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Research Article

Evaluation of Neem (*Azadirachta indica*) Seed Extract Against Fall Armyworm, *Spodoptera frugiperda* (Lepidoptera: Noctuidae) in Maize Fields

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Abstract

The increasing trends of damage to staple crops as well as the economic losses due to the fall armyworm (*Spodoptera frugiperda),* the notorious invasive insect pests prompted to devise effective pest management in colonized regions to ensure sustainable crop health. Deploying bioactive plant material is among the novel eco-friendly approaches to managing insect pests in maize agro-ecosystems. Therefore, the present study was conducted to determine the efficacy of neem seed extracts against S.*frugiperda* under field conditions at Babile, eastern Ethiopia. A total of 8 treatments, including 6 different neem seed extracts, Megathrin 0.5 L/ha, and un-sprayed (untreated) plots were set up in randomized complete block design with three replications to evaluate their efficacy against S.*frugiperda* in maize fields. Results showed that S.*frugiperda* infestation was significantly influenced by the treatments both at 32 days after sowing (DAS) and 39 DAS, however, a non-significant difference was observed at 25 DAS. Moreover, except for the number of rows per ear, all crop parameters were significantly influenced by the treatments. Notably, the treatments reduced S.*frugiperda* incidence and severity and achieved higher crop performance over untreated maize plants. Between 3.9% to 25.7% and 0.0% to 19.6%, reductions were recorded for S.*frugiperda* incidence at 32 DAS and 39 DAS, respectively, compared to untreated plants. Similarly, 22.7% to 47.7% and 33.8% to 46.2% reductions were observed for S.*frugiperda* severity at 32 DAS and 39 DAS, respectively. The highest grain yield (36.4 Qt/ha) was obtained from neem @ 75 gm/Lx3, which was followed by Megathrin 0.5 L/ha (31.9 Qt/ha), neem @ 62.5gm/Lx3 (31.6Qt/ha) and neem @ 75gm/Lx2 (31.2 Qt/ha), while significantly the lowest grain yield (21.8 Qt/ha) was obtained from untreated maize plants. Results indicated that the field application of neem seed extracts resulted in a significant reduction of S.*frugiperda* infestation and provided considerable yield advantages as compared to untreated plants. Hence, the promising efficacy of the locally available botanical insecticide could provide an opportunity to deploy it against S.*frugiperda* as an eco-friendly approach, although further study is needed to validate the findings of the present study across seasons and agroecologies.

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Keywords

Botanical Insecticide, Eastern Ethiopia, Field Efficacy, Maize, Pest Management, *Spodoptera frugiperda*

1. Introduction

Maize (*Zea mays* L.) is among the leading cereals in developing countries, including substantive areas in Sub-Saharan Africa [1]. In Ethiopia, it is the staple food crop grown in diverse agro-ecological zones and is known to play a dynamic role in food/nutrition security [2]. Besides, the crop is being grown in the drought-prone and most food-insecure areas including eastern parts of the country [3, 2]. Despite the importance, the national average yield of maize is about 4.1 tons/ha during 2020/2021 [2], which is far below the world's average yield; which might be due to several constraints such as the declining soil fertility, farm size, drought, lack of improved technology, and insect pests and diseases [4-6]. Insect pests, particularly *Spodoptera frugiperda* is become a key biotic constraint of maize crop production in Hararghe zones, eastern Ethiopia [7, 8], and thus signified for research priority to enhance sustainable crop production in the changing environmental conditions.

The fall armyworm, *Spodoptera frugiperda*, a new invasive species is severely attacking several crops, mainly maize and sorghum in recently colonized regions including Sub-Saharan African countries [9, 10, 6]. In Ethiopia, field infestation of 5% to 100% has been reported on maize due to larvae of *S.frugiperda* implying a significant yield penalty, even though the level of damage varied due to agroecology, crop growth stage, crop or pest management practices, and other factors [11-14]. *Spodoptera frugiperda* is posing severe damage to maize, the staple cereal in Hararghe, eastern Ethiopia. The pest is highly threatening the productivity of the crop in this area, implying the need for holistic and affordable ecological strategies to limit the increasing pest invasion and associated economic losses [8].

In response to *S.frugiperda* invasion various pest management methods, including cultural, mechanical or physical, bio-control, and synthetic insecticides have been proposed to combat the pest in the maize agro-ecosystem [12, 15-17]. Notably, the usage of conventional insecticide against *S.frugiperda* is high in recently colonized areas, including Ethiopian contexts [18, 19]; although it has serious environmental consequences [20, 21]. The strong environmental adaptability of *S.frugiperda* makes it challenging to attain effective control methods. For instance, several researchers have reported that synthetic chemicals and genetically improved varieties of maize are the most commonly used methods against *S.frugiperda* in America [11], however *S.frugiperda* is resistant to most of these chemicals [22, 23], and also recent studies have shown resistance of *S.frugiperda* to several genetically modified maize varieties [24, 25], implying the need for continued research effort to investigate ecological approaches to attain sustainable crop health, while reducing the load of synthetic insecticides from environment. Interestingly, botanical insecticides, push-pull technology, and bio-control are among promising agro ecological strategies to combat *S.frugiperda* in recently colonized countries to progress smallholder farmers' income [18, 16, 26, 6].

The use of botanical insecticide offers a more economically and environmentally safer alternative with a promising efficacy against *S.frugiperda* [27, 26], and remains an appropriate tool for resource-poor farmers [28]. Several extracts of plants have been evaluated for their activity against *S.frugiperda* [29]. Recent studies have indicated that different extracts of *Azadirachta indica* reported appreciable results against *S.frugiperda* in maize fields in many African countries [29, 14]. Field spraying of *Azadirachta indica* extracts has been proven to be effective against *S.frugiperda* infestation and resulted in higher growth and yield performance of maize [30, 31]. Moreover, a study [31] demonstrated that maize fields sprayed with the neem seed extracts had resulted in lower *S.frugiperda* infestation and higher grain yield as compared to un-sprayed plants. The maize yield advantages of 13.6% to 105.7% were obtained from treated plants as compared to untreated plants under field conditions [3-32]. *Azadirachta indica* exhibited antifeedant activity, disrupting growth and development, increased larval mortality, and reduced fecundity in insects [33, 12]. Besides, the use of botanical insecticide could lessen dependence on chemical insecticide [29] in addition to reducing the risk of pesticide resistance [34].

In Ethiopia, the application of neem extracts has provided high potency against *S.frugiperda* under greenhouse [12] and field settings [32, 14], although the information on the bio-efficacy of the botanical extracts is limited under field conditions in most parts of the country. In other words, research emphasis is needed to investigate the field efficacy of locally available potential insecticidal plants as ecological tools against *S.frugiperda* [29]. Convincingly, the availability of neem plants in Hararghe areas of eastern Ethiopia could provide an opportunity to deploy it against the pest, however, given that *S.frugiperda* is a new insect species in the country, there has been a lack of data looking at the efficacy of neem extracts against *S.frugiperda* under field settings, and thus necessitates for further examination to enhance the broad applicability of the botanical extracts under field settings for the management of the *S.frugiperda*. Therefore, in the present study we intended to determine the bio-efficacy of *Azadirachta indica* seed extracts against *S.frugiperda* under field conditions at Babile, eastern Ethiopia.

2. Materials and Methods

2.1. Description of the Study Areas

The field experiment was conducted during the 2023 main cropping seasons at Babile, eastern Hararghe zone of Oromia Regional State of Ethiopia (Figure 1). Babile district is located 31km away from Harar town and about 557 km east of Addis Ababa, the capital city of Ethiopia. The district lies between 8°, 9' 9°, 23'N latitude and 42°, 15'- 42°, 53' E longitude and has an altitude range between 1200-1960 m.a.s.l. It is characterized by a semi-arid and arid climate with an average annual rainfall of 410-800 mm and the annual temperature ranges from 24-28℃.

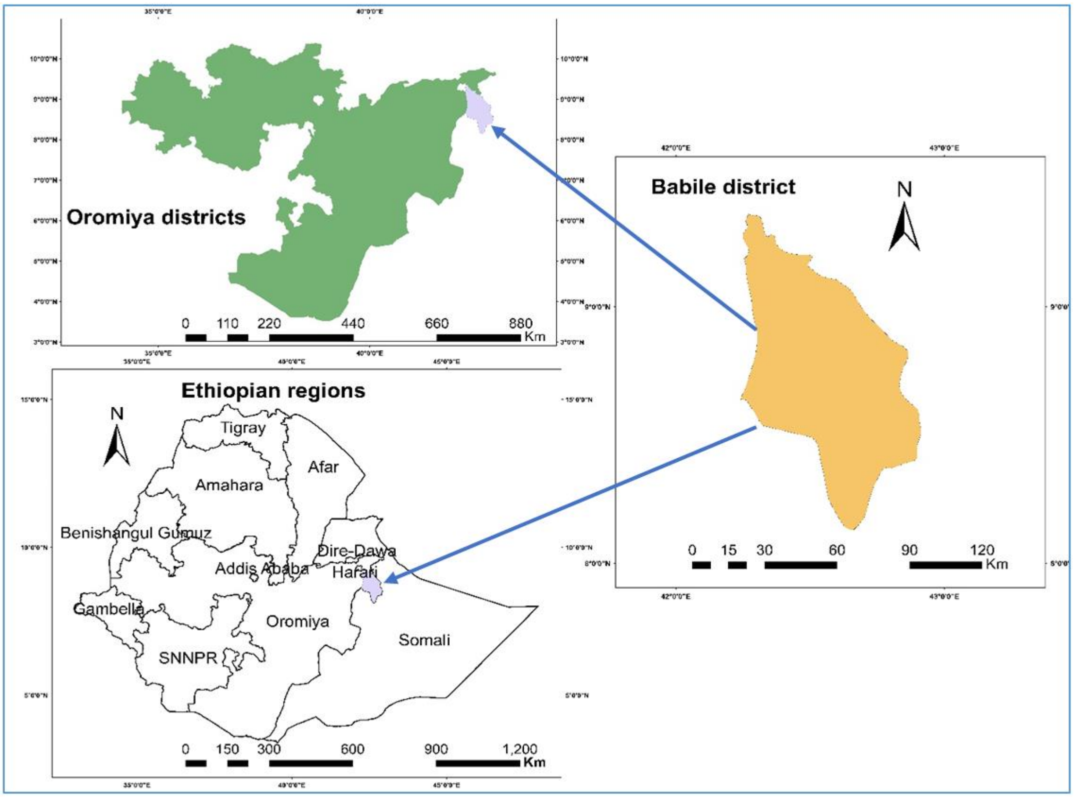

Figure 1. *Map of the study area (Babile district).*

2.2. Treatments and Experimental Procedure

A total of eight (8) treatments were evaluated against *S.frugiperda* in maize fields (Table 1). The treatments included three concentration levels of the neem *(Azadirachta indica*) seed extract (50 g/L, 62.5 g/L, and 75 g/L) each at two and three application frequencies, Lambda-Cyhalothrin 50g/l at the rate of 0.5 L/ha (standard check) and un-treated (un-sprayed). The treatments were laid out in a randomized complete block design with three replications. Improved maize variety, "Melkasa-4" was sown with two (2) seeds per hill at the 30 cm and 75 cm intra-row and inter-row spacing, respectively on the plot size of 21.2 m^2. The maize plants (seedlings) were thinned to one plant per hill 21 days after sowing. The spacing between plots and replications was 1 m and 1.5 m, respectively. Except for the experimental treatments, all other recommended crop husbandry practices were adopted uniformly throughout the seasons.

2.3. Preparation of Neem (*Azadirachta indica)* Seed Extracts

The botanical material, mature fruit/seed of neem *(Azadirachta indica)* was collected from Dire-Dawa by randomly identifying 5 individual plants to avoid any individual effect of the tree. The seeds were obtained from matured and completely ripened neem fruits. Following the collection of neem fruit/seed, the pulp of the seeds was removed, cleaned, and shade-dried after removing the seed coat from the dried seeds. After complete drying, neem seed was powdered by using an electric blender or pestle and mortar, and fine powder was collected by sieving. The powder of neem seed was soaked in water for 24 h and stirred periodically to mix the contents well, then filtered using a doubled muslin cloth to prepare different concentrations as per the treatment setup. Accordingly, the powdered seed was soaked in water at a rate of 50 g/L, 62.5 g/L, and 75 g/L. Newly prepared powders/ filtrate were used in each field spraying period.

2.4. Field Application

The treatments (Table 1) were applied using a knapsack sprayer at seven-day intervals with the designed treatment starting at 25 days after sowing (DAS) and repeated at 32 and 39 DAS as per the experimental set-up. The botanical insecticide (neem seed extracts) was sprayed as per the treatment set-up. Lambda-Cyhalothrin 50g/l, the standard insecticide was applied at the rate of 0.5 L/ha at 25, 32, and 39 DAS, while the control plots remained un-sprayed (un-treated). The amount of water used for field spraying was 300 L/ha for all of the treatments. After spraying each treatment, the sprayer was rinsed with liquid soap once and then washed with water.

Table 1. *Descriptions of different treatments used in the experiment and application time.*

Treatment (name)	Detail of the treatments and application time
Neem @ 50 gm/Lx2	Neem @ 50 gm/L two spraying round (i.e., 25 & 32 DAS)
Neem @ 50 gm/Lx3	Neem @ 50 gm/L three spraying rounds (i.e., 25, 32 & 39 DAS)
Neem @ 62.5 gm/Lx2	Neem @ 62.5 gm/L two spraying round (i.e., 25 & 32 DAS)
Neem @ 62.5 gm/Lx3	Neem @ 62.5 gm/L three spraying rounds (i.e., 25, 32 & 39 DAS)
Neem @ 75 gm/Lx2	Neem @ 75 gm/L two spraying round (i.e., 25 & 32 DAS)
Neem @ 75 gm/Lx3	Neem @ 75 gm/L three spraying rounds (i.e., 25, 32 & 39 DAS)
Megathrin 0.5 L ha-1	Lambda-Cyhalothrin 50g/l (standard chemical)
Un-sprayed	Untreated (control)

2.5. Data Collection

2.5.1. Assessment of *S.frugiperda* Infestation

Data on field infestation by *S.frugiperda* was recorded on randomly selected and tagged 25 maize plants in each of the plots. Border rows (each side) were excluded from observations to minimize border effects from the adjacent treatments. Before each spraying, the plants with characteristic foliar damage of *S.frugiperda* larval feeding were counted and expressed as the percentage of damaged plants (incidence). Likewise, the *S.frugiperda* severity was assessed on the leaves and leaf whorls of selected plants from each plot using a visual rating scale (0-9) described by Davis and Williams [35], where (0 = no visible leaf damage, 1= only pinhole damage on leaves, 2 = pinhole and shot hole damage to leaf, 3 = Small elongated lesions (5–10 mm) on 1–3 leaves, 4= midsized lesions (10–30 mm) on 4–7 leaves, 5 = Large elongated lesions (>30 mm) or small portions eaten on 3–5 leaves, 6 = elongated lesions (>30 mm) and large portions eaten on 3–5 leaves, 7 = elongated lesions (>30 cm) and 50% of leaf eaten, 8 = elongated lesions (30 cm) and large portions eaten on 70% of leaves, 9 = most leaves with long lesions and complete defoliation observed).

2.5.2. Agronomic Data of the Crop

Data on plant height was recorded from ten randomly selected plants of maize from harvestable rows in each plot. Data on yield components such as the number of rows per ear and ear length (cm) was recorded by selecting ten ears from each plot. Likewise, hundred seed weight (gm.), moisture content (%), and above-ground biomass (kg) were recorded at harvesting. Maize stand count at harvest and field weight (kg) per plot were measured from harvestable rows excluding one row on each side of the plot to avoid border effect at harvesting. The moisture of grain was adjusted to the standard moisture content of 12.5 and finally, the grain yield (ton) per hectare and the yield advantage was computed by using the following formula.

$$\text{Grain yield (ton/ha)} = (\text{Cw} * 0.81) * \frac{(100-\text{AM})}{(100-12.5)} \quad (1)$$

Where, CW is cob or ear field weight and AM is actual moisture at harvest.

$$\text{Percentage yield advantage (\%)} = \frac{(\text{Yt}-\text{Yc})}{\text{Yc}} * 100 \quad (2)$$

Where, Yt is yield in any treatment and Yc is yield in un-sprayed (untreated) plots.

2.6. Statistical Analysis

The collected data were subjected to Genstat Edition [64-Bit] version 22.1 software to undertake the statistical analysis. The significance test and means were separated using least significance difference (LSD) at $p < 0.05$.

3. Results

3.1. Field Infestation of the *Spodoptera frugiperda*

Results revealed that the field invasion (incidence and severity) of *S.frugiperda* was significantly affected by the treatments both at 32 days after sowing (DAS) and 39 DAS (Table 2). The *S.frugiperda* incidence was significantly ($P< 0.01$) influenced at 32 DAS and significantly ($P<0.05$) influenced at 39 DAS by the treatments; however, no significant differences were observed among treatments at 25 DAS. Similarly, significant differences ($P< 0.01$) were noted for the severity of *S.frugiperda* both at 32 DAS and 39 DAS, but no significant differences were observed at 25 DAS (Table 2). The maximum mean values of incidence (67.3%) was recorded from un-sprayed plots at 32 DAS, whereas the minimum (50.0%) was recorded from Megathrin 0.5 L/ha at 32 DAS, which was followed by neem @ 75 gm/Lx3 (51.3%). At 39 DAS, the maximum mean values of incidence (88.7%) was recorded from un-sprayed plots and neem seed extract at neem @ 50 gm/Lx2, while the minimum value (71.3%) was recorded from neem seed extract at neem @ 75 gm/Lx3, which was followed by Megathrin 0.5 L/ha (79.3%). Except for neem @ 75 gm/Lx3 and neem @ 50 gm/Lx2, there was a non-significant difference among neem seed extracts both at 32 DAS and 39 DAS regarding *S.frugiperda* incidence (Table 2). Furthermore, the maximum mean values of severity (4.4) was recorded from un-sprayed plots at 32 DAS, but the minimum values (2.3) was recorded from Megathrin 0.5 L/ha at 32 DAS, which was followed by the neem @ 75 gm/Lx3 and neem @ 62.5 gm/Lx3 with the mean values of 2.4 and 2.5, respectively. Similarly, the maximum (6.5) severity was recorded from un-sprayed plots at 39 DAS, while the minimum severity (3.5) was recorded from neem @ 75 gm/Lx3. There was a non-significant difference among neem seed extracts both at 32 DAS and 39 DAS for *S.frugiperda* severity (Table 2). Interestingly, except for mean incidence values of neem @ 50 gm/Lx2 at 32 DAS, there was non-significant differences between all neem seed extracts and Megathrin 0.5 L/ha regarding the mean incidence and severity values both at 32 DAS and 39 DAS.

Table 2. *Mean values of S.frugiperda incidence and severity as influenced by treatments at Babile during 2023.*

Treatments	Incidence			Severity		
	25DAS	32DAS	39DAS	25DAS	32DAS	39DAS
Neem @ 75 gm/Lx3	40.7a	51.3ab	71.3a	1.2a	2.4a	3.5a
Neem @ 75 gm/Lx2	32.7a	59.3bcd	80.7ab	1.4a	2.8a	3.6a
Neem @ 62.5 gm/Lx3	43.3a	59.3bcd	82.0ab	1.4a	2.5a	3.6a
Neem @ 62.5 gm/Lx2	44.7a	60.7cd	83.3ab	1.4a	2.8a	4.2a
Neem @ 50 gm/Lx3	47.3a	58.0abc	83.3ab	1.4a	2.6a	4.2a
Neem @ 50 gm/Lx2	39.3a	64.7cd	88.7b	1.5a	3.4b	4.3a
Megathrin 0.5 L/ha	43.3a	50.0a	79.3ab	1.4a	2.3a	3.6a
Un-sprayed	46.0a	67.3d	88.7b	1.5a	4.4c	6.5b
Lsd	17.2	8.3	13.8	0.43	0.5	1.3
Cv (%)	19.3	23.4	2.5	14.9	19.9	5.3
F-test (5%)	ns	**	*	ns	**	**

Means with the same letter within the column are not significantly different at $p < 0.05$ using LSD.
Note: **, * = significance difference at ($p<0.01$) and ($P < 0.05$), respectively; ns = no significance difference; Cv (%) = Cofficient of variation; F-test (5%) = Probability value; DAS = days after sowing

3.2. Maize Plant Height and Yield Related Parameters as Influenced by the Treatments

Data illustrated in Table 3 shows the influence of treatments on the plant height and yield related parameters of maize. The findings depicted that, except for the number of rows per ear, all of the measured parameters were significantly affected by the treatments (Table 3). Maize plant height, ear length, and thousand kernel weight were significantly ($P < 0.05$) influenced by the treatments. The percentage of infected ears and above-ground biomass was significantly ($P < 0.01$) affected by the treatments (Table 3). The maximum plant height (1.8 m) was recorded from neem @ 75 gm/Lx3, whereas the minimum (1.4 m) was recorded from un-sprayed plants. Likewise, the highest above-ground biomass (99.8 Qt/ha) was harvested from neem @ 75 gm/Lx3, which was followed by Megathrin 0.5 L/ha (83.9 Qt/ha), while the minimum (56.7 Qt/ha) was recorded from untreated plants. Moreover, the highest mean percentage of infected maize ear (37.4%) was recorded from un-treated plants, but the lowest mean values of 16.35% and 17.97% were recorded from plots treated with neem @ 75 gm/Lx3 and Megathrin 0.5 L/ha, respectively (Table 3).

Table 3. *Effect of treatments on maize plant height and yield related parameters at Babile in 2023.*

Treatments	Plant height (m)	Ear length (cm)	No. rows/ear	TKW (gm)	PIE (%)	B/mass (Qt/ha)
Neem @ 75 gm/L x3	1.8b	14.2b	13.1a	320.7bcd	16.4a	99.8d
Neem @ 75 gm/L x2	1.7b	14.3b	13.0a	300.3abc	19.7a	82.3bcd
Neem @ 62.5 gm/L x3	1.7b	13.6ab	13.3a	314.7abcd	21.6a	83.9bcd
Neem @ 62.5 gm/L x2	1.5ab	13.8ab	13.3a	323.7cd	18.2a	78.8bc
Neem @ 50 gm/L x3	1.6ab	12.9ab	13.5a	326.2d	22.2ab	82.3bcd
Neem @ 50 gm/Lx2	1.5ab	12.5ab	12.6a	291.2a	29.7bc	74.8ab
Megathrin 0.5 L/ha	1.7b	14.7b	13.1a	303.2abcd	17.8a	83.9bcd
Un-sprayed	1.4a	11.0a	13.3a	296.7ab	37.4c	56.7a
Lsd	0.3	2.8	2.5	23.7	7.734	19
Cv (%)	3.1	7.1	1.3	2	24.4	11.1
F-test (5%)	*	*	ns	*	**	**

Means followed by the same letter within the column are not significantly different at $p < 0.05$ using LSD.
Note: **, * = significance difference at ($p<0.01$) and ($P < 0.05$), respectively; ns = no significance difference; Cv (%) = coefficient of variation; F-test (5%) = probability value; No. rows/ear = number of rows per ear; TKW (gm)= thousand kernel weight (gm); PIE (%)= percentage of infected/damaged ear; B/mass (Qt/ha)= above ground biomass (Qt/ha)

3.3. Maize Grain Yield

Data (Figure 2) presented that maize grain yield was significantly ($P< 0.01$) influenced by the tested treatments. All of the treatments provided a better grain yield over untreated plants. The maximum (36.4 Qt/ha) grain yield was recorded from plots sprayed with a neem @ 75 gm/Lx3, which was followed by Megathrin 0.5 L/ha, neem @ 62.5 gm/Lx3, neem @ 75 gm/Lx2 and neem @ 50 gm/Lx3 with the grain yield of 31.9 Qt/ha, 31.6 Qt/ha, 31.2 Qt/ha and 31.1 Qt/ha, respectively. On the contrary, the minimum (21.8 Qt/ha) grain yield was obtained from un-sprayed plots (Figure 2). Figure 2 also illustrates that a yield advantage of 24.3% to 67.0% was obtained from the treatments. Field application of the neem @ 75 gm/Lx3, neem @ 75 gm/Lx2, and neem @ 62.5 gm/Lx3 achieved a significantly higher grain yield as compared to untreated maize plants (Figure 2). However, the maize plants sprayed with neem @ 50 gm/Lx2 provided a lower grain yield (27.1 Qt/ha) which was statistically at par with untreated plants. None significant difference was observed between neem seed extracts and Megathrin 0.5 L/ha, the standard chemical (Figure 2).

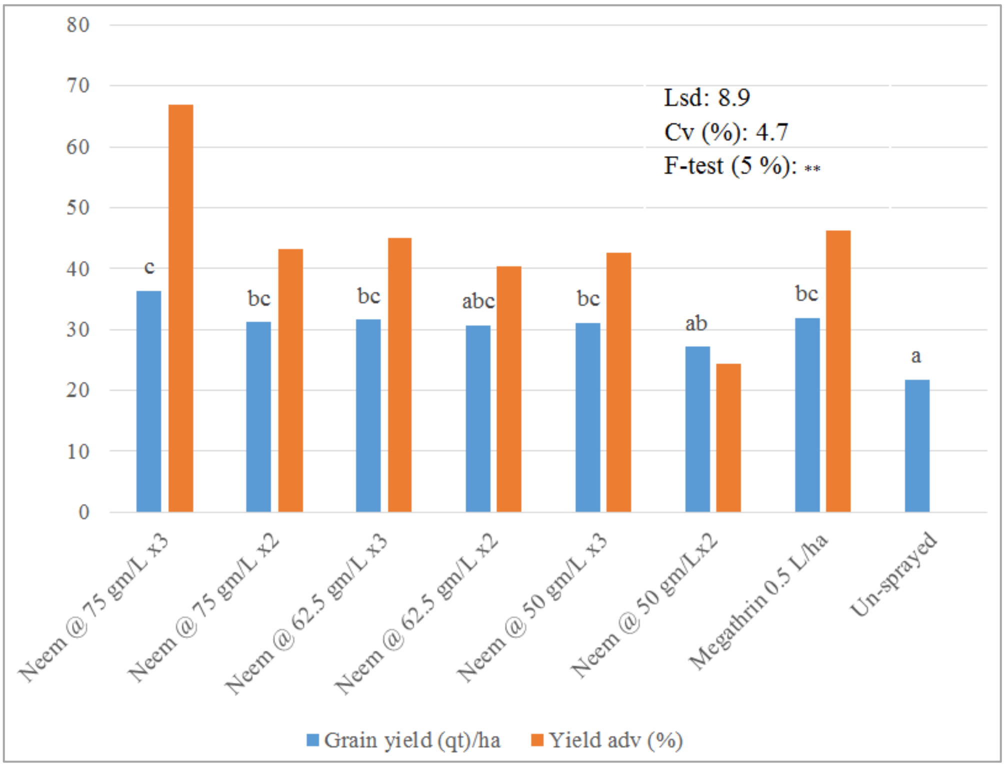

Figure 2. *Maize yield and yield advantage in response to the treatments during 2023 at Babile.*

Means followed by the same letter within the column are not significantly different at $p < 0.05$ using LSD.
Note: **, = significance difference at ($p<0.01$); Cv (%) = Cofficient of variation; F-test (5%) = Probability value; Grain yield (qt/ha) = yield per hectare (qt); Yield adv (%) = percentage yield advantage

4. Discussion

The results (Table 2) indicated that applications of the neem seed extracts had shown a decrement in the *S.frugiperda* field infestation and the subsequent crop damages as compared to un-sprayed plants. In analogy to our findings, Akhigbe et al. [30] demonstrated that the maize plants sprayed with neem seed extracts had shown a reduction in *S.frugiperda* infestation at vegetative stages. Likewise, Birhanu et al. [12] reported that the application of neem extracts at 32 DAS and 39 DAS had provided the lowest *S.frugiperda* infestation in maize fields. Promisingly, the botanical treatments provided equal efficacy against *S.frugiperda* infestation as compared to Megathrin 0.5 L/ha, the standard chemical. Moreover, the neem seed extracts had provided a high potency against *S.frugiperda* and resulted in lower incidence and severity, although a slight variation was noticed among the treatments mainly due to the application dosages (concentrations) and/or spraying rounds.

The incidence and severity of *S.frugiperda* were reduced between 3.9% to 25.7% and 22.7% to 47.7% at 32 DAS, respectively (Table 2). Similarly, the incidence and severity of *S.frugiperda* were reduced between 0.0% to 19.6% and 33.8% to 46.2% at 39 DAS, respectively. Notably, the treatments with a higher concentrations and spraying rounds of the botanical insecticide achieved greater toxicity against *S.frugiperda* leading to a lower field infestation or plant damage. In analogy to the present findings, a study [30] indicated that the infestation by *S.frugiperda* translated to the increase in incidence on the foliage and the number of damaged leaves recorded at 6 WAS, while a reduction of infestation was obtained in the treated maize plants. The plants treated with neem seed extracts resulted in lower leaf damage (severity), while un-sprayed plants showed extensive leaf damage both at 32 DAS and 39 DAS [12, 30, 14]. Likewise, a study [36] demonstrated a high efficacy of neem seed extract against *S.frugiperda*. The lowest infestation in the plants treated with neem seed extracts is attributed to the higher insecticidal activity of the treatments against *S.frugiperda* larvae mainly by feeding inhibition or deterrence, growth disruption, and increased larval mortality. *Azadirachta indica* seed extracts caused toxicity by acting as antifeeding inhibitors and showed repellent properties at high concentrations [33, 12].

The current study (Table 3) presented that all of the treatments achieved higher performance in almost all measured agronomic parameters of the plant over un-sprayed plots. Convincingly, the neem seed extracts were noted to increase the growth and yield-related parameters as compared to un-sprayed plots (Table 3). In analogy to the current results, a previous findings [31] demonstrated that the treated maize plants achieved higher crop performance as compared to untreated plants. Similarly, maize plants sprayed with neem extracts attained higher plant height, while untreated resulted in lower plant height [30]. The superior crop performance in maize in terms of plant height, above-ground biomass, earl length, and number of infected ears in plants treated with neem seed extracts might be due to maintained plant health and reduced *S.frugiperda* infestation following the toxicity of the botanical plant. In agreement with our result, Birhanu et al. [12] and Degife [32] investigated a substantial decrease in *S.frugiperda* infestation which resulted in higher crop biomass and a lower number of infected cob due to the higher insecticidal activity of neem extracts. Similarly, previous research [30] described that the active ingredient in neem which repelled the insect would have impaired the normal physiological activities and development in maize under field settings.

Data presented in Figure 2 indicated that the application of the neem seed extracts provided a higher grain yield as compared to untreated maize plants. In line with the present study, Degife [32] and Chekuri et al. [31] demonstrated that field application of neem extracts reduced foliar damage to maize enhanced maize growth performance, and resulted in higher grain yield as compared to untreated plants. Moreover, a study [31] investigated that the application of neem seed extracts resulted in maize grain yield increment of 36.8% to 105.7% over untreated plants under field conditions. In another study, a maize grain yield loss of 5% to 20% was reported following the maize foliar damage by *S.frugiperda* larvae [37]. Notably, all of the neem seed extracts achieved promising results which were statistically at par with Megathrin 0.5 L/ha (Figure 2). Furthermore, except for the neem @ 62.5 gm/Lx2 and neem @ 50 gm/Lx2, all of the botanical treatments had provided a significantly higher grain yield as compared to untreated plants. The highest grain yield obtained from the botanical insecticide might be due to the strong insecticidal activity of the neem seed extracts in limiting the *S.frugiperda* infestation and/or consequent crop damage which could enhance the photosynthesis process. The protected maize plants provided a higher grain yield as a result of the reduced foliar damage and enhanced photosynthesis following the high toxicity of neem extracts against *S.frugiperda* larvae [30, 31, 14]. The result of the present study indicates that the field application of neem seed extracts was proved to be effective against *S.frugiperda*, the notorious invasive insect pest in Hararghe, eastern Ethiopia, although further study is required to validate the efficacy in different seasons and/or locations.

5. Conclusions

The fall armyworm, *Spodoptera frugiperda* Smith (Lepidoptera: Noctuidae) is severely attacking the maize plants in Hararge, eastern Ethiopia, and this alerted for effective pest management strategies. The present results indicated that the field spraying of neem seed extracts had provided promising efficacy against *S.frugiperda* thereby significantly reducing the pest infestation. Interestingly, a maize yield advantage of 24.3% to 67.0% was obtained from the treatments over unsprayed (untreated) plots. Among the neem seed extracts, application of neem @ 75 gm/Lx3, neem @ 75 gm/Lx2, Neem @ 62.5 gm/Lx3, neem @ 62.5 gm/Lx2, and neem @ 50 gm/Lx3 were achieved higher efficacy and grain yield equal to Megathrin 0.5 L/ha under the field conditions. Convincingly, application of the effective control treatments against the *S.frugiperda* larvae during the vegetative stages of maize is the most imperative component of a successful pest management system. Findings from this study show that the application of the aqueous seed powder extracts proved to be an effective eco-friendly alternative to synthetic insecticides and the potential component of an integrated pest management program to limit the *S.frugiperda* infestation in maize fields in Ethiopia, although further research is needed to validate the present findings over years as well as across agro-ecologies to ensure its broad applicability against the invasive pest.

Abbreviations

CV	Coefficient of Variation
DAS	Days After Sowing
LSD	Least Significant Difference

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Declarations

Authors' contributions: Megersa K. conceptualization of study design, experimentation, statistical analysis, and manuscript write-up. Emana G., Mulatu W., Ashenafi K., Muluken G. and Tarekegn F. provided advice/supervision for the first author throughout the research work and evaluated/review the manuscript drafts. All authors review and approved the final draft for publication.

Ethical Approval

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Conflicts of Interest

The authors declare no conflicts of interest.

References

[1] FAO. 2021. FAOSTAT Crop Production Compare Data. Rome. Accessed on 1st May, 2021. http://www.fao.org/faostat/fr/#compare

[2] CSA (Central Statistical Agency), 2021. Report on area and production of major crops. The federal democratic republic of Ethiopia.

[3] Wedajo, G and Hussein, M. 2015. Study on adaptability and stability of drought tolerant maize varieties in drought prone areas of South Omo Zone, SNNPRS. *International Journal of Research in Agriculture and Foresty*, 2: 17.

[4] Yodit K., Frédéric, B., Felix, B and Pablo, T. 2018. Unpacking the push-pull system: Assessing the contribution of companion crops along a gradient of landscape complexity. *Agriculture, Ecosystems and Environment,* 268: 115–123. *https://doi.org/10.1016/j.agee.2018.09.012*

[5] Ketema K., Jafer M., Abdulalziz, T and Alemayehu, B 2020. "Characterization and Analysis of Crop Production System for Research and Development Intervention." *American Journal of Agricultural Research,* 1–20.

[6] Dessie, D., Ferede, B., Taye, W and Shimelash, D. 2024. Field infestation of the invasive fall armyworm, *Spodoptera frugiperda* (Lepidoptera: Noctuidae) on maize in Southern Ethiopia. *Crop Protection*, Volume 178, id. 106587 https://doi.org/10.1016/j.cropro.2024.106587

[7] Abebe, T and Belay, R. 2020. Evaluation of the Smallholder Farmers' Perception and Acceptance for Push-Pull Technology in Western Hararghe Zone of Oromia, Ethiopia. *American Journal of Agriculture and Forestry*, 8(3): 81-90. *https://doi.org/10.11648/j.ajaf.20200803.15*

[8] Misrak U., Mulugeta N., Girma D and Thangavel, S. 2020. Assessment of major field insect pests and their associated losses in maize crop production at West Hararghe Zone, Ethiopia. *Journal of Entomology and Zoology Studies*, 8(4): 2027-2037.

[9] Megersa, K and Tarekegn, F. 2022. RNA interference (RNAi) applications to the management of fall armyworm, *Spodoptera frugiperda* (Lepidoptera: Noctuidae): Its current trends and future prospects. *Front. Mol. Biosci*., 9: 944774. https://doi.org/10.3389/fmolb.2022.944774

[10] Abdel-Rahman, E. M, Kimathi, E, Mudereri, B. T, Tonnang, H. E, Mongare, R, Niassy, S and Subramanian, S. Computational biogeographic distribution of the fall armyworm (*Spodoptera frugiperda* J. E. Smith) moth in eastern Africa. *Heliyon.* 2023; 9 e16144. https://doi.org/10.1016/j.heliyon.2023.e16144

[11] Abrahams, P., Beale, T., Cock, M., Corniani, N., Day, R., Godwin, J., Murphy, S., Richards, G. and Vos. J. 2017. Impacts and control options in Africa: Preliminary Evidence Note (April 2017). CABI, 1-51.

[12] Sisay, B., Simiyu, J., Mendesil, E., Likhayo, P., Ayalew, G and Mohamed, S. 2019. Fall Armyworm, *Spodoptera Frugiperda* Infestations in East Africa: Assessment of Damage and Parasitism. *Insects.* 10, 195. https://doi.org/10.3390/insects10070195

[13] Hailu, T., Getu, E., Wakgari, M and Goftishu, M. 2023. Seasonal Distribution of *Spodoptera frugiperda* Smith (Lepidoptera: Noctuidae) in Ethiopia. *Advances in Life Science and Technology*, Vol. 98, ISSN 2224-7181 (Paper) ISSN 2225-062X (Online).

[14] Gebretsadkan, Z and Weldu, N. 2024. "Field Efficacy of Botanical and Chemical Insecticides against Maize Fall Armyworm [(*Spodoptera frugiperda* (J. E. Smith)] in Central Zone of Tigray, Ethiopia". *Asian Journal of Research and Review in Agriculture* 6(1): 434-44. *https://jagriculture.com/index.php/AJRRA/article/view/118*

[15] Hailu, G., Niassy, S., Khan, Z. R., Ochatum, N and Subramanian, S. 2018. Maize-legume intercropping and Push-pull for management of fall armyworm, stemborers and striga in Uganda. *Agronomy Journal*, 110: 1–10. *https://doi.org/10.2134/agronj2018.02.0110*

[16] Harrisona, R. D., Thierfelderb, C., Baudronc, F., Chinwadad, P., Midegae, C., Schafner, U and Berg, J. 2019. Agro-ecological options for fall armyworm (*Spodoptera frugiperda* JE Smith) management: Providing low-cost, smallholder friendly solutions to an invasive pest. *Journal of Environmental Management*, 243: 318–330. https://doi.org/*10.1016/j.jenvman.2019.05.011*

[17] Jia, J., Wang, A., Peng, S., Lian, Y., Wu, Q., Lin, Z., Zhang, Q and Ji, X. 2024. Prediction of the potential distribution area of *Spodoptera frugiperda* and its parasitic wasp, *Trichogramma pretiosum*. *Insect Biochemistry and Physiology*. https://doi.org/10.1002/arch.22092

[18] Prasanna, B. M., Huesing, J. E., Eddy, R and Peschke, V. M. Fall Armyworm in Africa: A Guide for Integrated Pest Management, 1st ed.; CIMMYT: Edo Mex, Mexico, 2018.

[19] Kumela T., Josephine, S., Birhanu S., B., Likhayo, P., Esayas M, Gohole, L and Tadele T. 2018. Farmers' knowledge, perceptions, and management practices of the new invasive pest, fall armyworm (*Spodoptera frugiperda*) in Ethiopia and Kenya. *International Journal of Pest Management*, https://doi.org/10.1080/09670874.2017.1423129

[20] Lewis, S. E., Silburn, D. M., Kookana, R. S and Shaw, M. 2016. Pesticide behavior, fate, and effects in the tropics: an overview of the current state of knowledge. *J. Agric. Food Chem*. 64, 3917-3924. https://doi.org/10.1021/acs.jafc.6b01320

[21] Day, R., Abrahams, P., Bateman, M., Beale, T., Clottey, V., Cock, M., Colmenarez, Y., Corniani, N., Early, R., Godwin, J., Gomez, J., Moreno, P. G., Murphy, S. T., Oppong-Mensah, B., Phiri, N., Pratt, C., Silvestri, S and Witt, A. 2017. Fall armyworm: impacts and implications for Africa. *Outlooks on Pest Management*, 28(5), 196-201. https://doi.org/10.4236/als.2019.74012

[22] Pitre, H. N. 1986. Chemical Control of the Fall Armyworm (Lepidoptera: Noctuidae): An Update. *Florida Entomologist*, *69*(3): 570–578.

[23] Yu, S. J. 1991. Insecticide resistance in the fall armyworm, *Spodoptera frugiperda* (J. E. Smith). *Journals of Pesticide Biochemistry and Physiology*, 39(1): 84-91. https://doi.org/10.1016/0048-3575(91)90216-9

[24] Farias, J. R., Andow, D. A., Horikoshi, R. J., Sorgatto, R. J., Fresia, P., dos Santos, A. C and Omoto, C. Field-evolved resistance to Cry1F maize by *Spodoptera frugiperda* Smith (Lepidoptera: Noctuidae) in Brazil. Crop. Pot. 2014, 64, 150-158. https://doi.org/10.1002/ps.4201

[25] Bernardi, D., Salmeron, E., Horikoshi, R. J., Bernardi, O., Dourado, P. M., Carvalho, R. A., Martinelli, S., Head, G. P and Omoto, C. 2015. Cross- Resistance between Cry1 Proteins in *Spodoptera frugiperda* Smith (Lepidoptera: Noctuidae) may affect the durability of current Pyramided Bt Maize hybrids in Brazil. PLOS ONE, 10, E0140130. https://doi.org/10.1371/journal.pone.0140130

[26] Jaoko, V., Taning, C., Backx, S., Motti, P., Mulatya, J and Vandenabeele, J. 2021. Laboratory and Greenhouse Evaluation of *Melia Volkensii* Extracts for Potency against T African Sweet Potato Weevil, *Cylas Puncticollis*, and Fall Armyworm, *Spodoptera Frugiperda*. *Agronomy*, 11, 1994. https://doi.org/10.3390/agronomy11101994

[27] Hikal, W. M., Baeshen, R. S and Said, A. H. 2017. Botanical insecticide as simple extractives for pest control, *Cogent Biology*, 3: 1.https://doi.org/10.1080/23312025.2017.1404274

[28] Schmutterer, H. 2009. Which insect pests can be controlled by application of neem seed kernel extracts under field conditions? *Journal of Applied Entomology*, 100: 468-475.

[29] Naomi, B and Philip, C. 2020. Opportunities and Scope for Botanical Extracts and Products for the Management of Fall Armyworm, *Spodoptera frugiperda* for Smallholders in Africa. *Plants*, *9*: 207. https://doi.org/10.3390/plants9020207

[30] Akhigbe, C. I., Oyerinde, A. A., Asala, S. W and Anjorin, T. S. 2021. Evaluation of fall armyworm (*Spodoptera frugiperda* J. E. Smith) infestation and efficacy of neem extracts in maize (*Zea mays* L.). *Nigerian Agricultural Journal*, 52(1), P. 77-82. http://www.ajol.info/index.php/naj

[31] Chekuri, N and Anoorag, R. T 2023. Efficacy of different Chemicals and Neem Products against Fall Armyworm, [*Spodoptera frugiperda* (J. E. Smith)] in Maize (*Zea mays* L.). *Biological Forum – An International Journal*, 15(6): 432-436.

[32] Degife, B. 2021. Assessment of possible integrated management alternatives for fall armyworm (*Spodoptera frugiperda* smith: Lepidoptera: Noctuidae) on maize at Melkasa Master's Thesis, Addis Ababa University, Addis Ababa, Ethiopia, 2021.

[33] Hail, K. S., John, L. C and Nawaf, M. F. 2015. Effects of Neem-Based Insecticides on Consumption and Utilization of Food in Larvae of *Spodoptera eridania* (Lepidoptera: Noctuidae). *J. Insect Sci*., 15(1): 152; https://doi.org/10.1093/jisesa/iev134

[34] Arya, M and Tiwari, R. 2013. Efficacy of plant and animal origin bio-products against lesser grain borer, *Rhyzopertha dominica* (Fab.) in stored wheat, *International Journal of Recent Scientific Research*, 4(5): 649–653.

[35] Davis, F. M and Williams, W. P. Visual Rating Scales for Screening Whorl-Stage Corn for Resistance to Fall Armyworm; *Technical Bulletin*, 186; Mississippi Agricultural and Forestry Research Experiment Station: Mississippi State, MS, USA, 1992. *Available online: http://www.nal.usda.gov/* (accessed on 1 October 2017).

[36] Silva, M. S., Broglio, S. F., Trindade, R. C. P., Ferrreira, E. S., Gomes, I. B and Micheletti, L. B. Toxicity and application of neem in fall armyworm. *Comun. Sci*. 2015, 6, 359–364. https://doi.org/10.14295/cs.v6i3.808

[37] Marenco, R. J., Foster, R. E., Sanchez. C. A. 1992. Sweet Corn Response to Fall Armyworm (Lepidoptera: Noctuidae) Damage During Vegetative Growth. *Journal of Economic Entomology*, 85(4): 1285–1292, https://doi.org/10.1093/jee/85.4.1285