



An Evaluation of the Efficacy of Botanical Pesticides for Fall Armyworm Control in Maize Production

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Abstract

Since the report of the Fall armyworm (FAW) (*Spodoptera frugiperda*) in 2016 in Africa, the FAW has widely spread in Zambia, causing significant damage to maize, rice sorghum and other crops. The botanical extracts from Neem leaves, Garlic cloves and Chinaberry leaves efficacies were compared to Cypermethrin insecticide for FAW control in maize. A Randomized Complete Block Design (RCBD) with four replications and Seedco SC 403 maize variety were used as a test crop. Ten FAW larvae were artificially introduced into the maize two weeks after planting followed by an application of insecticides for seven weeks after 20% infestation. Analysis of variance showed a significant difference ($p < 0.01$) in maize yields between the controls and all the treatments but not among the four treatments. The study also showed that Neem treatment had the highest maize yield of 4.9 t ha⁻¹ followed by Cypermethrin with 4.7 t ha⁻¹, Chinaberry and Garlic with 4.3 t ha⁻¹ corresponding to the effectiveness of 67%, 65%, 60% and 60% respectively in relation to the potential yield. It was concluded that the three botanicals' extracts were as effective as cypermethrin as a control measure for the FAW and may be an alternative method for FAW control among small scale farmers in Zambia.

Subject Areas

Agricultural Science, Plant Science

Keywords

Spodoptera frugiperda, Fall Armyworm, Infestation, Efficacy, Maize, Botanicals

1. Introduction

Native to the Americas, the Fall Armyworm “FAW” *Spodoptera frugiperda* (Lepidoptera, Noctuidae) a pest that feeds on leaves and stems of more than 80 plant species, was first reported as present on the African continent in January 2016 (Pavela, 2016) [1]. It was first detected in Central and Western Africa (Sao Tome and Principe, Nigeria, Benin and Togo) and in late 2016 and early 2017 in Angola, Botswana, Burundi, Democratic Republic of Congo, Ethiopia, Ghana, Kenya, Malawi, Mozambique, Namibia, Niger, Rwanda, Sierra Leone, South Africa, Tanzania, Uganda, Zambia, and Zimbabwe and it is expected to move further (FAO, 2017) [2]. Subsequent investigations have revealed the pest in nearly all of Sub-Saharan Africa (SSA), where it is causing extensive damage, especially to maize fields and to a lesser degree sorghum and other crops. Within a short span of its introduction in Africa, FAW has been confirmed in over 30 African countries and it is likely to become endemic in many. Its major preference for maize, a staple food for over 300 million African smallholder farm families, poses a threat to food security, nutrition and livelihoods (Prasanna, *et al.*, 2018) [3]. Maize, *Zea mays* L. (Poaceae), is one of the most important grains in the world and its production is affected by various biotic and abiotic factors such as mineral nutrition (Gunes *et al.*, 2007) [4] and attacked by defoliating insects like the Fall Armyworm, which is considered a severe maize pest in America (Tavares *et al.*, 2010 [5] [6], Dalvi *et al.*, 2011 [7], Silva *et al.* 2015 [8]). In Zambia, maize is the main staple food and its production is not only for domestic consumption but also for foreign markets as well.

FAW is an insect pest that feeds on more than 80 crop species (FAO, 2017) [2], causing damage to economically important cultivated cereals, legumes as well as vegetable crops and cotton. It lays its eggs on plants, from which larvae hatch and begin feeding. High infestations can lead to significant yield loss. Although it is too early to know the long-term impact of FAW on agricultural production and food security in Africa, it has the potential to cause serious damage and yield losses (FAO, 2017) [2]. Among a variety of remedial measures for FAW management, are plant extracts of various plant species that have pesticidal properties (toxic to insects) also called botanicals. These are secondary plant metabolites synthesized by the plant for protective purposes. Many of the plant botanicals are used as insecticides both in homes, in commercial as well as in subsistence agriculture by small-scale farmers. Plant insecticides have several advantages including their short life spans once applied, they are not poisonous to humans and livestock, they do not harm the natural enemies of the pests, they are cheap, easy to prepare and in most cases readily available and have more than one active ingredient which work synergistically making it difficult for pests to develop resistance (Kareru *et al.*, 2014) [9]. The objective of this study was to evaluate the effectiveness of botanicals namely: *Melia azedarach* (China-berry) leaves, *Allium sativa* (Garlic), *Azadirachta indica* (Neem) leaves in comparison to Cypermethrin (synthetic pesticide) in the control of *Spodoptera fru-*

giperda (FAW) in maize crop. The experiment was conducted in Livingstone District which lies about 475 km South of Zambia's Capital City, Lusaka. Livingstone lies in Region I of Zambia's three agro-ecological zones which receive below 800 mm of rainfall (MoA).

2. Methods and Materials

2.1. Experimental Design

The study employed a Randomized Complete Block Design (RCBD) with four replications. The four blocks were divided into six equal plots measuring 3 m × 5 m. The treatments were: Chinaberry leaf, Garlic clove, Neem leaf extracts, Cypermethrin, and two controls-not infested and the infected control. The rationale for the two controls was to show the potential yield of maize if not infested versus the effect of FAW on yields when infested and not treated. The experiment was fenced with polyethylene sheet around and covered with a shed net on top to protect the plots and the environment. Each plot had 5 rows measuring 5 m long. Maize seed SC403 variety produced by Seed Co Ltd, Zambia, was used in the experiment. SC403 is a very early maturing maize hybrid, heat and drought stress tolerant hybrid with a yield potential of up to 9 t/Ha (Seed Co, 2020) [10]. It was planted at a spacing of 60 cm inter-row and 20 cm intra-row. The crop was managed by following the recommended agronomic practices for maize production. The FAW armyworm larvae (at 5th and 6th instar) were artificially introduced into the experimental plots two weeks after planting the maize by introducing ten (10) larvae in each plot. The choice of the 5th and 6th larvae instar was to ensure that pupation and adult stages are reached quickly for mating and multiplication of the pest to bring about 20% infestation which is regarded as the FAW economic threshold for commencement of treatment intervention (Prasanna *et al.*, 2018) [3]. The 20% FAW infestation threshold was reached 23 days after infestation. The insecticides were administered weekly from the time of infestation level until cob maturity stage.

2.2. Preparation and Application of the Botanicals

The botanicals were prepared according to Stoll (2000) [11] methods. *Melia azedarach* pesticide was made from 1 kg fresh leaves pounded and soaked in 5 litres of water for 24 hours. The mixture was filtered, the filtrate was diluted with water at the rate of 1:10. One (1) teaspoon per litre of soapy water was added as a sticker. For *Allium sativa*, 85 g of crushed cloves were mixed with 50 ml of vegetable oil to which 10 ml of liquid soap was added as a sticker. The mixture was allowed to stand for 24 hours after which it was filtered. The filtrate was diluted to 20 litres and was shaken thoroughly before spraying. *Azadirachta indica* pesticide was made from fresh leaves by pounding 1.25 kg of leaves soak overnight in 5 litres of water. The extract obtained after sieving the mixture diluted to 12 litres with water and one teaspoon per litre of soapy water was added to act as a sticker. The synthetic insecticide, Cypermethrin was administered using the

recommended preparation and rate. 2.5 ml was diluted with 1 litre of water as per instructions on the chemical container label. Application of the botanicals and the synthetic insecticide was done by full cover spraying of the maize plants in the respective plots apart from the Controls.

2.3. Data Collection

FAW infestation assessment was categorized into two stages namely vegetative stage and cob or flower stage. The assessment at vegetative stage focused on leaf damage and FAW larva presence while at cob stage, the focus was on cob damage and FAW larva presence. Davis *et al.* (1992, 1989) methods of scoring were used to measure the following variables: 1) Infestation assessment at both vegetative stage and flower stages by way of scouting and scoring using a score sheet by Davis *et al.* (1992, 1989) [12] [13]. 2) interpretation of the scores was done using leaf damage rating scale of 0 - 9, cob damage rating scale of 0 - 9 and the extent of ear and kernel damage was done using the maize ear and kernel damage rating scale 0 - 9 according to Davis and Williams (1992 & 1989) and Wiseman and Widstrom (1984) [14] score ratings.

The vegetative stage was considered to be the crop growth stage from crop emergency up to cob and flower initiation stage while cob stage was considered to be from cob and flower initiation to cob maturity stage. Data were collected at two different stages of the crop weekly using a score sheet adapted from the Davis and Williams (1992, 1989) method of scoring.

2.4. Data Analysis

The Analysis of Variance (ANOVA) was used to determine the significance of the difference between the Control and the treatments based on maize yield while the Least Significant Difference (LSD) was used to test for any significant difference among the treatment yields. The yield loss which is a measure of the difference (in %) in grain yield (dry weight) between FAW-infested and uninfested plots (FAO, 2017) [2] was calculated with reference to the potential or attainable yield of the maize variety used which was obtained from the Not infested plots. Arising from yield loss calculations, the effectiveness of the botanicals (%) was calculated as a percentage of treatment yield over attainable yield (not infested treatment).

3. Results

3.1. The Effectiveness of Botanicals of Garlic, Neem, and Chinaberry Extracts in Comparison to Cypermethrin in the Control of Army FAW in Maize Crop

The summary table below shows the results of our investigation. The mean and the standard deviation of the Maize grain yield, percentage yield loss, damage score and larvae count for vegetative stage and kernel stages were compared among the treatments and with the two controls—infested control, (IControl),

non-infected control (NIControl)) see table below.

The mean maize yield among the botanicals treatments ranged from 4.3 t/ha in Chinaberry and Garlic treatments to 4.9 t/ha in Neem compared to the infected control with 2.3 t/ha and the no infected control of 7.3 t/ha (see **Table 1**). The comparison of the treatments in relation to cypermethrin standard showed 49% in infected control, 91% in chinaberry and Garlic, 103 in Neem and 154% in non-infected control. An ANOVA, post hoc multiple comparison using LSD test showed that the mean maize yield among Chinaberry, Garlic, Neem and Cypermethrin treatments (**Table 1** and **Figure 1(a)**) were not significantly different ($p > 0.01$) from each other but significantly different ($p < 0.01$) from the two controls (infected and non-infected controls). In terms of maize yield losses due to the FAW in the treatments in relation to the non-infected standard showed that there was 68% loss of yield in the infected control, 41% in Chinaberry and Garlic, 33% in Neem and 35% in Cypermethrin. Similarly, a multiple comparison using LSD showed no differences among the four treatments but different from the two controls, see **Table 1** and **Figure 1(a)**.

The mean score of vegetative damage and larvae count at vegetative stage showed that the two controls were significantly different ($p < 0.01$) from each other and from the rest of the treatments, while the mean scores of cob/kernel damage and larvae count at cob stage showed that only the infected control was significantly different ($p < 0.01$) from the rest of the treatments (see **Table 1** and **Figure 1(b)** and **Figure 1(c)**).

3.2. The FAW Infestation Variation across Experimental Plots during the Experiment

Figure 2(a) shows the leaf damage through FAW infestation for all the experimental plots during the experiment starting from 14th January 2018 when artificial infestation of FAW larva was introduced through to cob maturity stage

Table 1. Averages and standard deviations of the Maize grain yield, percentage efficacy, damage score and larvae count for vegetative stage, and kernel damage score and larvae count for cob stage infected control, (IControl), Chinaberry, Garlic, Neem, Cypermethrin and non-infected control (NIControl) treatments.

Treatment	Maize yield (t/Ha)	Yield Loss (%)	Vegetative stage damage	Larva count vegetative stage	Cob stage kernel damage	Larva count cob stage
IControl	2.3 ± 0.3 ^a	68.2 ± 3.9 ^a	5.6 ± 0.7 ^a	9.7 ± 5.0 ^a	2.7 ± 0.6 ^a	15 ± 1.4 ^a
Chinaberry	4.3 ± 1.0 ^c	40.8 ± 14.3 ^c	2.6 ± 0.5 ^c	5.4 ± 0.4 ^c	1.2 ± 0.1 ^b	0.9 ± 0.6 ^b
Garlic	4.3 ± 0.9 ^c	41.1 ± 11.9 ^c	2.4 ± 0.2 ^c	5.3 ± 0.9 ^c	1.2 ± 0.1 ^b	0.8 ± 0.9 ^b
Neem	4.9 ± 0.6 ^c	32.5 ± 08.1 ^c	2.7 ± 0.2 ^c	3.8 ± 0.6 ^c	1.1 ± 0.1 ^b	0.8 ± 0.2 ^b
Cypermethrin	4.8 ± 0.4 ^c	34.9 ± 05.6 ^c	2.3 ± 0.3 ^c	5.1 ± 1.0 ^c	1.1 ± 0.1 ^b	1.1 ± 0.3 ^b
NIControl	7.3 ± 0.9 ^b	0 ± 11.6 ^b	0 ^b	0 ^b	1.0 ± 0.0 ^b	0.1 ± 0.0 ^b

The superscript shows the LSD significant difference at $p < 0.01$ between/among treatments. Same letters within the column indicate not significant differences between/among treatments.

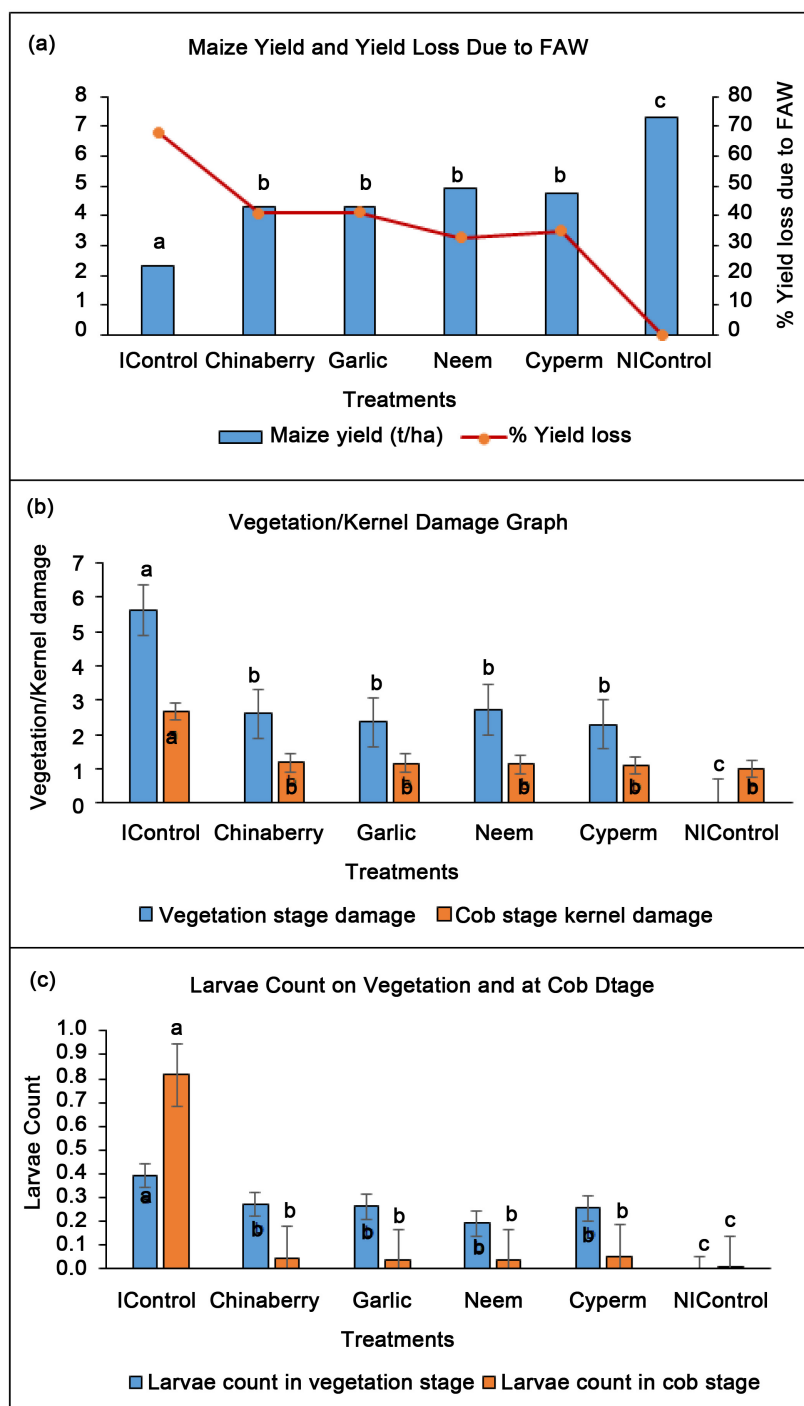


Figure 1. Bar charts showing the mean maize grain yield and the percent grain loss due to the FAW (a), the mean damage scores for vegetative stage and kernel (b) and the mean larvae count at vegetative and cob stages (c). The comparison is within the same stage across the treatments, and letters show differences between treatments.

on 26th February 2018. When the treatments were introduced (on the 5/02/2018), the leaf damage was controlled by all the treatments compared to the infected control (IControl). Over the following period through to 26th February,

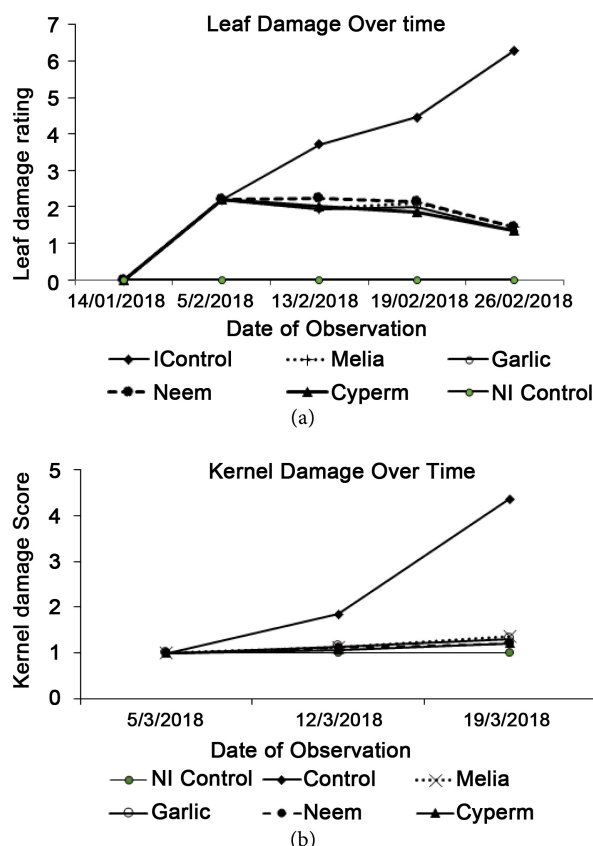


Figure 2. The FAW infestation levels at two different growth stages of maize during the experiment (a) leaf damage at vegetative stage and (b) at cob maturity stage. In both cases the damage in the infected control was significantly higher ($p < 0.01$) than in the treatments, but no significant difference among the treatments.

the Neem treatment was at the lower end while the cypermethrin was on the upper end of the effectiveness spectrum though the difference was not significant ($p > 0.01$). The leaf damage in the infected control was unabated and continued to rise over time to the rating above 6, while the not infected control maintained a nil damage status. However, Kernel/ear damage (cob damage) recorded from 5th March to 19th March 2018 (Figure 2(b)) shows that Neem and cypermethrin were slightly better than garlic and Chinaberry though the difference was not significant ($p > 0.01$). They all controlled the kernel damage below 1.5 rating compared to the infected control which recorded rating (Figure 2(b)).

3.3. The FAW Larva Population Variation across Experimental Plots during the Experiment

The FAW larva population variation across treatments from 14th January 2018 to 19th March 2018 showed that the population started to increase at a rapid rate to the average of 25 larvae, but upon application of the botanicals and Cypermethrin, the population started to reduce. Neem was the most effective in reducing

the count of larvae from 25 to 11, 8, 6 to 1 counts in the first week, second, third and last weeks of observation in comparison to the others, which on average dropped the populations from 25 to 18, 15, 7, to 3 count in the same period. In the second and the third weeks the larvae count was significantly lower ($p < 0.01$) in Neem compared to the average of the other treatments. In the infected Control, the rate of population growth was high from 25, 30, 32 to 70 in the same period (see **Figure 3**).

The mean larvae mortality was highest in Neem at 63%, and lowest was in Garlic at 30% in the first week. By the third week, the mortality was over 70% in all the treatments (see **Table 2**). At the end of the experiment, the mortality rate was above 95% for all the treatments.

4. Discussion

The effect of *Allium sativa* (Garlic), *Azadirachta indica* (Neem) leaves, *Melia azedarach* (Chinaberry) leaves and Cypermethrin in the control of *Spodoptera frugiperda* in maize.

The Analysis of Variance (ANOVA) comparing the maize yield (in Ton/Ha)

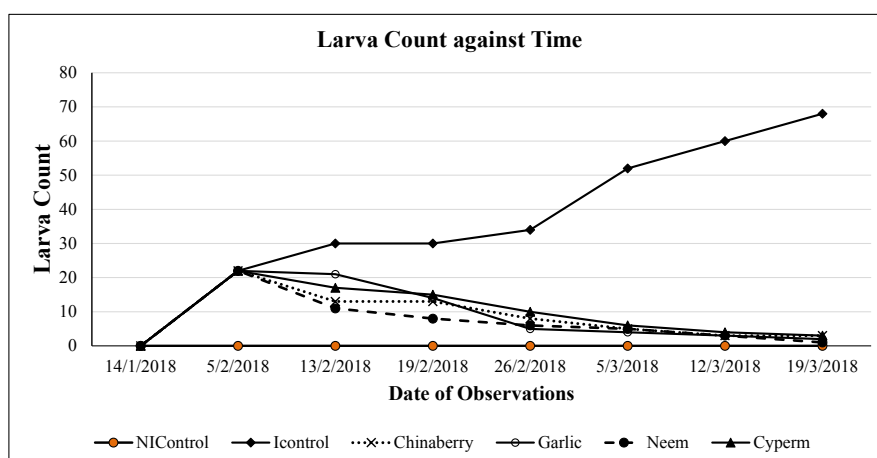


Figure 3. FAW larva count during the experiment. The larvae count in the infected control was significantly higher ($p < 0.01$) than in the treatments, the second and the third weeks the larvae count was significantly lower ($p < 0.01$) in Neem compared to the average larvae count for the other treatments.

Table 2. Percent mortality of FAW larvae compared to the infected control after treatment in six consecutive weeks compared to the infected.

Treatment	Mortality (%) of the larvae after						
	5/2/2018	13/2/2018	19/2/2018	26/2/2018	5/3/2018	12/3/2018	19/3/2018
	week 0	week 1	week 2	week 3	week 4	week 5	week 6
Chinaberry	0	56.7	56.7	76.5	90.4	95.0	95.6
Garlic	0	30.0	53.3	85.3	92.3	95.0	97.1
Neem	0	63.3	73.3	82.4	90.4	95.0	98.5
Cypermethrin	0	43.3	50.0	70.6	88.5	93.3	95.6

among the botanicals and cypermethrin treatments and with the Control showed that there was a significant difference ($p < 0.01$) in the mean yields. However, the LSD multiple comparison showed that only the two controls (infected control and the not infected control) were different from each other and from the other four treatment. The infected control yield was the least averaging 2.3 t/Ha while the uninfected control yields was highest with the average of 7.3 t/Ha which represents 71% loss of yield compared to the not infected standard. This is a huge loss of yield caused by the FAW. The low maize yield recorded in the control without any FAW control measure is consistent with the FAW severity and maize infestation, which likely reduced photosynthetic carbon fixation and consequently reduced plant growth and productivity (Silva *et al.*, 2015 [8]; Tanyi *et al.*, 2020 [15]). The rest of the treatments ranged between 4.3 - 4.9 t/Ha corresponding to a range of 59% - 67% recovery of yields (effectiveness) compared to the non-infected control. Ranking the effectiveness of the insecticides revealed that the Neem leaf extract was the most effective at 67%, followed by Cypermethrin at 65%, Chinaberry at 59% and Garlic 59%. Comparing the botanicals with the cypermethrin standard showed that Neem was 103% followed by chinaberry at 91.0% and Garlic at 90.5%. The comparison showed no significant differences ($p > 0.01$) among the four insecticides (*i.e.* the botanicals and the synthetic pesticide) regarding their performance. This means that the botanicals were as effective as the synthetic pesticide in controlling the FAW highlighting the effectiveness of the extracts as a sustainable alternative control measure against FAW (Pavel *et al.*, 2012) [16]. In other words, the botanicals and cypermethrin insecticide killed and reduced the larvae population leading to reduced plant damage in both vegetative and cob stages leading to more crop growth and photosynthesis that resulted in a significantly higher maize yield compared to the infected control (Tanyi *et al.*, 2020) [15]. The yields were consistent with the FAW infestation levels and the FAW larva count, showing that where infestation and larva population were higher, the yield was lower and vice versa.

The apparent effectiveness of the Neem extract could be attributed to its immediate aggression in controlling the larvae population growth in the first three weeks (see **Figure 3**) thereby reducing the leaf and kernel damage to maize in the early stages of the crop development. In the first week, in comparison to the infected control, Neem caused 63% larval mortality, chinaberry at 57%, Cypermethrin at 43% and lastly garlic at 30%. These insecticides continued to reduce the larval counts over time to over 80% by the third week after the application of the treatments. This consequently reduced the leaf damage of the maize crop. The reduction in leaf damage mitigated the photosynthetic inhibition (Tanyi *et al.*, 2020) [15] that occurred in the infected control due to loss of leaves, which lead to yield losses in the maturity stages of the crop. The decrease in the leaf damage shown in **Figure 2(a)** indicates the recovery of the plant from the damage by the FAW. Kernel and ear damage was constantly low (**Figure 2(b)**) in the

infected control for the first two weeks but rose sharply in the third probably due to the fact that initially the cobbing and silking was still at its initial stage and probably not accessed by the larvae. Thus in the third week these were developed and accessed. On the other hand, in the treated plots there was no damage to the kernels and ears as there was very few or no larvae present implying that all the treatments were an effective measure in preventing cob damage. Usually, only at very high populations does the FAW penetrate the maize ears causing direct damage to the harvest (FAO, 2017) [2]. Since the larval population in the treatments was low, the damage was restricted only to the leaves in the insecticides treatments.

These findings therefore, warrant basis for an option of these botanicals in the control of FAW in maize more particularly as this relates to small scale farmers whose financial muscle usually falls short of the reach of the highly priced synthetic insecticides. Opting for botanicals would not only be cost effective on the part of the farmer but also a milestone in environmental protection including human and animal health protection (Pavela, 2009) [17]. Moreover, Cypermethrin which is commonly and widely used insecticide in FAW control by small scale farmers in Zambia was proved not to be any more efficacious than the three botanicals in FAW control in maize.

The use of botanicals in the control of FAW can be embraced under the concept of Integrated Pest Management (IPM) so that the rather moderate efficacy levels of these botanicals when combined with other control measures, can lead to more effective FAW management results thereby achieving better maize yields (Birhanu *et al.*, 2019) [18] which can be adopted under smallholder farmer conditions. Furthermore, this alternative can help in preventing the overuse or misuse that can lead to ecological backlashes such as resistance (Chamberlain *et al.*, 2006 [19], Lucena *et al.*, 2017 [20], Tanyi *et al.*, 2020 [15]) in the use of the cypermethrin

5. Conclusion

Natural chemicals extracted from Neem, Garlic and Chinaberry plants have insecticidal properties that can be used to manage FAW in maize leading to prevention of yield losses. A comparison of maize yields treated with these botanicals showed that they were as effective as the cypermethrin, a common synthetic pesticide. Therefore the three botanicals are an excellent alternative to synthetic or chemical pesticides for crop protection against FAW and therefore recommended for use to avoid negative effects of synthetic insecticides. Furthermore, these botanicals can be used as components for integrated pest management plans for sustainable FAW under smallholder farmer conditions.

Conflicts of Interest

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

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