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# Bio-efficacy of Crude Aqueous Leaf Extracts against the Fall Armyworm (*Spodoptera frugiperda*) and Maize Ear Rots in Zambia

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## Abstract

The use of crude aqueous leaf extracts (=plant extracts) provides an excellent opportunity to explore their potential as an alternative control method to chemical insecticides. Following the invasion of Zambia by Fall armyworm, *Spodoptera frugiperda* (FAW), huge amounts of chemical pesticides have been procured and applied to control the pest, potentially creating an environmental health hazard. This study was therefore conducted to assess the bio-efficacy of crude aqueous leaf extracts of selected plants against FAW and maize ear rots. A no-choice bioassay set up prior to a field trial revealed that extracts of *Azadirachta indica*, *Gliricidia sepium*, *Nicotiana tabacum*, *Ricinus communis*, and *Tephrosia vogelii* applied rate of 10% weight by volume exerted more than 40% FAW larvae mortality. These extracts when tested in a field experiment over two seasons, 2020 and 2021 with two checks, chemical insecticide, Lambda-cyhalothrin 5EC and untreated control significantly reduced FAW infestation by 21.7 to 33.3%, had low number of larvae per plant, and less leaf damage compared to the untreated control, though significantly higher than that insecticide control. It was further observed that more than two sprays were required to effectively control the pest. At harvest, there were significantly less incidence and severity of maize ear rot, low levels of cob damage and higher grain yield in leaf extract treatments than the unprotected maize. Overall, *R. communis* followed by *A. indica and N. tabacum* were most effective in reducing FAW attack and maize ear rot infection. Given their effectiveness, it is imperative these extracts are included in an Integrated Pest Management Program for FAW.

## Keywords

Fall Armyworm, Maize ear rots, Crude aqueous leaf extracts, Integrated pest management

## 1. Introduction

Fall armyworm Spodoptera frugiperda (FAW), a serious highly destructive insect pest with its origins in the Americas, first appeared in Africa in early 2016 [1, 2] and by December 2017, had spread to all sub-Saharan African (SSA) countries except Lesotho, and has now become endemic [3, 4]. It is reported to infest and feed on maize, sorghum, sugarcane, rice, millet, wild sorghum, cotton, and several other SSA crop species, and their wild relatives (at least 380 host plants), henceforth its effects on SSA agriculture have been so devastating [1]. The FAW moths are migratory in nature and are capable of flying up to a 100 kilometres in 24 hours resulting in extensive sporadic outbreaks. Because of its edacious feeding habits, diverse host range, ability to fly longer distances, capacity to multiply fast, and short life cycle with no diapause growth phase, it has been difficult to control, manage or eradicate [3, 5, 6]. Since its arrival on the African Continent, between 11-54% of maize production is reported to be lost annually [7, 8]. In Zambia, the pest was first detected in December 2016 on the Copperbelt Province, about 400km northwest of Lusaka, and has since spread to all the ten provinces of the country [9], with the infestation as high as 40% in some cases and with farm-level yield losses of more than 35% [10].

In most SSA countries including Zambia, due to the high FAW infestation rates, huge amounts of synthetic pesticides are bought by the National governments and cooperating partners, and distributed to farmers, annually [9]. A lot of these pesticides could have been effective if applied correctly but are often applied without following appropriate safety precautions and dose rates. This has resulted in indiscriminate spraying by farmers [11]. Also because of the inherent procurement impediments within the African government bureaucratic systems, the same pesticides or of the same class are often bought, this has led to repeated use of the same class of pesticides thereby increasing the chances of insecticide accumulation in the environment [7], and undesirable changes in the genetic make-up of the targeted pest resulting in pesticide resistance [11, 12]. Additionally, the continued use of synthetic chemical insecticides has detrimental food safety consequences such as leaving residues in food and water and the elimination of beneficial insects [13]. In humans, synthetic pesticides such as organophosphates and carbamates are potent cholinesterase inhibitors capable of causing serious health risks [14]. Besides the hazardous nature of synthetic pesticides, most small-scale farmers in SSA countries cannot afford low-risk chemical insecticides, either because they are too expensive or are not readily available. There are also instances, due to the non-availability of recommended pesticides, some farmers resorted to using very dangerous chemicals such as soaps and petroleum by-products. Plant extracts from several trees such as neem trees (*Azadirachta indica*-Juss.), *Tephrosia vogelii*, *Ricinus communis*, etc. are known to possess pesticide properties and are readily available across most of Sub-Saharan Africa including Zambia [15]. These extracts are relatively fast-acting and cause death by suffocation, thereby blocking the spiracles. Since time immemorial, plant extracts have been used to control insect pests in both subsistence and commercial crop production systems. Insecticidal chemicals occur naturally in plants and act as repellants, attractants, antifeedants, and growth inhibitors [16]. More recent studies show that farmers on their own have been using plant extracts or botanicals to control insect pests [17]. For example, Cocoa farmers in West Africa, have been using aqueous extracts of *Thevetia peruviana* (Yellow oleander) and *Azadirachta indica* (Neem) in controlling cocoa mirids, *Sahlbergella singularis* Haglund [18]. Other farmers have been reported to use *Cannabis sativa* L. to control particularly capsid insect populations [19]. The *Cannabis sativa* aqueous extract is applied alone or in a mixture with other local available insecticidal plant extracts such as *Nicotiana tabacum* and *Pachyelasmatessmannii* (Harms). Similarly, in Uganda, farmers use extracts of *Azadirachta indica*, *Cannabis sativa*, *Capsicum* spp., *Moringa*, *Nicotiana tabacum*, *Tagetes* spp, *Tithonia diversifolia*, *Lantana camara*, and *Tephrosia vogelii* as field and storage protectants [20]. Several scientific studies have been carried out to examine the mode of bio-activity, dosages, and duration of protection of both known and unexploited plant species with pesticidal properties among them, *A. indica*, *T. vogelii*, *Ricinus communis*, *Nicotiana tabacum*, etc. against armyworm, bollworm, caterpillars, pink stalk borer, and thrips [16]. Besides, targeting insect pests, the majority of these plant-derived pesticides have been observed to control plant parasites, such as nematodes, fungi, bacteria, and viruses [21, 22].

With the arrival of the FAW on the African continent, there has been renewed interest in several plant extracts, and these bio-friendly products are being tested for their efficacy against the pest with promising but varying results [23]. Several studies have suggested some plant extracts with insecticidal properties are effective and could be used by farmers against FAW [24, 25]. However, most of these studies have been conducted either as a laboratory experiment or limited to a single season if it's a field study, as such the uptake of proven plant-based pesticides has remained small and further constrained by limited data on other beneficial aspects [26, 27]. The acceptance and adoption of these technologies at the farm level are also hindered by a lack of data on the effectiveness of the farmers' experiential dose rate and spraying regimes and other plant health-related benefits such as reduction in the incidence and severity of maize ear rots. In addition, due to the existence of diverse agro-ecological systems in many SSA countries, only a few of these known plant extracts may be within the farmer's reach, and coupled with other socioeconomic factors hence not readily available, or affordable. Therefore, the efficacy of the cheaper, readily available sources of plant extracts must be investigated and packaged for use by farmers as part of the integrated pest management strategy against FAW. The objective of this study was therefore, to assess the toxicity of selected crude aqueous leaf extracts against FAW and their effect on the incidence and severity of maize ear rots.

## 2. Materials and Methods

### 2.1. Collection of Materials and Preparation of Extracts

Fresh, clean leaves of eight (8) plants, *Capsicum annuum* L (Bell pepper) *Gliricidia sepium* (Jacq.) Kunth ex. Walp (Gliricidia), *Melia azedarach* L. (Chinaberry), *Moringa oleifera* Lam. (Moringa), *Azadirachta indica* A. Juss. (Neem), *Ricinus communis* L. (Castor bean), *Tephrosia vogelii* Hook f. (Vogel's tephrosia), and *Tithonia rotundifolia* (Mexican sunflower) were collected from different fields around Chilanga while dried *Nicotiana tabacum* L. (Tobacco) leaves were sourced from the largest wet market in Lusaka, Soweto. The chemical insecticide, Lambda-cyhalothrin (Karate 5EC) (dosage: 3.5ml per liter of water), a synthetic pyrethroid whose mode of action is contact or ingestion, used in this study as a control, was bought from a local agrochemical distributor, Farms Barn Zambia Limited in Lusaka. The leaves were first rinsed in water and left to stand for 20 minutes on a sink dish rack on a drain board. They were then cut into small pieces using a kitchen knife, then transferred to a large homemade wooden mortar. They were pounded into a paste using a pestle. Ten (10) kg paste of each plant material was weighed and poured into a plastic bucket containing 10 litres of distilled water. The mixture (paste and water) was manually stirred with a wooden cooking stick vigorously for ten minutes and then left to stand overnight, i.e., 24 hours, before sieving using a muslin cloth. The resulting concentrate was 1kg per litre of water (w/v) extract. To get the final spraying solution of 10% weight by volume (w/v), 9 litres of water was added to 1 litre of the concentrate. Then mix 100-150 g soap powder to 250ml water, add the resulting soapy water to spray solution as a sticker.

### 2.2. Laboratory bioassay

A laboratory bioassay was conducted in the Entomology laboratory, Plant Protection Unit, Mount Makulu Central Research Station, Chilanga January 2020 using 3rd instar larvae obtained from a field population of FAW collected from the Mount Makulu research fields. A fine spray of each of the nine (9) crude aqueous leaf extracts: *C. annuum*, *R.communis*, *G. sepium*, *T. rotundifolia*, *T. vogelii*, *A.indica*, *M. oleifera*, *N. tabacum*, and *Melia azedarach* and synthetic pyrethroid, Lambda-cyhalothrin (Karate 5 EC) which was the insecticide control, was applied to the cut maize leaf bits (2-4cm long)placed on the moisten Whatman No. 10 filter paper in the Petri dishes (150mm diameter x 15mm height, Sigma-Aldrich®). The filter paper was moistened to maintain relative humidity, and a sparsely perforated Petri-dish cover to provide ventilation. Vapours from the treated leave bits and filter paper mimicked the field spray coverage. To avoid cannibalism, five field-collected 3rd instar larvae were placed on each Petri dish and allowed to feed for 72-hrs. In the Petri-dishes with untreated control larvae, the leaf bits and filter paper were sprayed with sterilized water. Each treatment comprised five (5) Petri-dishes, replicated five times in a completely randomized design. The total numbers of larvae exposed in each treatment was recorded. The experiment was repeated three (3) times. During the experiment, larval mortality was assessed at 24, 36, 48, and 72-hrafter exposure to the treated leaves bits. Larvae were considered dead if they failed to make any coordinated movement 30 second after prodding. Percent mortality data was corrected using the Abbott's formula [1]:

$$\text{Percent mortality} = (L_t - L_l)/L_t \times 100;$$

where $L_t$ =total number of larvae per treatment, and $L_l$=number of live larvae

### 2.3. Field studies

**Sites:** Five (5) best performing plant extracts from Laboratory bioassay were evaluated in field trials at two sites, Mount Makulu, Chilanga (15°33'S, 28°15'E, 1213m above sea level), agro-ecological region (AER) II during 2020 and 2021 rainy seasons and Chirundu (16°7'60" S and 28°49'60" E; 394 m asl), AER I during 2021 rainy seasons. Chilanga and Chirundu are located in Lusaka and Southern Province of Zambia, approx. 15km and 115km southwest of Lusaka, respectively. AER I is characterized by mean annual rainfall of less than 800 mm, relatively short crop growing season, 80-120 days and poorly distributed rains, which often result in crop failure due to persistent dry spells and droughts. It also experiences very high temperatures (35 - 40°C) between September and November. AER II receives between 800 and 1000mm of rainfall annually, which is evenly distributed throughout the crop growing season. The growing season is slight longer than in AER

I, between 100-140 days. The average annual temperature during the crop growing season is between 22 - 29$^{o}$C. In Zambia, the rainy season which is main crop growing season, starts in November and ends in April, the following year. Maize and many other annual crops are planted preferably at the onset of the rainy season up to early January. The two sites for the field trials were purposely selected based on the abundance of FAW (Natural "hot spot") and idea environment for the growth of target crop.

**Treatments:**

Five (5) best-performing crude aqueous leaf extracts from the bioassay namely, *A. indica*, *G. sepium*, *N. tabacum*, *R. communis,* and *T. vogelii,* and chemical insecticide Lambda-cyhalothrin (Karate 5EC, Chemical class: Synthetic pyrethroid), and control without any treatment (untreated maize) were evaluated in a randomized complete block design (RCBD) with 4 replications at each site.

Early maturing white dent grained maize hybrid Seed Co Maize variety, SC 513 seeds with yield potential of up to 10t ha-1 were sown at 2-3 centimeters (cm) depth, at 25cm and 75 cm intra-row and inter-row spacing, respectively. The maize seed was sourced from Seed Co Zambia Limited, Lusaka. Standard agricultural practices were followed. Basal fertilizer (NPK 10-20-10) at the rate of 200kg/ha at planting and top dressing fertilizer Urea (46% N) at the same rate. Since the invasion of FAW, Lambda-cyhalothrin has been one of the insecticides included on the Zambian Government's approved list of FAW pesticides bought and distributed to small-scale farmers in Zambia. Weeding was done using a hand hoe and carried out twice at 2 - 3 weeks and 7 weeks old. Five plant extracts (10% w/v) and the chemical insecticide were applied three (3) times. The treatment sprays were applied at 14, 24, and 38 days after crop emergence, using a 20-litre Jacto knapsack sprayer. Each experimental plot, 6 x 6m (36m2) was sprayed with a single designated test material except the no-spray (untreated) control.

## 2.4. Data Collection

Data were collected from 20 plants per plot randomly selected using the zig-zag, one or two days before spraying, i.e., 12, 22, and 36, and at 50 days after crop emergence, both destructive (number of live larvae per plant) and non-destructive samples (leaf damage score) were taken. Leaf or foliar damage was assessed using the Davis scale (from 0-no damage to 9-heavy damage) [29]. The level of FAW infestation or abundance, i.e., the proportion of infested plants (as a %) in a field was determined using the formula:

Percent FAW infestation = [Number of plants infested] / [Number of plants in the plot] x 100

At harvest, the percentage of cobs with characteristic signs of FAW damage was assessed using 20 randomly selected cobs per plot using the rating scale of 1 – 9, where 1= No grain damaged and 9=>75% damaged [1]. Maize ear rot was assessed using the scale 1-7, where 1=No ear rot and 7= >75% ear infected [30]. Grain yield (kg/ha) was assessed per plot by collecting all healthy grains from the 4 inner rows (neglecting the outer two from the total of 6 rows per plot). The grain yield per hectare was obtained by multiplying the field weight i.e., grain yield per plot divided by plot area and adjusted for moisture content of 12-13% [31] i.e.:

$$\text{GY (t/ha)} = [\text{Grain Weight} \times 10 \times (100 - \text{MC})/\ (100 - \text{Adjusted MC})/\ (\text{Plot Area})]$$

where grain weight is in kg, moisture content (MC) is in percentage (%), and plot area is in m$^2$.

## 2.5. Statistical analysis

For the laboratory bioassay, statistical analysis was carried out using the Genstat® Statistical Software 13th Edition [32]. Mortality data were tested for normality and homogeneity of variances using the Barlett test [33]. Analysis of variance was conducted to analyze differences in larval mortality. For post hoc comparisons, Tukey's HSD test was used ($\alpha = 0.05$) [34].

From the field trials, data on the number of plants infested with FAW, leaf damage, number of larvae per plant, percent cob damage, incidence and severity of maize ear rots, and grain yield (t/ha) were analysed using the Analysis of Variance (ANOVA) using the same statistical program as the laboratory bioassay. The analysis was done for each season and then pooled across the two seasons. The treatment means were compared and separated using Tukey's test [34]. A correlation analysis was thereafter conducted to determine the nature of the relationship between infestation, leaf damage, larval densities, cob damage, incidence and severity of maize rot, and grain yield (t/ha).

# 3. Results

## 3.1. Laboratory studies

The mean percentage FAW mortality treated with different crude aqueous leaf extracts is summarized in Table 1.

Twenty-four (24) after being exposed to extracts, there was significant FAW mortality ($p<0.5$) in all treatments except the untreated control (Table 1). The mean percent mortality ranged between 3-15% in the plant extract treatments, with the highest in *N. tabacum*, 15% followed by *A. indica*, 12% and the lowest was *M. oleifera*, 3%. However, this was 5 times less than the synthetic chemical insecticide, Lambda-cyhalothrin, 72%. After 36hrs, mortality increased on average by 10-20% in all the treatments. At 48-hr, there was another significant increase ($p<0.05$) in mortality in all treatments, this continued until the experiment was terminated after 72-hr. The increased mortality could have occurred as a result of residual action. Most of the extracts effectively killed the FAW larvae though slow acting compared to the synthetic insecticide, Lambda-cyhalothrin treatment as time progressed. After 72-hr of exposure, the highest mortality among the plant extracts was recorded in *N. tabacum* and *A. indica* treatments reaching 60% and 52%, respectively. In other treatments, FAW larvae mortality was significantly low ($p<0.05$), ranging between 27-50%. The overall efficacy shows that larval mortality increased by more than threefold across all treatments except the untreated control. Among the crude aqueous leaf extracts, the least effective was *T. rotundifolia*, 31%. Based on mortality data, the performance of the crude aqueous leaf extracts could be ranked as follows: *N. tabacum* > *A. indica* > *G. sepium* > *R. communis* > *T. vogelii* > *C. annum* > *T. rotundifolia* > *M. azedarach* > *M. oleifera*. Only the extracts that produced cumulative mortality above 40% in Laboratory bioassay were selected for field trials. These were *G. sepium*, *A. indica*, *R. communis*, *T. vogelii*, and *N. tabacum*.

**Table 1. Mean Percentage Mortality of FAW treated with different plant extracts after 72-hr**

| **Plant Leaf Extracts** | *Dosage* | *Mean Percent mortality* | | | |
|---|---|---|---|---|---|
| | | *24-hr* | *36-hr* | *48-hr* | *72-hr* |
| *Capsicum annum* | 10% (w/v) | $6.0^{c}$ | $17.0^{bc}$ | $27.0^{cd}$ | $35.0^{d}$ |
| *Gliricidia sepium* | 10% (w/v) | $9.0^{bc}$ | $27.0^{de}$ | $35.0^{bc}$ | $50.0^{bc}$ |
| *Melia azedarach* | 10% (w/v) | $10.0^{b}$ | $24.0^{cd}$ | $29.0^{bc}$ | $30.0^{cd}$ |
| *Moringa oleifera* | 10% (w/v) | $3.0^{d}$ | $16.0^{b}$ | $21.0^{d}$ | $27.0^{d}$ |
| *Azadirachta indica* | 10% (w/v) | $12.0^{b}$ | $32.0^{b}$ | $40.0^{b}$ | $52.0^{bc}$ |
| *Ricinus communis* | 10% (w/v) | $9.0^{bc}$ | $29.0^{b}$ | $41.0^{b}$ | $49.0^{c}$ |
| *Tephrosia vogelii* | 10% (w/v) | $10.0^{b}$ | $24.0^{cd}$ | $34.0^{bc}$ | $45.0^{cd}$ |
| *Tithonia rotundifolia* | 10% (w/v) | $6.0^{c}$ | $20.0^{c}$ | $28.0^{c}$ | $31.0^{d}$ |
| *Nicotiana tabacum* | 10% (w/v) | $15.0^{b}$ | $35.0^{b}$ | $46.0^{b}$ | $60.0^{b}$ |
| Lambda-cyhalothrin | 3.2ml/ L | $72.0^{a}$ | $88.0^{a}$ | $94.0^{a}$ | $98.0^{a}$ |
| Control | - | $0.0^{e}$ | $0.0^{e}$ | $0.0^{e}$ | $0.0^{e}$ |

*w/v=weight by volume; Within columns, means followed by the same letters are not significantly different at 5% Using Tukey' test*

## 3.2. Field trials

(a) *FAW infestation, leaf damage and number of larvae per plant*

There were significant differences among the treatments for the level of infestation ($F_{6,249}$, 44.24, $p<0.001$), leaf damage ($F_{6,249}$, 68.06, $p<0.001$) and larvae density ($F_{6,249}$, 25.63, $p<0.001$). The level of infestation was also significantly affected ($F_{6,249}$, 5.46; $p<0.001$) by treatment by year interaction. The level of infestation ranged from 5 to 100%. The infestation was highest in 2020, about 20% more than in 2021 (Table 2). In both years, the lowest infestation occurred in insecticide Lambda-cyhalothrin treated maize followed byA. Indica (73.8%) and *N. tabacum* (73.8%) in 2020 and *R. communis* (48.0%) *in 2021*, and the highest in untreated control (Table 2). On average, *R. communis* had the lowest mean infestation (63.1%), followed by *N. tabacum* (66.1%), while *T. vogelii* (73.1%) had the highest infestation over the two seasons though not significant different from other leaf extracts.

**Table 2. Mean percent FAW infested host crop in maize plots received different aqueous leaf extracts over two seasons: 2020 and 2021**

| Treatment | 2020 | 2021 | Average |
|---|---|---|---|
| *G. sepium* | $86.9^{ab}$ | $55.5^{b}$ | $71.2^{b}$ |
| *A. indica* | $73.8^{b}$ | $60.0^{b}$ | $66.9^{b}$ |

| | | | |
|---|---|---|---|
| *N. tabacum* | 73.8 $^{b}$ | 58.3$^{b}$ | 66.1$^{b}$ |
| *R. communis* | 78.1$^{b}$ | 48.0 $^{b}$ | 63.1$^{b}$ |
| *T. vogelii* | 87.5$^{ab}$ | 58.6$^{b}$ | 73.1$^{b}$ |
| Lambda | 46.6 $^{c}$ | 38.1 $^{c}$ | 42.4$^{c}$ |
| Control | 92.8$^{a}$ | 85.9$^{a}$ | 89.4$^{a}$ |
| Mean | 77.1 | 57.8 | 67.4 |

*Within columns, means followed by the same letters are not significantly different at 5% Using Tukey' test*

Highest effect against leaf damage and larval density was observed in the insecticide treated maize, and least in the untreated control (Table 3). The mean larval density ranged from 0.4 to 1.51 with an overall mean of 1.12 per plant while the leaf damage ranged from 0.45 to 8.05 and its overall mean score was 3.03. The highest number of larvae were recorded in the untreated control and lowest in the insecticide treated maize. Among the plant extracts, *R. communis* had the lowest number larvae per plant, 0.91 per plant, followed by *N. tabacum* 1.04 and *A. indica*, 1.08. The highest was in *T. vogelii* treated maize, 1.18.TheFAWleaf damage was 2-3 times more in the plant extract treatments compared to insecticide treated crop, and ranged from 2.76 to 3.23. The lowest leaf damage among the plant extracts was in *R. communis* treated maize, 2.76 followed by *A. indica*, 2.91 though not statistically different from the other extracts. (Table 3) *T. vogelii* had the highest leaf damage, 3.23. On average, the plant extracts incurred between 33 and 50 percent less leaf damage than untreated maize.

**Table 3. Effect of different aqueous leaf extracts on Fall armyworm leaf damage and Larval density**

| Treatment | Mean number of Larva/20 plant | Leaf damage (score 0-9) |
|---|---|---|
| *Gliricidia sepium* | 1.16$^{b}$ | 3.10$^{b}$ |
| *Azadirachta indica* | 1.08$^{b}$ | 2.91$^{b}$ |
| *Ricinus communis* | 0.98$^{b}$ | 2.76$^{b}$ |
| *Tephrosia vogelii* | 1.18$^{b}$ | 3.23$^{b}$ |
| *Nicotiana tabacum* | 1.04$^{b}$ | 2.89$^{b}$ |
| Lambda-cyhalothrin | 0.63$^{a}$ | 1.36$^{a}$ |
| Untreated control | 1.74$^{c}$ | 5.00$^{c}$ |
| Mean | 1.12 | 3.03 |

*Within columns, Means followed by the same letters are not significantly different at 5% Using Tukey'test (HSD)*

### (b) *Effect of number spraying times on FAW larval abundance and leaf damage*

Significantly low larval numbers ($F_{1,6} = 4.07$, $p<0.002$) were observed in all treatments after 1st spray was applied except in the untreated control (Figure 1). The lowest number of live FAW larva was recorded in the insecticide treated maize. The number of larvae was significantly reduced in treated plants in the second ($F_{1,6} = 18.72$; $p < 0.001$) and third ($F_{1,6} = 23.51$; $p < 0.001$) sprayings. Lambda treatment had lowest number of larvae (Figure 1). After the 3rdspay, the population of larvae in plant extract treated maize reduced by 13 – 72% compared to the untreated maize, with significantly high reduction occurring in *N. tabacum* treated maize, 72.8 followed by *R. communis*, 62.2%.

In terms of leaf damage, there were significant differences in leaf damage among the treatments after first ($F_{1,6}$ 6.48, $p<0.001$), second ($F_{1,6}$ 46.23, $p<0.001$) and third rounds of spray ($F_{1,6}$ 138.10, $p<0.001$). The untreated control plant suffered heavy FAW leaf damage compared to the synthetic insecticide- and plant extract-treated crop (Figure 2). After the first-round spraying, the lowest leaf damage was recorded in plants treated with Lambda, 1.98, followed by *R. communis*, 2.89. and similar results were obtained in the second while after the third round of spray, the insecticide treatment, 1.01 was followed by *R. communis* and *N. tabacum*, 2.05 *(*Figure 2). The insecticide treatment consistently posted significantly low level of FAW leaf damage compared to the plant extracts throughout the experiment.

### (c)*Effect on the FAW cob damage*

Significant low cob damage ($F_{6,60}$ 15.91; $p< 0.001$) was recorded in the plant extract treated maize though higher than the insecticide treatment. Cob damaged ranged from 0 to 31.3%, with a mean 4.46%. The untreated control had significantly high ($p<0.05$) cob damage, 14.10, followed *Tephrosia vogelii*, 5.43% (Table 4). The lowest damage was in the insecticide treated maize, 1.58% though not statistically different ($p>0.05$) from that observed in the plant extract treated crop.

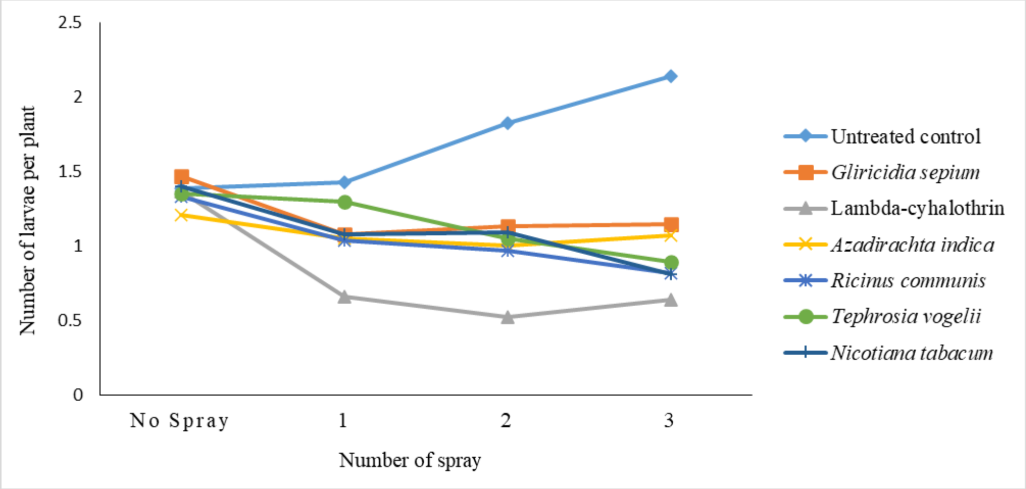

**Figure 1. Mean effect of the number of sprays on the Number of FAW larvae per plant.**

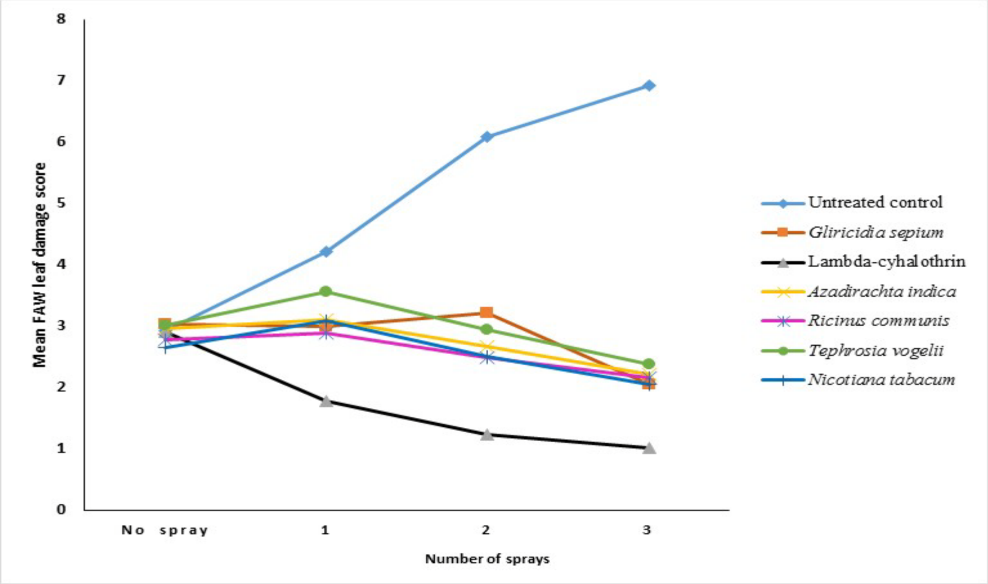

**Figure 2. Mean effect of the number of sprays on the FAW leaf damage.**

(d) *Effect on the incidence and severity of maize ear rots*

The Analysis of Variance (ANOVA) revealed significant difference among treatments for the incidence ($F_{6,60}$ 6.86; p< 0.001) and severity ($F_{6,60}$ 15.1; p< 0.001) of maize ear rot. This clearly shows that the ear rots significantly affected grain yield obtained treated maize. The incidence of maize ear rot ranged from 35.2 to 82.9% while severity was in the range of 2.8 to 18.7% (Table 4). The ear rots were significantly more severe ($F_{6,60}$ 4.79; p< 0.001) in 2020 (9.1%) than in 2021 (7.7%). The highest incidence and severity of maize ear infection occurred in the untreated control, 82.9 and 18.10 %, respectively. On the other hand, the insecticide treated maize had the lowest incidence and severity of maize, 35.42 and 2.86, respectively. Though there were no significant difference (p<0.05) in the incidence of maize ear rot among the plant extracts, the least incidence occurred in *G. sepium* treated maize, 42.9% and the highest was in A. indica, 57.92%. In the case of severity, apart from *T. vogelii*, which had significantly (p< 0.05) the highest severity, 10.35, the rest were not statistically different (p >0.05) with a range of 4.5 - 8.2%.Although the prevalence and incidence of maize ear rots was significantly increased in FAW infested maize, there were however considerable differences in the impact of the ear rot infection on grain yield recorded from plant extract treatments (Table 4).

### (e) *Effect on the grain yield (t ha$^{-1}$)*

There was significant variation ($F_{6,60}$ 10.32; $p < 0.001$)in grain yield among the treatments (Table 4). The mean grain yield ranged from 2.27 to 4.64 t ha-$^{1,}$ with the highest yield obtained from insecticide protected maize, 4.64 t ha$^{-1}$ followed by *A. indica*, 4.15 t ha$^{-1}$ (Table 4). Even though the grain yield from insecticide treated maize was 10 – 21% more than that of plant extracts, it was not significant different from the latter except Tephrosia treated maize which was lowest, 3.82 tha$^{-1}$ among the plant extracts. Overall, the lowest yield was recorded in the untreated control, 2.27 t ha$^{-1}$. Among the leaf extract treatments, highest yield was recorded from *A. indica* treated maize, 4.15 t ha$^{-1}$ followed by *N. tabacum*, 4.06 t ha$^{-1}$and *R. communis,* 3.97 t ha$^{-1}$corresponding to 59.4 – 82.8% more yield (effectiveness) than the untreated control (Table 4).

### (f) *The strength of association between FAW infestation, Larva population density, leaf damage, cob damage, maize ear rot and yield (t ha-1) in different plant leaf extract treatments*

The estimates of the correlation analysis show that a significantly ($p < 0.05$) positive relationship existed between damage maize leaf damage rating (0.82**), mean larval density (0.85**), cob damage (0.48**), incidence (0.51**) and severity of maize ear rot (0.46**), and FAW infestation (Table 5). While grain yield exhibited a highly significant negative correlation with FAW infestation (-0.67**), leaf damage (-0.44**), incidence (- 0.65**) and severity of maize ear rots (-0.44**), and cob damage (-0.48**). This shows FAW infestation and foliar feeding negatively impact grain yield obtained from different plant extract treatments. While the existence of a significant correlation relationship between cob damage and maize ear rot incidence (0.49**) and severity (0.41**) indicates that FAW-damaged ears are more susceptible to ear rot fungal infection, and are more likely to accumulate mycotoxins. Mycotoxins are a complex mixture of secondary metabolites produced by maize ear rot fungi in their host crop.

**Table 4. Mean effect of plant leaf extracts on incidence of cob loss, incidence and severity of cob rot, and maize grain yield (t ha$^{-1}$)**

| Treatment | Cob damage | Ear rot | | Grain yield | Above |
|---|---|---|---|---|---|
| | % | Incidence | Severity | (t/ha) | Untreated Control |
| *Gliricidiasepium* | 2.83$^{a}$ | 42.50$^{a}$ | 4.50$^{cd}$ | 3.82$^{bc}$ | 74.13 |
| *Azadirachta indica* | 2.82$^{a}$ | 57.92$^{a}$ | 8.26$^{c}$ | 4.15$^{bc}$ | 82.81 |
| *Nicotiana tabacum* | 1.92$^{a}$ | 53.53$^{a}$ | 7.46$^{c}$ | 4.06$^{bc}$ | 78.85 |
| *Ricinus communis* | 2.50$^{a}$ | 49.17$^{a}$ | 5.27$^{cd}$ | 3.97$^{bc}$ | 74.88 |
| *Tephrosia vogelii* | 5.43$^{a}$ | 50.42$^{a}$ | 10.35$^{b}$ | 3.62$^{b}$ | 59.47 |
| Lambda-cyhalothrin | 1.58$^{a}$ | 35.42$^{a}$ | 2.86$^{c}$ | 4.64$^{c}$ | 104.4 |
| Control –untreated | 14.10$^{b}$ | 82.92$^{b}$ | 18.75$^{a}$ | 2.27$^{a}$ | |
| Mean | 4.46 | 53.1 | 8.21 | 4.09 | |

*Within columns, Means followed by the same letters are not significantly different at 5% Using Tukey'test*

**Table 5. Strength of association between FAW infestation, leaf damage, larval population, cob damage, maize ear rot and grain yield (t ha$^{-1}$)**

| Parameters | Leaf damage | Larva/plant | Cob damage | Maize Ear rot | | Grain yield |
|---|---|---|---|---|---|---|
| | | | | Incidence | Severity | (t ha$^{-1}$) |
| Infestation | 0.824$^{**}$ | 0.852$^{**}$ | 0.482$^{**}$ | 0.511$^{**}$ | 0.462$^{**}$ | -0.676$^{**}$ |
| Leaf damage | | 0.830$^{**}$ | 0.523$^{**}$ | 0.351$^{**}$ | 0.535$^{**}$ | -0.441$^{**}$ |
| Larva/plant | | | 0.453$^{**}$ | 0.434$^{**}$ | 0.427$^{**}$ | -0.500$^{**}$ |
| Cob damage | | | | 0.493$^{**}$ | 0.407$^{**}$ | -0.485$^{**}$ |
| Ear rot incidence | | | | | 0.650$^{**}$ | -0.652$^{**}$ |
| Ear rot severity | | | | | | -0.438$^{**}$ |

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

## 4. Discussion

Although all crude aqueous leaf extracts tested in this study were to reduce the level of FAW infestation and foliar leaf damage, *Ricinius communis* leaf extract cumulatively outperformed the other plant extracts. In the laboratory bioassay, the extracts were able to exert larval mortality of 27 – 60% more than untreated control larvae within 72-hr (Table 1). In the field trials, the leaf extracts significantly reduced the rate of infestation by 21.7- 33.3% compared to the untreated control and had about 44 - 58% fewer larvae numbers per plant. The presence of low numbers of larvae in the maize treated with extracts impacted positively grain yield whereas the high number of FAW larvae in the unprotected maize resulted increased leaf feeding hence the observed damage to the crop (Table 4). It's most likely that the plant extracts were able to kill larvae, thereby reducing the larval population. This consequently led to a significant reduction in the leaf damage during the vegetative and reproductive stages of the crop resulting in enhanced crop growth and photosynthesis inevitably resulting in significantly higher maize yield compared to the untreated control [3]. Though all extracts tested were effective, *A. indica* and *R. communis* were more potent, followed by *N. tabacum*. Similar reduction in damage by FAW has been reported using different crude leaf extracts [30].

The results further show before the first spray was carried out, the leaf damage was initially low in all treatments including the untreated control as it coincided with the first two weeks of growth, but however rose sharply as the numbers of FAW larvae and their consumption increased probably due to increased production of physio-chemicals and sugars by the plant during the 4th and 5th week. The strong significant correlation between FAW abundance and leaf damage (0.83**) and a significant negative relationship that occurred between levels of infestation and yield (-0.68**) further supports the notion that the high FAW infestation observed in the untreated control most likely reduced photosynthetic carbon fixation and consequently affected plant growth and productivity. While, the relatively slow rate of exerting larval mortality by crude aqueous leaf extracts may have resulted in treated maize incurring some significant amount of leaf damage between 1st and 2nd spray compared to the crop treated with Lambda. This may suggest that while the plant extracts maybe effective in reducing FAW leaf damage, they may be less effective than the synthetic insecticide treatment.

It is clear that three (3) round of sprays of crude leaf extracts applied at 14 day intervals to protect maize during the first cycle of FAW infestation and during the late whorl stage (V6–V12) could be adequate in protecting the crop. Studies conducted to investigate FAW infestations show that the most damage period is from early to late whorl stages [4]. Further, it is well-known feeding on leaves by FAW larvae depends on the age and quality of leaf because these factors impact on the FAW establishment, larva growth and survival [14]. The age of maize leaf influences quality parameters such as water availability, toughness and nitrogen; any reduction in these leaf qualities may lead to high mortality even if the same leaves are suitable for older instars [25].

The results of this study further suggest that two sprays of synthetic pesticide, Lambda-cyhalothrin were able to provide good crop protection against the fall armyworm and resulted in significant high yields. This agrees with the findings from other studies on synthetic pesticides [21]. The slight low mortality exerted by aqueous crude extracts compared to the synthetic pesticide, suggest that more sprays of the extracts required and at shorter intervals effectively control FAW. Additional spray applications may confer better crop protection and lead to further reductions in larval numbers and foliar leaf damage. Reduction in leaf damage inevitably mitigate the loss in photosynthesis incurred in the untreated plants whose loss in leaf area may have significantly contributed to the yield losses recorded at harvest [3]. The late health leaves on the plants treated with the crude aqueous leaf extracts were able to compensate for leaf damage caused by the FAW during the early stages of growth as shown in Figure 2.

At harvest, there was a significant reduction in cob damage, and low incidence and severity of maize ear rot in crude aqueous leaf extract treatments compared to untreated control, translated into healthy cobs and higher yields. While no documentation exists, cob damage by FAW of below 5% may be more desirable. In the plant extract and insecticide-treated plots, there was little damage to the kernels and ears was probably due to low larvae population which may been restricted only to the leaves unlike in the unprotected control. It is also observed that when a very high larvae population in untreated maize crop occurs especially in the later stages of plant growth, the FAW larvae starts to migrate to maize ears and cause significantly high direct cob damage consequently negatively affect quality and quantity of grain yield [13]. This is more destructive as it usually coincides with the crop at milk cob milk stage.

The correlation analysis conducted in this study show that a significant positive relationship between exists between FAW abundance and incidence of maize ear rot (0.51**) and between FAW infestation and maize severity (0.46**), this shows there an increase in the prevalence and incidence of ear rots in the FAW infested crop. The lower levels of infection observed in leaf extracts treatment could be attributed to effect of these had on the pathogens responsible for this disease. This is the first report on the association of FAW and maize ear rots in Zambia. The high efficacy exhibited plant extract treatments against FAW and ear rot infection was significantly correlated with higher grain yield compared to unprotected maize crop (untreated control).

Overall, the ranking order of effectiveness among the plant extracts were: *R. communis* >*A. indica* >*N. tabacum*>*G. sepium*>*T. vogelii*. This apparent effectiveness of the *R. communis*, *A. indica and N. tabacum* extracts could be attributed to its high contact toxicity effect on the larvae population growth in the first four weeks which overlapped with first and second sprays (see Figure 3) thereby reducing the leaf damage to maize in the early stages of the crop development. Based on performance alone, the use of plant extracts may exhibit varying levels of FAW control, and statistically lower mortality and damage rates compared to synthetic pesticides [26], but may nevertheless be an excellent alternative to synthetic pesticides. Besides being insecticidal, some of these plant leaf extracts like *A. indica* possess growth promoting substances, hence when applied before anthesis may boost grain yield.

## 5. Conclusion

The results of this study, therefore, stresses the need to incorporate the plant extracts in an IPM strategy for FAW especially among resource-poor small-scale farmers as they are not able to afford highly-priced synthetic insecticides. Using plant extracts is not only cost-effective but environmentally benign approach that ensures human and animal safety. Natural chemicals extracted from plants with insecticidal properties, have the potential to effectively manage FAW in maize in farmers' fields thereby preventing yield losses. All the five botanicals tested here were reasonably effective against FAW, and impacted on maize yield positively compared to the synthetic pesticide. However, the plant extracts on their own cannot be used as ' silver bullet' rather should be combined with other control methods in order to maximize their efficacy against FAW. It's also advisable, farmers may have to employ at least three (3) rounds of spaying if they have achieved effective control of the FAW. Promoting the use of the plant extracts can lead to a significant reduction in indiscriminate use of dangerous pesticides that may have severe ecological consequences. The results of this study have provided further evidence why the plant extracts could be an excellent alternative to commercial pesticides and recommended for use in FAW IPM program.

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## Authors' contribution

Mweshi Mukanga - Main author, Principal Investigator.

Gilson Chipabika and Matthews Matimelo - Experiment with design and layout.

Owen Machuku, Sylvia Misengo Tembo, Kelvin Mumba, Ndalamei Demaino Mabote, Vincent Simwinga, Isaiah Nthenga, and Marian Lupulula - Data collection, trial location and discussions.

Kabosha Lwinya – Statistics and proofreading.

## Conflict of Interest

The authors declare no conflict of interest regarding the publication of this paper.

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