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Full Length Research Article

Methanolic Extracts of Selected Botanicals against Fall Armyworm, *Spodoptera* frugiperda (J. E. SMITH) On Maize Infestation in Kaduna and Katsina States, Nigeria

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ABSTRACT
An experiment was conducted to evaluate the efficacy of methanolic extracts of selected botanicals against the larvae of *Spodoptera frugiperda* under laboratory, screen-house, and field conditions. Treatments comprised methanolic extracts of *Khaya senegalensis*, *Hyptis suaveolens*, *Capsicum frutescens* and *Azadirachta indica*, including their binary mixtures in a 50:50 ratio, each applied at concentrations of 2.5 %, 5.0 % and 10.0 % (w/v). Emamectin benzoate (5% WDG) served as the positive control, while water + 0.1 % tween 80 acted as the negative control. Results revealed significant variations among treatments across all parameters. The combination of *H. suaveolens* + *A. indica* exhibited the highest larval mortality: feeding toxicity (72.53±1.44%) and contact toxicity (50.18±5.39%), greatest antifeedant effect (74.76±3.66%), and lowest leaf damage incidence (1.34±0.21%, and 1.77±0.08%) and severity (1.31±0.03%, and 1.29±0.03%) under screen house and field conditions respectively, with consequent increase in maize dry matter weight (3.85±0.52 t ha^{-1}) and overall grain yield (8.12±0.15 tha^{-1}) comparable to Emamectin benzoate. The findings demonstrate the bio-efficacy of *H. suaveolens* + *A. indica* mixtures as potential alternatives to synthetic insecticides in the management of fall armyworm (FAW) infestation on maize.
Keywords: *Spodoptera frugiperda*, *Hyptis suaveolens*, *Azadirachta indica*, botanical mixtures, methanolic extract, Emamectin benzoate.

Introduction
Maize (*Zea mays* L.) is one of the most widely cultivated cereal crops worldwide, serving as a major source of food, feed, and industrial raw material. In Sub-Saharan

Africa, particularly Nigeria, maize play a critical role in household food security and income generation due to its adaptability to diverse agro-ecological zones and high yield potential (FAO, 2017; CABI, 2017). However, its productivity is severely constrained by numerous biotic and abiotic factors, among which insect pests are the most destructive.

The Fall armyworm (FAW), native to the tropical and sub-tropical regions of the Americas, has emerged as one of the most invasive pests in Africa since its first detection in Nigeria in 2016. It is a highly polyphagous pest known to attack more than 80 plant species, including maize, sorghum, millet, sugarcane, and various vegetables (Prasoona *et al*., 2022; Goergen *et al*., 2016). An estimated earning loss of USD 268 million for maize crop in Abia, Ekiti, Ondo and Oyo States of Nigeria are due to FAW infestation (FAO, 2018).

Chemical insecticides remain the most common control measures adopted by farmers; however, their indiscriminate use poses lots of disadvantages such as insecticide resistance, pest resurgence, pest replacement, pesticide poisoning and deleterious effect on non-target organisms (Santosh *et al.,* 2020). Hence, there is increasing emphasis on safer and more sustainable alternatives such as plant derived insecticides. Botanicals have various merits such as: non-persistent nature once applied, non-toxic to humans, livestock and natural enemies of the pests, affordability in terms of cost, easy to prepare and in most cases readily available containing multiple of active ingredient which work synergistically making it difficult for pests to develop resistance (Kareru *et al*., 2013).

Several botanicals, notably *Azadirachta indica*, *Hyptis. suaveolens*, *Khaya senegalensis*, and *Capsicum frutescens*, have shown promise in the management of various lepidopterans pests (Paula *et al*., 2000; Amusan *et al*., 2005; Falko *et al*., 2010; Abdullahi *et al*., 2012; Lucena *et al*., 2017; Birhanu *et al*., 2019; Kelita *et al*., 2020; Prasoona *et al*., 2022). Nonetheless, their efficacy against *S. frugiperda* under Nigerian agro-ecological conditions remains limited. Therefore, this study was conducted to evaluate the effectiveness of methanolic extracts of selected botanicals and their mixtures for the management of *S. frugiperda* infestation in Kaduna and Katsina States, Nigeria.

Materials and Methods

Laboratory Experiments

Experimental Design

The experiments were laid out in a factorial Completely Randomized Design (CRD) with four repetitions. Treatments consisted of seed extracts of four plant materials, namely; Mahogany (*K. senegalensis*), African bush tea (*H. suaveolens*), Neem kernel (*A. indica*), Hot pepper (*C. frutescens*), and their mixtures (Khaya + Capsicum, Khaya + Hyptis, Khaya + Neem, Capsicum + Hyptis, Capsicum + Neem and Hyptis + Neem), in a ratio of 50:50 each at three different concentrations (2.5 %, 5.0 % and 10.0 % w/v), a standard check (Emamectin benzoate 5% WDG) and control (water + 0.1 % tween 80), tested

under feeding and contact toxicity and antifeedant activity response variables.

Collection, Preparation and Extraction of Plant Material

Freshly matured Seeds of *K. senegalensis, A. indica*, and *H. suaveolens* were collected within Zaria environs, washed with clean water tap water, and shade-dried to complete dryness. Dried *C. frutescens* seeds were purchase from Zaria market. Each seed sample was separately ground into powder using a laboratory blender and stored until extraction.

Extraction was carried out in the Mycotoxicology Laboratory, Department of Crop Protection, ABU, Zaria, using cold maceration method with methanol as solvent (Doughari, 2012; Ujang *et al*., 2013; Pandey and Tripathi, 2014; Majekodunmi, 2015; Azwanida, 2015; Ingle *et al*., 2017). Two kilograms (2 kg) of each powdered sample were soaked in 6 L of methanol for 48 hours in a 12 L aspirator bottle. The filtrate obtained was concentrated using a rotary evaporator to yield a syrupy crude oily extract. Serial dilution of 100 ml of each extract were prepared using distilled water and 0.1% Tween 80 (as emulsifier, sticker, and surfactant) to obtain concentrations of 2.5%, 5.0% and 10.0% (w/v). Since oily extract was obtained, specific gravity of each extract oil was used to in the calculation of each concentration, that is why the concentration computation was in w/v. The synthetic check, Emamectin benzoate (5% WDG), was prepared according to the manufacturer's recommendation (10 g per 15 L of water).

Formulation of the mixtures

The mixtures were formulated in a ratio of 50:50 as: 50 % of 2.5 % Khaya + 50 % of 2.5 % Capsicum, 50 % of 2.5 % Khaya + 50 % of 2.5 % Hyptis, 50 % of 2.5 % Khaya + 50 % of 2.5 % Neem, 50 % of 5.0 % Khaya + 50 % of 5.0 % Capsicum, 50 % of 5.0 % Khaya + 50 % of 5.0 % Hyptis, 50 % of 5.0 % Khaya + 50 % of 5.0 % Neem, 50 % of 10.0 % Khaya + 50 % of 10.0 % Capsicum, 50 % of 10.0 % Khaya + 50 % of 10.0 % Hyptis, 50 % of 10.0 % Khaya + 50 % of 10.0 % Neem, 50 % of 2.5 % Capsicum + 50 % of 2.5 % Hyptis, 50 % of 2.5 % Capsicum + 50 % of 2.5 % Neem, 50 % of 5.0 % Capsicum + 50 % of 5.0 % Hyptis, 50 % of 5.0 % Capsicum + 50 % of 5.0 % Neem, 50 % of 10.0 % Capsicum + 50 % of 10.0 % Hyptis, 50 % of 10.0 % Capsicum + 50 % of 10.0 % Neem, 50 % of 2.5 % Hyptis + 50 % of 2.5 % Neem, 50 % of 5.0 % Hyptis + 50 % of 5.0 % Neem and 50 % of 10.0 % Hyptis + 50 % of 10.0 % Neem). The choice of ratio was obtained from preliminary trials carried out prior to the experiments.

Fall Armyworm Rearing and Diet formulation

Larvae of *S. frugiperda* (instars 6 – 7) were collected from Institute of Agricultural Research (IAR) maize trial farms and reared under artificial diet conditions at the Insectary, Department of Crop Protection,

ABU, Zaria. The artificial diet was prepared following Prasanna *et al*. (2018) protocol. A total of 3 L of diet was prepared and poured (50 ml each) into 34 small plastic bowls (9 cm × 4 cm dia.). After solidification at room temperature, the diet was cut into eight equal portions for use in the feeding and contact toxicity bioassay.

Feeding Toxicity Test

This test was conducted using the formulated FAW diet instead of maize leaves used by Edley *et al*. (2019), Kelita *et al*. (2020), Emmanuel *et al*. (2022a), and Prasoona *et al*. (2022). This is to maintain feeding consistency and avoid diet-changing stress. Portions of plain artificial diet were dipped into 50 ml of each extract concentration (2.5%, 5.0% and 10.0% w/v) for 20 seconds and air-dried for 1 hour. The treated diets were transferred to 9 cm diameter plastic bowls, and five second-instar larvae were introduced with a camel-hair brush. Bowls were covered with perforated lids.

Treatments including standard check (Emamectin benzoate 5% WDG) and control (water + 0.1% Tween 80), were repeated four times in a Completely Randomized Design (CRD). Percentage mortality was recorded for 7 days at 24 h intervals and corrected using Abbott's formula (Abbott, 1987).

$$\textbf{\%mortality} = \frac{\text{Number of dead FAW larvae}}{\text{Number of introduced FAW larvae}} \times 100 \qquad \textbf{Corrected mortality} = \frac{(\%\text{ of death in treated} - \%\text{ death in control})}{(100 - \%\text{ death in control})} \times 100$$

Contact Toxicity Test

Following Aryani and Auamacharoen (2016) and Kelita *et al*. (2020), 5µL (1µL per larva) of each extract concentration was topically applied to the dorsal prothoracic region of five second-instar larvae using a micropipette. Treated larvae were placed on plain diet portions in 9 cm diameter rubber bowls and covered with perforated lids. Percentage mortality was recorded and corrected as in the feeding toxicity test.

Antifeedant Activity Test

This assay was carried out using the leaf-dip method on maize leaves (*Zea mays*) following the procedure of Edley *et al*. (2019), Emmanuel *et al*. (2022b), and Prasoona *et al*. (2022). Maize leaves were washed thoroughly with tap water, cut into 4 cm × 4 cm square, dipped in 50 ml of each extract concentration for 20 second, and air-dried at room temperature for one hour, after which they were transferred into labeled plastic bowls (9 cm diameter). A single pre-starved (2 h) third-instar larva was placed on each treated leaf, covered with serviette paper and sealed with perforated plastic lid. Each treatment including standard check and control had four repetitions in a Completely Randomized Design. The antifeedant effect was determined after 24 hours of exposure by measuring the leaf area consumed using graph paper, and the percentage antifeedant activity was calculated as follows:

$$\frac{\text{(Leaf area consumed by the larvae in the control)} - \text{(leaf area consumed by the larvae in the treated)}}{}$$

$$\% \text{ antifeedant} = \frac{\text{(Leaf area consumed by the larvae in the control) + (leaf area consumed by the larvae in the treated)}}{} \times 100$$

Screen house and Field Experiments

Based on bioassay results, *C. frutescens* was excluded due to its irritant properties and high dosage dependency. A 2.5% w/v concentration was chosen for sustainability and cost-effectiveness. SAMAZ-17, a medium-maturing (90 – 100 days), high-yielding (5.0 tha^{-1}) maize variety, tolerant to *Striga*, was used.

The experiments were conducted at the Screen house of the Department of Crop Protection and at IAR farm, ABU Samaru Zaria, Kaduna State, and Bakori irrigation site, Katsina State. Samaru lies at $11^0$10'N, $07^0$37'E, while Bakori is at $11^0$33'N, $07^0$25'E.

Treatments consisted of Khaya, Hyptis, Neem, and their mixtures (Khaya + Neem, Hyptis + Neem, Khaya + Hyptis) at 2.5% w/v, a standard check, and an untreated control (8 treatments). These were laid out in a Randomized Complete Block Design (RCBD) with four replications.

In the screen house, four seeds were sown per pot (4 cm depth), later thinned to two stands per pot. NPK 15:15:15 was applied at 120:60:60 kg ha^{-1} in two splits (800 kg ha^{-1} at planting and 130 kg ha^{-1} urea at 4 weeks). Five neonate larvae per stand were release (space at different inter nodes to avoid cannibalism) 21 days after emergence, early in the morning, and cages (2 m × 1 m × 0.5 m) were used to prevent larval movement.

For field trials, plots (6 m × 4.5 m) were arranged in four blocks separated by 1.5 m alleys. Sowing was done by dibbling at 75 cm × 25 cm spacing, two seeds per hole and thinned to one. Standard agronomic practices were followed. Treatments were applied using hand-held sprayer 10 h post-infestation in the screen house and from the third week after sowing in the field, followed by three weekly sprays in the evening to coincide with larval activity.

In the screen house, observation began 10 h post-infestation (before first spray) and continue weekly after each application. For field trial, 40 Maize stands from the four middle rows were selected for assessment and data were collected weekly before and after sprays.

Parameter measured were:

- **Larval count:** number of larvae per plot.
- **Foliar damage incidence:** using the formula bellow;

$$\text{Percent incidence} = \frac{\text{Number of leaves damaged}}{\text{Total number of leaves inspected}} \times 100$$

- **Foliar damage severity:** using a visual rating scale (1-9) modified from (Davis and Williams 1992 as cited in Prasanna *et al*. (2018).
- **Dry matter yield:** weight of dry stalks (screen house).
- **Damaged cobs count:** number of damaged cobs per plot.

- **Cob and kernel damage severity:** using a visual rating (1-9) (CYMMIT, 2020 unpublished protocol; as cited in Mbaidiro and Onzo, (2022).
- **Cob yield:** weight of cobs before threshing per plot.
- **1000 grain yield:** weight of 1000 grains per plot.
- **Grain yield:**

$$\text{Yield (kgha}^{-1}) = \frac{a \times 10{,}000}{b \times 1000}$$

Where; a = sample yield (g) and b = plot size (m^2) (Raheja, 1976; Aliyu *et al*., 2011)

$$\text{Avoidable yield loss (\%)} = \frac{Yp - Yu}{Yp} \times 100$$

Where; Yp = Yield from protected plot and Yu = yield from unprotected plot (Adamu, 2005; unpublished).

Data Analysis

Bioassay data were angular transformed, while screen house and field insect data were square-root transformed. All data were subjected to (ANOVA) using R Studio, and significant means were separated using Student-Newman-Keuls (SNK) test at 5% level of significance.

Results

Bioassay Results

Feeding Toxicity

Table 1a presents the mean percentage feeding toxicity of methanolic seed extracts of *K. senegalensis*, *C. frutescence*, *H. suaveolens*, *A. indica* and their mixtures against *S. frugiperda* larvae. Results showed that Khaya, Hyptis, Neem, Khaya + Neem, Capsicum + Neem, Hyptis + Neem and standard check recorded significantly ($p < 0.05$) higher (71.40±6.25%, 69.20±2.00%, 69.20±2.00%, 67.11±2.57%, 64.82±2.58%, 72.53±1.44% and 77.08±0.00% respectively) larval mortality, and were statistically similar to *Capsicum* (58.77±4.04%), but significantly different from Khaya + Capsicum (35.62±4.71%), Khaya + Hyptis (40.62±5.44%), and Capsicum + Hyptis (38.87±5.32%). The mortality caused by Capsicum was not statistically different from that of Khaya + Hyptis. No significant differences were observed among concentrations (P-value 0.853). However, significant interaction effects were recorded (Table 1b).

Contact Toxicity

Results on contact toxicity (Table 1a) revealed that Hyptis + Neem recorded the highest (50.18±5.39%) larval mortality among the botanical treatments, although it was statistically similar to Capsicum (46.08±6.28%), Neem (41.85±4.86%), Khaya + Capsicum (43.95±3.15%), Khaya + Hyptis (43.77±7.06%), Khaya + Neem (33.69±3.90%), Capsicum + Hyptis

(46.97±4.15%) and Capsicum + Neem (40.79±3.99%), but significantly different ($p < 0.05$) from Khaya and Hyptis (19.66±2.60% and 22.99±2.88%). Larval mortality in Hyptis was statistically similar to Neem, Khaya + Neem and Capsicum + Neem. The least mortality was recorded in Khaya which was statistically comparable with Hyptis and Khaya + Neem. The standard check (Emamectin benzoate 5% WDG) as expected, recorded significantly ($p < 0.05$) higher (77.08±0.00%) larval mortality than most treatment, but was not statistically different from Hyptis + Neem. Similar to feeding toxicity, no significant (P value 0.513) concentration effect was observed, though there was a significant interaction effect between extract type and concentration (Table 1b).

Antifeedant Activity

Antifeedant activity results (Table 1a) showed that all botanical extracts and their mixtures deterred larval feeding to varying degrees. Hyptis + Neem produced the strongest (74.76±3.66%) antifeedant effect, followed by Khaya + Neem (72.07±3.27%), Capsicum + Neem (71.223.81%) and Khaya + Capsicum (70.01±2.55%). No significant difference was observed among concentrations (P-value 0.287) and interaction effect (P-value 0.740).

Overall, the combined used of Hyptis + Neem was the most effective treatment across all toxicity parameters, showing comparable larvicidal (feeding toxicity: 72.53±1.44% vs 77.08±0.00; contact toxicity: 50.18±5.39% vs 77.08±0.00%) and deterrent (74.76±3.66% vs 76.63±1.14%) effects to the chemical standard.

Table 1a: Mean percentage feeding toxicity, contact toxicity and antifeedant activity effects of methanolic seed extracts of *K. senegalensis*, *C. frutescence*, *H. suaveolens*, *A. indica* and mixtures at varying concentrations and exposure periods on *S. frugiperda* larvae in 2023

Treatments	Feeding toxicity (%) at 7 days	Contact toxicity (%) at 7 days	Antifeedant activity (%) at 24 hours
Plant extract (P)			
Khaya	71.40±6.25^{a}	19.66±2.60^{d}	67.69±2.26^{a}
Capsicum	58.77±4.04^{ab}	46.08±6.28^{b}	66.18±2.66^{a}
Hyptis	69.20±2.00^{a}	22.99±2.88^{cd}	61.49±3.55^{a}
Neem	69.20±2.00^{a}	41.85±4.86^{bc}	66.11±3.14^{a}
Khaya + Capsicum	35.62±4.71^{c}	43.95±3.15^{b}	70.01±2.55^{a}
Khaya + Hyptis	40.62±5.44^{bc}	43.77±7.06^{b}	57.18±4.48^{ab}
Khaya + Neem	67.11±2.57^{a}	33.69±3.90^{bcd}	72.07±3.27^{a}
Capsicum + Hyptis	38.87±5.32^{c}	46.94±4.15^{b}	67.16±4.69^{a}
Capsicum + Neem	64.82±2.58^{a}	40.79±3.99^{bc}	71.22±3.81^{a}
Hyptis + Neem	72.53±1.44^{a}	50.18±5.39^{ab}	74.76±3.66^{a}
Standard check	77.08±0.00^{a}	77.08±0.00^{a}	76.63±1.14^{a}
Significance	***	***	***
Concentration (C) (%w/v)			
2.5	58.94±3.22	37.37±2.57	63.00±2.09
5.0	58.61±2.99	39.35±3.07	66.44±2.13
10.0	60.71±2.66	42.11±3.00	67.74±1.67
Significance	NS	NS	NS
Interaction			
P*C	**	*	NS

Means followed by same letter (in superscript) are statistically the same using SNK at 5%

Table 1b: Mean percentage feeding and contact toxicity interaction effects of methanolic seed extracts of *K. senegalensis*, *C. frutescence*, *H. suaveolens*, *A. indica* and mixtures at varying concentrations on *S. frugiperda* larvae in 2023

Plant extract (P)	Feeding toxicity (%)			Contact toxicity (%)		
	Concentration (w/v)					
	2.5	5	10	2.5	5	10
Khaya	73.67±0.12^{a}	70.26±0.23^{a}	70.26±0.23^{a}	16.33±8.45^{d}	16.33±8.45^{d}	26.32±13.59^{bcd}
Capsicum	57.63±7.60^{ab}	57.63±7.60^{ab}	61.04±8.92^{ab}	23.16±11.78^{cd}	48.17±24.36^{abcd}	66.91±33.86^{ab}
Hyptis	67.09±6.32^{ab}	70.26±0.23^{a}	70.26±0.23^{a}	16.33±8.45^{d}	22.91±12.13^{cd}	29.74±15.00^{bcd}
Neem	73.67s±0.12^{a}	70.26±0.23^{a}	67.09±6.32^{ab}	41.59±21.88^{abcd}	42.12±21.61^{abcd}	41.84±21.71^{abcd}
Khaya + Capsicum	29.73±3.17^{d}	38.71±7.71^{cd}	38.43±12.92^{cd}	42.12±21.14^{abcd}	41.84±21.23^{abcd}	47.89±24.43^{abcd}
Khaya + Hyptis	38.43±10.76^{cd}	32.37±5.82^{cd}	51.06±10.74^{bc}	44.72±22.68^{abcd}	57.63±30.38^{abc}	28.96±16.33^{bcd}
Khaya + Neem	64.21±6.58^{ab}	70.26±3.94^{a}	66.85±3.41^{ab}	32.90±16.61^{bcd}	32.37±16.99^{bcd}	35.79±18.82^{bcd}
Capsicum + Hyptis	29.49±6.28^{d}	35.54±8.69^{cd}	51.58±9.38^{bc}	51.05±25.72^{abcd}	35.54±18.48^{bcd}	54.22±27.36^{abcd}
Capsicum + Neem	67.09±3.94^{ab}	67.09±6.58^{ab}	60.27±3.41^{ab}	45.00±23.05^{abcd}	38.95±19.72^{abcd}	38.42±20.02^{abcd}
Hyptis + Neem	73.67±0.12^{a}	73.67±0.12^{a}	70.26±0.23^{a}	41.84±21.71^{abcd}	57.63±29.62^{abc}	51.06±26.11^{abcd}

Means followed by same letter (in superscript) are statistically the same using SNK at 5%.

Screen House Results

Foliar Damage Incidence

Table 2 shows that foliar damage incidence differed significantly ($p < 0.05$) among treatments. The combination Hyptis + Neem recorded the lowest (1.34±0.21%) damage incidence, followed by Khaya + Neem (2.43±0.18%), which were comparable with the standard check (0.71±0.00%). In contrast, Khaya, Hyptis (3.22±0.55%,) and Neem (1.96±0.60%) individually exhibited the highest foliar damage levels, but significantly different from the control which recorded the highest (7.39±0.71%) foliar damage level.

Foliar damage Severity

Significant differences ($p < 0.05$) were observed in leaf damage severity (Table 2). Hyptis + Neem mixture (1.31±0.31%) and Neem (1.44±0.11%) exhibited the least severity scores, which were statistically similar to Emamectin benzoate (1.22±0.00%) but lower than other botanical treatments. The control recorded the highest (2.97±0.03%) damage severity score across all sampling periods.

Larval Population

Results on larval population (Table 2) indicated that all botanical treatments significantly ($p < 0.05$) reduced the number of *S. frugiperda* larvae compared to the untreated control. Among the treatments, Hyptis + Neem (0.07±0.02) recorded the lowest mean larval population, followed by Khaya + Neem (0.94±0.07) and Neem (0.92±0.04). These treatments were statistically similar to the standard check (0.01±0.00) (Emamectin benzoate 5%b WDG) but significantly different from Khaya (1.30±0.09), Hyptis (1.70±0.07) and Khaya + Hyptis (1.00±0.06). The control consistently maintains the highest larval population throughout the observation periods.

Dry Matter Yield

Dry matter yield (Table 2) varied significantly among treatments. The highest dry matter yield was obtained from Hyptis + Neem (3.85±0.44 t ha^{-1}), followed by Neem (3.25±0.54 t ha^{-1}) and Khaya + Neem (2.95±0.18 t ha^{-1}), which did not differ significantly from the standard check. The least dry matter yield occurred in the control plots (1.63±0.45 t ha^{-1}), followed closely by Khaya (2.15±0.32 t ha^{-1}), Hyptis (2.49±0.33 t ha^{-1}) and Khaya + Hyptis (2.51±0.29 t ha^{-1}) treatments.

Overall, screen house evaluation revealed that mixtures involving Neem and *Hyptis* consistently provided the best protection against FAW damage and improved yield parameters comparable to the synthetic insecticide standard

Field Results

Foliar Damage Incidence

Results on foliar damage incidence (Table 3) combined, showed that Hyptis + Neem (1.77±0.08%) produced the lowest percentage of damaged levels, followed by Khaya + Neem (2.07±0.14%), Khaya + Hyptis (2.28±0.25%), Neem (2.32±0.17%) and Khaya (2.45±0.34%). These were statistically comparable to the synthetic check (1.60±0.17%). The low (2.84±0.23%) larval population recorded by Hyptis singly was not statistically different from Khaya +

Neem, Khaya + Hyptis, Neem and Khaya, but significantly differ from Hyptis + Neem. The control plots recorded the highest (3.93±0.33%) leaf damage incidence.

Foliar damage Severity

Leaf damage severity (Table 3) followed a similar trend to foliar damage incidence. The least severity score was recorded in *Hyptis* + Neem (1.29±0.03%), *Khaya* + Neem (1.48±0.02%), *Khaya* + *Hyptis* (1.51±0.07%), Neem (1.43±0.07%), which were statistically similar to the standard check (1.28±0.03%). The highest (2.02±0.07%) severity score was recorded in the control, indicating sever defoliation.

Table 2: Mean effect of methanolic seed extracts sprays of Khaya, Hyptis, Neem and mixtures against *S. frugiperda* foliar damage incidence and severity, larval count and dry matter weight on maize infestation under screen house conditions at Weekly Interval at Samaru in 2023

Treatments	Foliar damage incidence (%)	Foliar damage severity (%)	Larval Count	Dry Matter weight (tha^{-1})
Khaya	3.22±0.55^{b}	1.69±0.09^{bc}	1.30±0.09^{b}	2.15±0.32^{bc}
Hyptis	3.22±0.45^{b}	1.77±0.19^{b}	1.70±0.07^{bc}	2.49±0.33^{bc}
Neem	1.96±0.60^{b}	1.44±0.11^{bc}	0.92±0.04^{cd}	3.25±0.54^{ab}
Khaya + Hyptis	2.82±0.39^{b}	1.64±0.02^{bc}	1.00±0.06^{c}	2.51±0.29^{bc}
Khaya + Neem	2.43±0.18^{c}	1.63±0.15^{bc}	0.94±0.07^{cd}	2.95±0.18^{ab}
Hyptis + Neem	1.34±0.21^{bc}	1.31±0.03^{bc}	0.07±0.02^{d}	3.85±0.44^{a}
Standard check	0.71±0.00^{c}	1.22±0.00^{c}	0.01±0.00^{d}	3.90±0.52^{a}
Control	7.39±0.71^{a}	2.97±0.03^{a}	2.04±0.06^{a}	1.63±0.45^{c}
Significance	*	*	*	*

Means followed by same letter (in superscript) are statistically the same using SNK at 5%

Larval Population

Table 3 presents the men larval population of *S. frugiperda* under field conditions. All botanical treatments significantly ($p < 0.05$) reduced larval populations (1.51±0.13, 1.56±0.10, 1.32±0.04, 1.41±0.15, 1.21±0.06 and 1.22±0.03), statistically similar to the

standard check (1.06±0.07) but differ significantly from the untreated control (2.61±0.17).

Number of damaged cobs

Results on percentage number of damaged cobs (Table 3) reveals that Hyptis + Neem produce the least (10.31±0.07%) number of damaged cobs, followed by Neem singly (10.63±0.16%). These were statistically similar to synthetic check (9.00±0.12%). The control plots recorded the highest (16.87±0.24%) number of damaged cobs but was not significantly ($p < 0.05$) different from Khaya (14.06±0.05%), Hyptis (12.50±0.15%) singly and mixtures of Khaya + Hyptis (13.44±0.08%) and Khaya + Neem (12.81±0.15%).

Cob and Kernel Damage severity

Significant differences ($p < 0.05$) were observed in cob and kernel damage (Table 3). The Hyptis + Neem mixture recorded the least (14.13±0.04%) damage score, comparable to Khaya + Neem (14.13±0.04%) and Hyptis (15.00±0.10%) and Neem (15.75±0.08%) singly, and were statistically similar to the standard check (14.13±0.04%). The control showed the highest cob and kernel (22.13±0.03%) damage score, followed by mixture of Khaya (19.13±0.03%) single and Khaya + Hyptis (17.13±0.06%) extracts.

Cob, 1000 grain, Overall Grain Yields and Avoidable Yield loss

Cob yield, 1000 grain yield, overall grain yield and avoidable Yield loss data (Table 3) indicated that all botanical treatments significantly improved yield (7.69±0.81, 7.75±0.33, 8.07±0.71, 7.75±0.23, 7.92±0.23, 8.25±0.15, and 8.12±0.31 t ha^{-1}) relative to the control (6.06±0.35 t ha^{-1}). The Hyptis + Neem mixture produced the highest (8.25±0.15 t ha^{-1}) mean grain yield comparable to Neem single extract (8.07±0.17 t ha^{-1}) and the standard check (8.12±0.31 t ha^{-1}), while the control recorded the lowest yield (0.06±0.35 t ha^{-1}). Avoidable yield loss was lowest (26.55%) in Hyptis + Neem treatments, confirming their superior protection and effectiveness under field conditions.

Overall, field results corroborated laboratory and screen house findings, showing that mixtures involving *H. suaveolens* and *A. indica* provided effective, environmentally safe alternatives to synthetic insecticides for the management of *S. frugiperda* in maize.

Discussion

The results of this study demonstrated that methanolic seed extracts of *K. senegalensis*, *H. suaveolens*, *C. frutescens*, and *A. indica*, as well as their mixtures, exhibited varying levels of toxicity and antifeedant activity against *S. frugiperda* larvae. The observed mortality and feeding deterrence corroborate the findings of some authors (Paula *et al*., 2000; Amusan *et al*., 2005; Falko *et al*., 2010; Abdullahi *et al*., 2012; Lucena *et al*., 2017; Birhanu *et al*., 2019; Kelita *et al*., 2020; Prasoona *et al*., 2022), who reported larvicidal and antifeedant effects of these botanicals.

The relative high efficacy recorded for the Hyptis + Neem mixture suggests a synergistic interaction between their active compounds, which may enhance larvicidal potency, feeding inhibition, and repellency.

Similarly, synergistic effects have been documented in mixtures of *A. indica* with other botanicals (Oparaeke *et al*., 2005).

The high mortality recorded in Khaya + Neem and Capsicum + Neem mixtures also supports the compatibility of Neem's Azadirachtin with other plant-derived compounds in integrated pest management (IPM).

Table 3: Mean effect of methanolic seed extracts sprays of Khaya, Hyptis, Neem and mixtures on foliar damage incidence, severity, larval count, and yield and related parameters by *S. frugiperda* at Samaru and Bakori (2023)

Treatments	Foliar damage incidence (%)	Foliar damage severity (%)	Larval Count	Number of damaged cobs (%)	Cob and kernel damage severity (%)	cob weight (kg)	1000 Grains weight (kg)	Yield (tha^{-1})	Yield difference (%)
Plant extract (P)									
Khaya	2.45±0.34^{bc}	1.58±0.10^{bc}	1.51±0.13^{b}	14.06±0.05^{ab}	19.13±0.03^{ab}	1.69±0.02^{a}	0.26±0.00^{a}	7.69±0.18^{a}	21.20
Hyptis	2.84±0.23^{b}	1.62±0.05^{b}	1.56±0.10^{b}	12.50±0.15^{ab}	15.00±0.10^{b}	1.73±0.14^{a}	0.25±0.00^{a}	7.75±0.33^{a}	21.81
Neem	2.32±0.17^{bc}	1.43±0.07^{bcd}	1.32±0.04^{b}	10.63±0.16^{b}	15.75±0.08^{b}	1.78±0.08^{a}	0.26±0.00^{a}	8.07±0.17^{a}	24.91
Khaya + Hyptis	2.28±0.25^{bc}	1.51±0.07^{bcd}	1.41±0.15^{b}	13.44±0.08^{ab}	17.13±0.06^{ab}	1.71±0.08^{a}	0.25±0.00^{a}	7.75±0.23^{a}	21.81
Khaya+ Neem	2.07±0.14^{bc}	1.48±0.02^{bcd}	1.21±0.06^{b}	12.81±0.15^{ab}	14.13±0.04^{b}	1.86±0.08^{a}	0.26±0.00^{a}	7.92±0.23^{a}	23.48
Hyptis + Neem	1.77±0.08^{c}	1.29±0.03^{cd}	1.22±0.03^{b}	10.31±0.07^{b}	14.13±0.04^{b}	1.86±0.09^{a}	0.25±0.00^{a}	8.25±0.15^{a}	26.55
Standard check	1.60±0.17^{c}	1.28±0.03^{d}	1.06±0.07^{b}	9.00±0.12^{b}	14.13±0.04^{b}	1.87±0.16^{a}	0.26±0.01^{a}	8.12±0.31^{a}	25.40
Control	3.93±0.33^{a}	2.02±0.07^{a}	2.61±0.17^{a}	16.87±0.24^{a}	22.13±0.03^{a}	0.15±0.02^{b}	0.05±0.01^{b}	6.06±0.35^{b}	
Significant	*	*	*	**	**	*	*	*	
Location (L)									
Samaru	2.22±0.15^{b}	1.55±0.06	1.40±0.09^{b}	5.22±0.07	19.16±0.03^{a}	1.63±0.06^{b}	0.25±0.00^{b}	7.49±0.17^{b}	
Bakori	2.59±0.17^{a}	1.51±0.04	1.58±0.10^{a}	4.88±0.08	13.91±0.05^{b}	1.92±0.04^{a}	0.26±0.00^{a}	8.35±0.16^{a}	
Significant	*	NS	*	NS	**	*	*	*	

Means followed by same letter (in superscript) are statistically the same using SNK at 5%

Furthermore, Bulus *et al*. (2023) reported the pesticidal efficacy of Neem and Hyptis extracts mixture with nematicidal effect, inhabiting *Meloidogyne* eggs hatching.

Reduced larval feeding and defoliation under screen house and field conditions further confirm the systemic and contact actions of the extracts. This aligns with the reports of Edley *et al*. (2019), who attributed decreased leaf consumption to neurotoxic and antifeedant effects of phytochemicals interfering with the insect's gustatory receptors. The consistent reduction in larval population leaf damage in treated plots, particularly with Hyptis + Neem, indicate persistence and residual activity, which could offer sustained protection during early maize growth stages.

The higher dry matter and grain yield observed in Hyptis + Neem and Khaya + Neem treatments suggest that botanical combinations can effectively suppress FAW infestation and reduce yield losses comparable to synthetic insecticides. The findings agree with the report of Oparaeke *et al*. (2005), Adebayo *et al*. (2020) and Mbaidiro and Onzo (2022), who found that neem-based botanical mixtures reduced infestation and enhanced yield in cowpea and maize respectively.

The difference in performance of the treatments could be attributed to variations in phytochemical profiles, extraction efficiency and mode of action of the bioactive compounds. For instance, *H. suaveolens* is known to contain eucalyptol and β-caryophyllene, which possess fumigant and contact toxicity, while *A. indica* contains azadirachtin, a potent growth regulator. The combined action of these constituents may enhance larval mortality and inhibit molting or feeding.

Overall, the comparable performance of Hyptis + Neem and the synthetic insecticide demonstrates that botanical mixtures can serve as sustainable alternative to chemical control in FAW management. This provides strong support for incorporating plant-based insecticides into IPM programs to reduce dependence on synthetic chemicals and minimize environmental contamination.

Conclusion and Recommendation

This study established that methanolic extracts of *K. senegalensis*, *H. suaveolens*, *C. frutescens* and *A. indica* both individual and in mixtures, exhibited varying degrees of toxicity and antifeedant activity against FAW. Among the treatments, the *Hyptis* + Neem mixture consistently recorded the highest larval mortality, strongest antifeedant activity, lowest leaf and cob damage, and highest yield performance under both screen house and field conditions.

The comparable efficacy of Hyptis + Neem to synthetic insecticide (Emamectin benzoate 5% WDG) indicates that botanical combinations can serve as viable, eco-friendly alternatives for the management of *S. frugiperda* in maize production. Therefore, the integration of such botanicals into pest management strategies can significantly reduce reliance on chemical insecticides, promote environmental safety and enhance sustainable maize productivity in Nigeria.

Further research is recommended to evaluate the field persistence, mode of action and potential formulation improvements of these botanicals for large-scale application.

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