tukey's HSD test, $P = 0.05$). AEZ: agro-ecological zone. *, ** and ***: significant at the 0.05, 0.01 and 0.001 levels, respectively, ns: no significant difference at the 0.05 level

Table 6 Cost benefit analysis

Type of insecticide	Quantity (ha)	Cost (\$)	Labour (\$)	Total (\$)
Chemical insecticide	1 L	20.83	17.36	38.19
Botanical insecticide	1,5 L	7.81	17.36	25.17

Botanical insecticide was cheaper compared to chemical insecticide (Table 6).

3.6 Correlation

Analysis of the correlation (Fig. 1) between the parameters measured and evaluated shows that all these variables were significantly correlated. Dead heart incidence was positively and highly significantly correlated with the number of larvae ($r = 0.703^{**}$), severity ($r = 0.906^{**}$) and incidence ($r = 0.950^{**}$). Dead heart was negatively and highly significantly correlated with yield ($r = -0.949^{**}$). The number of larvae was positively and highly significantly correlated with incidence ($r = 0.748^{**}$) and severity ($r = 0.752^{**}$).

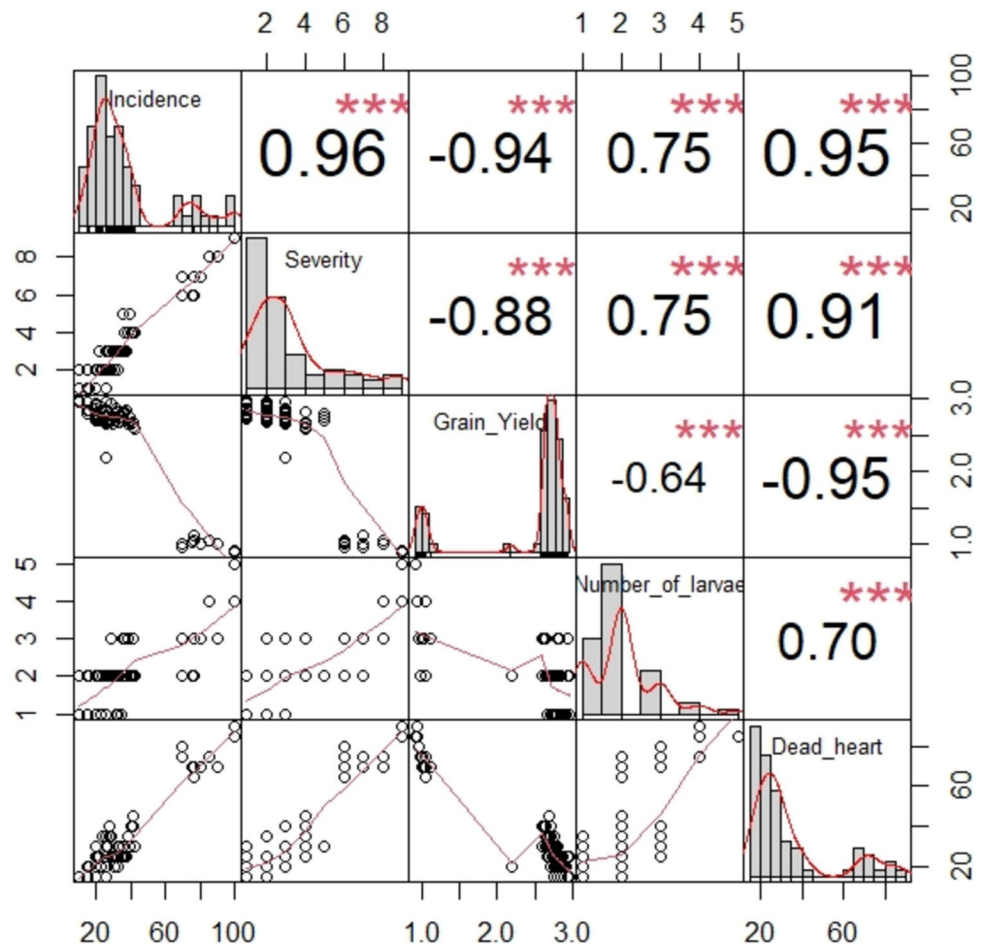
3.7 Discussion

Three factors (treatments, seasons and AEZ) were used in this study to evaluate incidence, severity, number of leaves, number of larvae and grain yield.

Caterpillar evaluation parameters (incidence, severity and number of larvae) for all treatments were higher in the dry season than in the rainy season. This would be because, during this season at the study sites, very few growers cultivate maize. Most maize growers prefer the rainy season. Indeed, the fall armyworm, despite its polyphagia has a clear affinity for maize (Faye 2010; Prasanna et al. 2018). This suggests that the caterpillars were concentrated on the few available maize plots at the site which may partly explain the high infestation pressure in the dry season.

Zone III was more susceptible to armyworms compared to Zone V. This could be explained, on the one hand, by the excessive use of chemical pesticides by market gardeners in the zone, which may have promoted the resistance in crop pests, including armyworms. On the other hand, the proximity of the trial site to market garden fields could also be a factor. The findings of Kasongo et al. (2021) revealed that maize fields located near market garden crops are more

Fig. 1 Correlation. ***: significant at the 0.001 level; values in the figure represent correlation coefficient



frequently attacked by armyworms, with an average incidence of $52 \pm 17\%$ compared to those surrounded by other vegetation.

The synthetic pesticide Emamectin benzoate (Gremec) had a highly significant effect on armyworm incidence, followed by tobacco extract and neem oil. It controls lepidopteran pests by acting as a gamma-aminobutyric acid (GABA) and glutamate-dependent chloride channel agonist of insect neuronal membranes (Batiha et al. 2020). Intoxication results in gait and posture disorders, followed by lethargy, tremors and convulsions. Neurological manifestations are due to hyperexcitability of the central nervous system, resulting from non-competitive, reversible inhibition of the chloride-dependent RDL subunit of the normally inhibitory GABA receptor (Testud and Grillet 2017). These synthetic active ingredients act quickly, inducing caterpillar mortality in a short time (Nboyine et al. 2022). The different properties of Emamectin benzoate used in this study explain the reduced infestation levels observed in both dry and rainy seasons. These findings are consistent with those of other researchers who compared the effects of neem and synthetic products, particularly Emamectin benzoate (Phambala et al. 2020; Nboyine et al. 2022).

Neem oil, aqueous tobacco extract and *L. camara* are effective natural insecticides that are harmless to human and animal health but lethal to fungal pathogens and insects (Bidiga 2014). The active ingredient in neem acts on insects either by: i) preventing feeding, or ii) inducing physiological disorders, leading to death upon ingestion (Bidiga 2014).

Aqueous extracts were less effective than synthetic pesticides. Two possible explanations exist: i) the active ingredients in these plant extracts act through contact or ingestion and exert anti-appetent, sterilizing, and growth regulating effects on insects (Aribi et al. 2020; Looli et al. 2021). In this way, caterpillars may hide inside the ears or between the spikes to protect themselves from the product; ii) the short exposure period of the ear caterpillars. Looli et al. (2021) stated that the effectiveness of some biological products declines as caterpillars develop.

The plant extracts used (neem, tobacco, Gremec, and *L. camara*) significantly reduced caterpillar severity, number of larvae, and leaf damage in treated plots. Foliar application of these extracts may have prevented caterpillars from feeding on maize leaves. In addition, the insecticidal properties of these extracts (particularly neem oil) likely killed the larvae feeding on treated plants, thereby reducing the larval population and associated damage. These results are similar to those of Patricia and Eliane (2010) and Estefânia et al. (2016), who reported that neem extracts were effective against wheat aphids.

Several bioactive molecules extracted from neem seed oil including azadirachtin, nimbidinin, solanine, deacetylazadirachtinol and melantriol have been identified (Diedhou

2017). Azadirachtin, the main active compound, disrupts insect morphogenesis (Aziz et al. 2013). Considered the most active compound in neem since 1972, azadirachtin has insecticidal and repellent activity against over 200 insect species. Schmutterer and Rembold first demonstrated its growth-inhibiting properties in 1980 (Faye 2010). Azadirachtin's structure resembles that of ecdysone, the insect hormone that controls metamorphosis (the passage from the larval stage to adulthood). It affects the corpus cardiacum which regulates hormone secretion. Morphological change requires precise synchronization of numerous hormones and other physiological changes. Azadirachtin blocks ecdysone and hormonal secretion, halting insect development and molting.

These effects have been observed in several insect families, namely Lepidoptera, Diptera, Orthoptera (grasshoppers, locusts, etc.), Hymenoptera (very weak for bees) and certain aphid species. The LD50 varies by species, ranging from 1 to 4 µg of azadirachtin per gram of insect. Structure–activity relationship also confirms its anorectic activity, inhibiting insect growth and causing malformations or death (Traore et al. 2019). The insecticidal effects of azadirachtin can be summarized in three ways: (i) it blocks hormone secretion, halting insect development; (ii) it disrupts respiration across muscle, nervous, and glandular tissues, causing loss of coordination; (iii) it suppresses feeding behavior (anorexia), leading to starvation (Mehlhorn et al. 2011). Despite its potency, azadirachtin is non-phytotoxic and considered safe for most non-target organisms (Diedhou 2017).

Gremec, tobacco, and neem treatments resulted in significantly lower incidence of dead hearts than the control and other treatments across both seasons and study sites. This confirms the bio efficacy of neem and tobacco in controlling maize pests in general and insect activity in particular. These results support those of Ogah et al. (2011) who also successfully controlled crop pests with neem.

The low presence of larvae on maize leaves and stalks in all treatments except the control, from 21 to 42 days after sowing, can be attributed to the effectiveness of the applied plant extracts, which likely prevented larvae from feeding. This corroborates findings by Kammo et al. (2019), who reported that by 75 days after sowing, larvae were absent from maize leaves and stalks in all treated plots.

Grain yield was significantly influenced by treatment, with the lowest yield observed in the untreated control (T-) in both seasons. Yields were at least 1.6 times higher in treated plots. The synthetic insecticide produced the highest yields, followed by tobacco, neem, and *L. camara*. Similar results were obtained by Nboyine et al. (2022) in Ghana. The efficacy of synthetic insecticides, particularly Emamectin benzoate and acetamiprid, confirms findings by Sisay et al. (2019), Babendreier et al. (2020), Yahaya et al. (2021), and Nboyine et al. (2022). However, despite their effectiveness,

synthetic pesticides are ecologically and socially unsustainable and entail high financial costs (Kumela et al. 2019). These products are also responsible for numerous poisoning incidents, the UN estimates 11,000 deaths out of 385 million non-fatal poisonings annually (ONU 2022).

Although the yield difference between plant extract-treated plots and those treated with synthetic pesticides was significant, when factoring in pesticide costs and long-term environmental effects, plant extracts emerge as an ecologically viable alternative. They are biodegradable, fertilizing, and safe for the environment (Sane et al. 2018). According to Bélanger and Musabyimana (2005), neem-based extracts pose no harm to beneficial insects.

Biopesticides have the unique advantage of preventing resistance development in pests like armyworms. Nevertheless, their adoption by Cameroonian farmers remains low. This may be due to limited awareness of their benefits and effectiveness, resulting from inadequate dissemination. Even among farmers who acknowledge their effectiveness, challenges include unavailability of ready-to-use formulations, the labor-intensive nature of processing plant material into powder, and the lack of premium pricing for organic products.

A correlation analysis of all variables revealed a statistically significant relationship, indicating interdependence among the assessed parameters (fall armyworm incidence, fall armyworm severity, number of larvae, incidence of dead heart, and yield).

4 Conclusion

The armyworm is a real threat to maize production in Cameroon. The present study, whose aim was to assess the efficacy of plant extracts in controlling armyworms, shows that tobacco, neem and *L. camara* were highly effective insecticides. This work shows that the Western highlands zone was the most sensitive to caterpillars. The dry season was the most propitious for the proliferation of armyworms. Tobacco extracts, neem and *L. camara*, could be an alternative to synthetic insecticides for managing armyworms in maize fields. However, it would be more interesting to evaluate the bio efficacy of these plant extracts in other agro-ecological zones of Cameroon with more than one variety of maize to better appreciate the most sensitive areas and those tolerant to armyworms and a varietal effect.

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Authors' contributions Kamtchoum Stéphane Martial designed the protocol, set up the trials and wrote the report. Carine Nono Temegne interpreted the results and corrected the project. Hervé Sime Djomo

was responsible for data analysis. Emmanuel Youmbi designed and supervised the subject.

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Materials availability Not applicable.

Code availability Not applicable.

Declarations

Ethics approval and consent to participate Not applicable.

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