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Assessment and Control Strategies for Fall Armyworm (*Spodoptera frugiperda* J.E. Smith) Infestation in Maize (*Zea mays* L.) Cultivation, Ethiopia

Ethiopia Agemasu Getu[1], Abaynew Jemal Jenber[2]*, Adane Tesfaye[2], Bewket Wubshet[2]

[1]Bahir Dar Plant Health Clinic, Amhara Agricultural Berou, Bahir Dar, Ethiopia.
[2]Department of Plant Sciences, Bahir Dar University, Bahir Dar, Ethiopia.

***E-mail** ✉ abujemal900@gmail.com

ABSTRACT

Maize is the most important crop in Ethiopia, but its production faces significant constraints due to various challenges, especially insect pests such as armyworms. This study was conducted to assess the occurrence of fall armyworms and investigate management strategies using different maize varieties and insecticides in the Dera district, Ethiopia. The survey was conducted in four selected Kebeles with data analysis using SPSS. A factorial experiment was designed, incorporating a randomized complete block layout with three replications, testing a combination of 4 synthetic insecticides (dimethoate 40% EC, karate 5%, Agrolambsin supper 315, and malathion 50%) alongside a control and 3 maize varieties (BH-540, BH-546, and local). Data on pest incidence, vegetative growth, and yield-related attributes were collected and analyzed using SAS. The findings showed a fall armyworm prevalence rate of 72.92% and an infestation level of 30.69%. Both insecticide type and maize variety significantly affected pest damage, vegetative traits, and yield-related factors. The interaction between insecticide application and variety selection affected plant height, grain yield, ear length, and the harvest index. Among the tested combinations, Agrolambsin supper 315 applied to the BH-546 variety resulted in the highest plant height, longest ears, and maximum grain yield. In addition, the independent effects of Agrolambsin supper 315 and BH-546 led to the highest number of ears per plant, higher biomass yield, and an increased number of green leaves. Although all maize varieties examined in this study were affected by armyworm infestation, the yield losses can be mitigated by cultivating BH-546 in conjunction with Agrolambsin supper 315 application.

Keywords: Yield, Infestation, Maize varieties, Insecticides, Pest

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Introduction

Each year, approximately Eight hundred forty-four million tons of maize (*Zea mays* L.) are cultivated on One hundred sixty-two million hectares across more than 180 countries. Recognized by the Food and Agriculture Organization (FAO) [1] as one of Africa's most vital cereal crops, maize is predominantly grown by smallholder farmers on an estimated 40 million hectares, yielding around 81 million tons of grain annually. As the highest-yielding cereal, maize plays a crucial role in Ethiopia's economic growth and social development.

The Amhara National Regional State is among Ethiopia's leading maize-producing areas. During the 2019/2020 growing season, the region allocated 532,483.26 hectares to maize cultivation, producing a total of 2,275,120.81 tons, with an average yield of 4.27 t ha^{-1} [2]. South Gondar also possesses significant potential for maize farming, covering 57,308.9 hectares in the same season and producing 220,856.77 tons, with an average yield of 3.84 t ha^{-1} [2]. Despite this potential, maize productivity remains low due to various challenges, including biotic factors such as insect pests and diseases, abiotic stressors, and socio-economic constraints [3]. Among these, insect infestations are a primary limiting factor.

A major biotic threat to maize production is the fall armyworm, which significantly reduces yield. This pest, *Spodoptera frugiperda* J.E. Smith (Lepidoptera: Noctuidae), is native to tropical and subtropical regions of the Americas [1]. Considered one of the most destructive invasive insect pests to enter Africa in recent decades, the fall armyworm was first detected in Central and West Africa in early 2016. By 2018, it had spread across nearly all of Sub-Saharan Africa, with the exceptions of Lesotho, Djibouti, and Eritrea, and had also been identified in the Indian Ocean island nations of Mauritius and Seychelles [4].

The autumn armyworm larvae can feed on more than 80 plant species, including cotton, sorghum, rice, millet, sugarcane, and various vegetable crops. Damage occurs when the larvae consume plant leaves, with younger larvae primarily feeding on the epidermal leaf tissue, leaving characteristic holes as an early sign of infestation. When feeding occurs at the whorl stage in young plants, it can result in a "dead heart" symptom. In older plants, larger larvae found in the whorl may damage maize kernels or cobs, leading to reductions in both yield and quality [5].

The fall armyworm was first detected in Ethiopia in 2017. Due to its rapid reproductive cycle and favorable environmental conditions, it has now spread to eight of the country's nine regions, producing up to 5 generations annually in the southern areas. Without timely and effective management, the pest is estimated to cause up to a 30% reduction in maize yields across Ethiopia [6]. The infestation has affected approximately 411 districts, covering more than 500,000 hectares of land. Since its initial outbreak in 2017, the pest has destroyed a quarter of the total 2.6 million hectares allocated for maize cultivation. The persistence of re-infestations and the emergence of new outbreaks pose significant obstacles to pest control efforts. The migration route of the fall armyworm extends over a thousand kilometers, beginning in the southern regions and moving northward through key maize-producing areas [7].

Since the emergence of autumn armyworms in African countries, synthetic pesticides have frequently been used as a last measure to minimize damage to maize fields and curb the pest's spread. However, no officially approved synthetic pesticide is currently available for fall armyworm control in African nations, apart from those authorized under emergency use labels. This highlights the urgent need for screening and evaluation of synthetic insecticides. Many farmers have reported frustration with the limited effectiveness of existing synthetic pesticides in protecting their maize crops from fall armyworm infestations. As a result, they resort to frequent applications of high pesticide doses, which can lead to excessive pesticide accumulation in the environment and accelerate the development of resistance in the pest population [8]. Given these challenges, this study was conducted to evaluate the efficacy of artificial pesticides in managing fall armyworms across different maize varieties cultivated in the research area.

Materials and Methods

Field survey

Description of the survey area

A field survey took place in the Dera district, located in the South Gondar administrative zone of the Amhara National Regional State, during the 2020 primary cropping season. Geographically, Dera district is situated at 11°37′11″ N and 37°22′37″ E in Ethiopia. It shares borders with the Abay River to the southeast, Lake Tana to the west, Fogera district to the north, and Estie district to the east. The district lies 47 km south of Bahir Dar, the regional administrative center, and approximately 607 km northwest of Addis Ababa, the national capital. Covering an estimated 149,724 hectares, Dera district is administratively divided into 36 rural kebeles (the smallest administrative units) **(Figure 1)** [9].

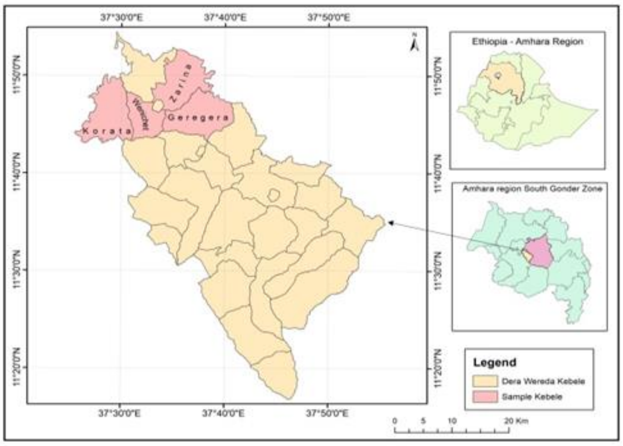

Figure 1. Map of the study area.

Survey sampling techniques and size

The kebele administrations for this study were chosen based on reports of autumn armyworm presence, the region's potential for maize cultivation, and the occurrence of insect pests. The study focused on four kebele administrations within the district: Geregera, Zara, Wonichet, and Korata. Using Yamane's method, the sample size was calculated with a 95% confidence level and P = 0.05. Farmers were selected randomly [10]. A total of 1006 farm fields were surveyed by randomly walking along roads in each selected kebele [11]. The surveys took place between May and July 2020. Farm households in these areas were asked to fill out a semi-structured questionnaire, which collected data on their socio-economic backgrounds, farming practices, awareness, and attitudes toward the autumn armyworm, its prevalence, and pest management approaches.

In each farm field, an assessment was carried out by placing a quadrant of 3.2 m × 4 m (12.8 m²) and walking diagonally in an "X" pattern. Within the quadrant, plants were then counted as either damaged or undamaged. The sample size was calculated using Yamane's formula, as shown in Eq. 1 as follows [10]:

$$\mathrm{n} = \frac{N}{1 + N(e)^2} \quad (1)$$

In this formula, n represents the sample size, N denotes the population size, and e indicates the desired level of precision.

Data collection and analysis

Prevalence: The occurrence or non-occurrence of insects was recorded across 1,006 fields from the four kebele administrations. This was calculated using Eq. 2, as follows:

$$\text{Prevalence (\%)} = \frac{\text{Number fields exhibited the insects}}{\text{Total number of examined fields}} \times 100 \quad (2)$$

Infestation: A total of 741 out of 1,006 farmer fields, where pests were present, were chosen for the infestation evaluation. Infested plants within the quadrant sample (3.2 m × 4 m) were recorded three times per field for each kebele administration. A plant exhibiting symptoms was collected from each of the 741 fields, and samples from all plant parts were taken for analysis [12]. This was calculated using Eq. 3, as follows:

$$\text{FAW infestation (\%)} = \frac{\text{Number of infested plants}}{\text{Total number of plants assessed}} \times 100 \quad (3)$$

The survey data were compiled, and descriptive statistics, including means and percentages, were computed using the Statistical Package for Social Sciences (SPSS).

Field experiment

Description of the experimental site

The experiment took place at the farmers' training center located in the Geregera kebele administration, situated at 11°75′93″ N and 37°60′06″ E **(Figure 1)**. The site lies at an elevation of 1500 meters above sea level, within the Woyna Dega (mid-land) agroecological zone, and has red sandy soil. Rainfall follows a uni-modal distribution, with the main rainy season occurring from May to September, yielding an average annual rainfall of 1300 mm and an average temperature of 18 °C. Key crops cultivated in the area include finger millet, maize, and tef [9].

Treatments, experimental design, and procedures

A randomized complete block design (RCBD) with 3 replications was employed to establish control and unsprayed plots. The study included four types of synthetic insecticides—dimethoate 40% EC, karate 5% EC, Agrolambasin supper 315, and malathion 50% EC—and three maize varieties—BH 540, BH 546, and a local variety—arranged in a factorial combination. Based on this design, a field layout was developed, and experimental plots were randomly assigned within each block using a lottery system. Each plot measured 3 meters by 4 meters (12 square meters), with 2 seeds per hill and 80 centimeters spacing between plant rows. A gap of 0.5 meters between plots and 1 meter between blocks was maintained. The maize was sown according to the recommended seed rate of 25 kg ha-1, with 80 centimeters between rows and 40 centimeters between plants, placing 2 seeds per hill. Fertilizer application followed regional crop recommendations [13], with phosphorous applied at two hundred kg P2 O5 ha-1 and nitrogen at 200 kg N ha-1, as per the approved rates. Phosphorous was applied in full as a band at planting when the plants were 35-40 days old, and nitrogen was side-dressed at 3-5 cm distance from the plants until fully incorporated into the soil. Weeding was done manually as required [13].

Treatment application: Treatments were applied using a backpack sprayer one week after infestation and 30 days after planting. Before and following the treatment, the number of larvae present was recorded. Data on the number of surviving larvae were gathered twice about the insecticide applications.

Scouting and detection: 2 weeks after maize emergence, the presence of egg clusters, newly hatched larvae, and early-stage FAW damage, such as small window-like holes or pinpricks on the leaves, was monitored. The number of larvae and the extent of damage (damage severity) per plot were assessed for three consecutive days before insecticide application.

Data collection

Pest parameters

Prevalence: The absence or presence of insects was evaluated and recorded for each plot.

Infestation: Each plot was assessed, and infested plants were noted. A plant showing symptoms was collected, and samples from all parts of the infected plants were taken for analysis [14].

Number of damaged plants per plot: This was determined by counting five randomly selected plants from the central area of the net plot.

Percentage of damaged leaves per plant: The count of 5 randomly selected plants from the central net plot areas was used to record the percentage of damaged leaves.

Number of larvae per plant: This was documented by counting five randomly selected plants from the central net plot sections.

Number of surviving larvae per plant: Observations and counts were made from five randomly selected plants in the central net plot areas.

Larval mortality percentage: The mortality of larvae was calculated following each insecticide application.

Vegetative parameters

Number of leaves per plant: The total number of green leaves per plant at tasseling was determined by counting the leaves on 5 randomly selected plants. The average count was used to calculate the number of green leaves per plant.

Plant height (centimeters): The height of 5 randomly selected plants, which were physiologically mature, was measured from the soil surface to the base of the tassels. These plants were taken from the central net plot areas.

Yield parameters

- *Number of ears per plant*: This was determined by counting the ears from five randomly selected plants in the central net plot areas.

- *Ear length (centimeters):* The ear length was measured from the point where the ear attaches to the stem to the tip of the ear.

Grain yield (GY t/ha): Grain yield was calculated by weighing the grains harvested from the middle 2 rows of each plot. After adjusting for a grain moisture content of 12.5%, the weight was converted to kilograms per hectare. The following formula was applied to calculate the moisture adjustment factor, considering Eq. 4 as such:

$$\text{Adjusted Yield} = \frac{100 - \text{Measured moisture content (\%)}}{100 - 12.5\%} \tag{4}$$

As a result, the grain yield adjusted to 12.5% moisture content is obtained by multiplying the moisture correction factors by the grain yield collected from each plot [15].

- *Above-ground dry biomass (BY t/ha):* The plants from 2 rows of a plot were harvested and weighed, and the weight was converted to tons per hectare.
- *Thousand-kernel weight (TKW gram):* The weight of 1000 kernels was measured by counting the grains with an electronic seed counter and then using a sensitive balance (accuracy of +0.001 g) to weigh the counted kernels from the plot. The weight was measured after adjusting the moisture content of the grains to 12.5% using a Draminski Gmm small fast moisture tester.

Harvest index (HI %): The harvest index was calculated as the ratio of grain yield to total biomass (including both straw and grain) yield per plant, following the method of Donald (1962). The results were presented as percentages, following Eq. 5 [16]:

$$\text{Harvest index (\%)} = \frac{\text{Economic yield (t per ha)}}{\text{Total biological yield (t per ha)}} \times 100 \tag{5}$$

Data analysis

Statistical analysis was conducted using SAS software version 9.4, where analysis of variance (ANOVA) was performed on the experimental data according to the statistical methods described by Gomez and Gomez. To assess the economic feasibility of the treatments, a partial budget analysis was carried out. This analysis followed the CIMMYT approach to determine dominance, partial budget, and marginal rate of return [17].

Results and Discussion

Survey results and discussion

Fall armyworm prevalence and infestation

A survey of 1,006 maize farmers revealed that 72.92% had already encountered fall armyworm infestations, a figure higher than that reported for the 2019 growing season, according to the respondents. The insect prevalence in the various kebeles was recorded as 58.3%, 66.67%, 91.67%, and 75% in the Geregera, Zara, Wonichet, and Korata kebeles of Dera district, respectively. The district's average infestation rate for fall armyworm was 30.69% **(Table 1)**. Farmers in Ethiopia reported that the maize infection rates from fall armyworm ranged from 24.1% to 39.4%, with an overall average of 32% [12].

Maize production losses

The yield losses attributed to fall armyworm infestations in maize fields were assessed. In the study area, approximately 77.8% of respondents reported yield reductions ranging from 20% to 50%, while around 22.2% estimated losses between 51% and 81%. Among the 1,006 farmers surveyed in Dera district, the infestation rate during the 2020 cropping season was found to be between 35% and 50%.

Farmer's knowledge and perception

The results revealed a significant positive correlation between maize production and farmers' views on pesticide use and their adoption of cultural practices to control fall armyworms. This suggests that farmers who applied chemical treatments or cultural methods were likely to achieve higher yields than those who didn't. This could partially explain why these management strategies were regarded as effective. A study by Kumela *et al*. [12] indicated that 99% of farmers across Ethiopia were aware of the fall armyworm. Additionally, a negative correlation was found between maize yield and farmers' perceptions of insect infestation. This implies that as the damage caused by fall armyworms increases, the likelihood of severe maize crop losses also rises.

Table 1. Survey on prevalence and infestation of fall armyworm, Dera district, during 2020

Name of Keble's	No of respondents/ kebele (%)	Prevalence	Infestation		
			Total number of plants assessed	Average number of plants infected	Infestation (%)
Geregera	240	140 (58.30%)	800.00	260.00	32.5%
Zara	222	148 (66.67%)	740.00	262.70	35.5%
Wonichet	267	245 (91.67%)	890.00	258.10	29.0%
Korata	277	208 (75.00%)	923.00	237.80	25.75%
Total	1,006	183.4 (72.92%)	838.00	257.40	30.69%

Field experiment

Effects of variety and insecticide on pest parameters

Number of damaged plants per plot and percent of leaves damage

The highest percentage of damaged plants per plot (16.20%) and the greatest proportion of damaged plants per plant (32.26%) were observed in the BH-546 variety. This was followed by the BH-540 variety, which showed 15.21% of damaged plants per plot and 31.02% of damaged plants per plant. The local maize variety exhibited the lowest damage, with 13.86% of damaged plants per plot and 29.55% of damaged plants per plant **(Table 2)**. This difference may be attributed to the leaf toughness of the local variety, possibly due to a thicker epidermal layer [18].

Number of larvae per plot before spray

Data analysis showed that maize infestations by fall armyworm larvae were more prevalent in improved varieties compared to local varieties. The BH-546 maize variety exhibited the highest infestation rate, with 71.01% of fall armyworm larvae observed before insecticide application. In contrast, the local maize variety had the lowest infestation rate, with 65.93% of larvae recorded **(Table 2)**.

Number of survived larvae per plant

The lowest number of surviving larvae (n = 11) was recorded after the first insecticide application from the plots treated with Agrolambasin super 315, followed by 13 larvae in plots treated with Karate 5% EC on various maize varieties. The highest number of surviving larvae (n = 81) was observed in the control (unsprayed) plots, while the second-highest survival rates were 23 and 17 larvae, which were found in plots treated with malathion 50% EC and dimethoate, respectively. The unsprayed control plants showed severe leaf damage from FAW larvae compared to those treated with synthetic insecticides **(Tables 2, 3)**. These findings align with the results of Osae *et al*. [19].

Table 2. Number of damaged plants per plot, percent of damaged leaves per plant, larva number, and number of survived larvae as influenced by insecticides

Treatments	Variables				
	NDPPP	DLPP	NLPPBS	NSLPP after 1st spray	NSLPP after 1st and 2nd spray
Insecticides					
Agrolambasin supper 315	15.11^{a}	30.93^{a}	68.67^{a}	11.00^{e}	3.00^{e}
Karate 5% EC	15.10^{a}	30.94^{a}	68.66^{a}	13.00^{d}	5.11^{d}
Dimethoate 40% EC	15.10^{a}	30.94^{a}	68.66^{a}	17.00^{c}	7.00^{c}
Malathion 50% EC	15.02^{a}	30.95^{a}	68.65^{a}	23.00^{b}	11.00^{b}
Control	15.12^{a}	30.93^{a}	68.64^{a}	81.00^{a}	89.00^{a}
LSD (0.05)	0.33^{ns}	0.11^{ns}	0.12^{ns}	0.68*	0.53*

SE +	0.07	0.03	0.03	0.14	0.11
Variety					
BH-540	15.21[b]	31.02[b]	69.03[b]	29.00[a]	28.80[a]
BH-546	16.20[a]	32.26[a]	71.01[a]	28.80[a]	23.20[a]
Local	13.86[c]	29.55[c]	65.93[c]	29.20[a]	23.06[a]
LSD (0.05)	0.25**	0.10*	0.01*	0.52[ns]	0.41[ns]
SE +	0.24	0.09	0.09	0.50	0.39
CV (%)	2.30	0.39	0.19	2.44	2.42

Values within a column that share the same letter(s) are not statistically different at the 5% significance level. NDPPP represents the Number of Damaged Plants per Plot, % DLPP refers to the percent of damaged leaves per plant, NLPPBS indicates the number of larvae before spray, NSLPP before the first spray denotes the number of surviving larvae per plot after the first spray, and NSLPP before first and second spray represents the number of surviving larvae per plot after both the first and second sprays. LSD (0.05) refers to the least significant difference at the 5% level, SE+ denotes the standard error, and CV (%) indicates the coefficient of variation in percentage.

Larva mortality percentage

The highest larval mortality rates, 83.82%, and 95.5%, were observed in plots treated with Agrolambasin super 315 after the 1st and 2nd sprays, respectively. Plots treated with karate 5% EC and dimethoate showed mortality rates of 77.95% and 76.10% after the first spray, and 91.13% and 91.10% after the second spray, respectively. The lowest mortality rates, 63.49% and 82.53%, were recorded in plots treated with malathion after the 1st and 2nd sprays. In untreated plots, no larval mortality was observed, aside from a decrease in larvae numbers because of cannibalism and the presence of other natural predators [20].

Table 3. Larva mortality percentage as influenced by insecticides

Treatments	Variables	
	LMPA	**LMPB**
Chemicals		
Agrolambasin supper 315	83.81[a]	95.58[a]
Karate 5% EC	77.95[b]	91.13[b]
Dimethoate 40% EC	76.10[c]	90.10[c]
Malathion 50% EC	63.49[d]	82.53[d]
Control	00[e]	00e
LSD (0.05)	0.83*	0.6*
SE +	0.17	0.12
Variety		
BH-540	60.08[a]	71.84[a]
BH-546	60.23[a]	72.09[a]
Local	60.49[a]	71.90[a]
LSD (0.05)	0.65[ns]	0.46[ns]
SE +	0.61	0.44
CV (%)	1.44	0.87

Effects of variety and insecticide on vegetative parameters

Plant height

The tallest plants (2.18 m) were observed in the BH-546 variety treated with Agrolambasin super 315, followed by plants measuring 2.13 m when the same variety was treated with karate 5% EC. Maize varieties treated with malathion and dimethoate exhibited similar plant heights, both around 1.60 m, for the BH-540 and local varieties **(Table 4)**.

Ear length

The longest ears (18.55 cm) were found on BH-546 variety plants treated with Agrolambasin super 315, with the second longest ears (18.00 cm) observed when the same variety was treated with karate 5% EC. In contrast, the shortest ear length (9.63 centimeters) was recorded in maize varieties that were not treated with insecticides during the FAW infestation **(Table 4)**. This finding is consistent with the results of Young [21].

Plant height

The application of insecticides, maize variety, and their interaction had a significant effect ($P < 0.05$) on plant height. The tallest plants (2.18 meters) were observed in the BH-546 variety treated with Agrolambasin super 315, followed by a height of 2.13 meters in the same variety treated with Karate 5% EC. Maize varieties treated with Malathion and dimethoate exhibited similar heights (1.60 meters) in both BH-540 and the local variety. The shortest height (1.31 meters) was recorded in the untreated control plants **(Table 4)**. These findings indicate that fall armyworm infestation can have an impact on maize plant height [22].

Ear length

The analysis showed that ear length was highly significantly ($P < 0.01$) affected by the type of insecticide applied, maize variety, and their interaction. The longest ears (18.55 cm) were observed in the BH-546 variety treated with Agrolambasin super 315, followed by 18.00 centimeters in the same variety treated with Karate 5% EC. In contrast, the shortest average ear length (9.63 centimeters) was recorded in maize varieties that were not treated with insecticides during the fall armyworm infestation **(Table 4)**.

Table 4. Plant height and ear length as influenced by the interaction effect of insecticides and maize variety

Insecticides	Variables					
	PH (m)			EL (cm)		
	BH-540	BH-546	Local	BH-540	BH-546	Local
Agrolambasin supper 315	1.91^{d}	2.18^{a}	1.81^{e}	17.55^{b}	18.55^{a}	16.55^{c}
Karate 5% EC	1.79^{e}	2.13^{b}	1.69^{f}	17.55^{b}	18.00^{ab}	15.58^{d}
Dimethoate 40% EC	1.60^{g}	2.00^{c}	1.60^{g}	16.60^{c}	17.41^{b}	16.41^{c}
Malathion 50% EC	1.60^{g}	1.88^{d}	1.61^{g}	14.48^{e}	16.50^{c}	13.86^{f}
Control	1.31^{h}	1.31^{h}	1.31^{h}	9.63^{h}	10.30^{g}	9.86^{gh}
LSD (0.05)		0.05*			0.63*	
SE ±		0.04			0.01	
CV (%)		1.70			2.36	

Means in the column followed by the same letter (s) are not significantly different at a 5% level of significance. PH = Plant Height, EL = Ear Length, LSD (0.05) = Least significant difference at 5% level SE ± standard errors, and CV = coefficient of variation in percent.

Effects of variety and insecticide on yield parameters

Aboveground dry biomass (ton/hectare)

The highest above-ground dry biomass (16.50 t/ha) was observed in maize plants treated with Agrolambasin super 315. In comparison, the use of Karate 5% EC, dimethoate, and malathion insecticides resulted in significantly different biomass yields of 16.16, 15.38, and 15.05 t/ha, respectively **(Table 5)**.

Thousand kernels weight

The greatest thousand-kernel weight (292.59 g) was observed in maize crops treated with Agrolambasin super 315 on fall armyworm-affected plots. The second-highest weight (290.80 g) was recorded in plots treated with Lambda-cyhalothrin insecticide. The lowest thousand-kernel weight (285.5 g) was found in maize varieties that were not treated with any insecticide for fall armyworm control **(Table 5)**.

Table 5. Biomass yield and thousand kernels weight as influenced by insecticides and maize variety

Treatments	Variables	
	Biomass yield (t/ha)	Thousand kernel weight (gram)
Insecticides		
Agrolambasin supper 315	16.50[a]	292.59[a]
Karate 5% EC	16.16[b]	290.80[b]
Dimethoate 40% EC	15.38[c]	289.77[c]
Malathion 50% EC	15.05[d]	289.25[c]
Control	9.18[e]	285.51[d]
LSD (0.05)	0.26**	0.68*
SE±	0.05	0.18
Variety		
BH-540	14.44[ab]	291.04[b]
BH-546	14.62[a]	298.11[a]
Local	14.29[b]	288.60[b]
LSD (0.05)	0.2*	0.52*
SE ±	0.01	0.51
CV (%)	1.85	0.24

Grain yield (ton/hectare)

The highest grain yield (5.90 tons per hectare) was achieved with Agrolambasin supper 315 treatment on the BH-546 maize variety, which was 2% greater than the yield from the same treatment on the BH-540 variety (5.78 tons per hectare). When Karate 5% EC insecticide was applied to both BH-546 and BH-540 varieties, similar yields of 5.50 and 5.46 tons per hectare were recorded. For Dimethoate treatment, the grain yields for BH-540, BH-546, and the Local variety were 5.18, 5.21, and 5.02 tons per hectare, respectively **(Table 6)**.

Harvest index (%)

The highest harvest index, recorded at 35.41% for the local variety and 35.21% for BH-546, was achieved with Agrolambasin supper 315 treatment on fall armyworm-infested maize. In contrast, the application of Karate 5% EC and Dimethoate on BH-546 and BH-540 varieties produced statistically similar harvest index values in FAW-affected maize crops **(Table 6)**.

Table 6. Grain Yield and Harvest Index as influenced by the interaction effect of insecticides and Maize variety

Insecticides	Variables					
	Grain yield (t/ha)			Harvest index (%)		
	BH-540	BH-546	Local	BH-540	BH-546	Local
Agrolambasin supper 315	5.78[ab]	5.90[a]	5.72[b]	34.88[ab]	35.21[a]	35.41[a]
Karate 5% EC	5.46[c]	5.50[c]	5.32[d]	33.99[bc]	33.95[bc]	32.88[cd]
Dimethoate 40% EC	5.18[e]	5.21[de]	5.02[f]	33.66[bc]	33.59[c]	32.93[cd]
Malathion 50% EC	4.14[g]	4.92[f]	4.03[g]	27.67[e]	31.78[d]	27.52[e]
Control	2.92[h]	2.91[h]	2.93[h]	31.99[d]	31.77[d]	31.95[d]
LSD (0.05)		0.123*			1.24*	

SE±	0.04	0.19
CV (%)	1.56	2.28

Correlation analyses among agronomic parameters of maize

The analysis revealed significant correlations between various pest-related factors and yield components of maize, as shown in the correlation matrix **(Table 7)**. A strong positive relationship was observed between larval mortality percentage and the number of surviving larvae, with correlation values of r = 0.99 and 0.98 after the 1st and 2nd applications, respectively. Additionally, a significant positive correlation (r = 0.78*) was found between larval mortality and plant height, indicating that the absence of pesticide treatment could lead to significant reductions in maize plant height due to FAW larvae. The number of surviving larvae (r = 0.92) and larval mortality (r = 0.94) also showed a highly significant positive correlation with grain yield. Furthermore, plant height (r = 0.85), number of ears per plant (r = 0.71), ear length (r = 0.96), biomass yield (r = 0.87), and thousand kernel weight (r = 0.29) all exhibited strong correlations with grain yield, with increases in these parameters linked to higher grain yield **(Table 7)**.

Table 7. Simple correlation analyses among pest, growth, yield, and yield component parameters

	NDPPP	NDLPP	NLPPBS	NSLPPASA	NSLPPSB	LMPA	LMPB	NGLPP	PH	NEPP	EL	GY	BY	TKW
NDPPP	1													
NDLPP	0.94**	1												
NLPPBS	0.95**	0.99***	1											
NSLPPASA	0.03^{NS}	0.04^{NS}	0.01^{NS}	1										
NSLPPSB	0.01^{NS}	0.04^{NS}	0.03^{NS}	0.99**	1									
LMPA	0.01^{NS}	0.06^{NS}	0.06^{NS}	0.99*	0.98**	1								
LMPM	0.00^{NS}	0.01^{NS}	0.05^{NS}	0.99*	0.99*	0.99*	1							
NGLPP	0.15^{NS}	0.14^{NS}	0.14^{NS}	0.38**	0.39**	0.37*	0.39**	1						
PH	0.40**	0.43**	0.42^{NS}	0.79*	0.77*	0.79*	0.78*	0.40**	1					

NFPP	0.36^{**}	0.38^{**}	0.36^{*}	0.61^{*}	0.59^{*}	0.62^{*}	0.60^{*}	0.41^{**}	0.79^{**}	1					
FL	0.22^{NS}	0.23^{NS}	0.23^{NS}	0.94^{*}	0.92^{*}	0.94^{*}	0.93^{*}	0.35^{*}	0.89^{**}	0.93^{**}	1				
GY	0.10^{NS}	0.10^{NS}	0.10^{NS}	0.92^{*}	0.89^{*}	0.94^{***}	0.91^{*}	0.30^{*}	0.85^{**}	0.71^{**}	0.96^{**}	1			
BY	0.02^{NS}	0.04^{NS}	0.05^{NS}	0.99^{*}	0.98^{*}	0.48^{***}	0.98^{*}	0.39^{**}	0.82^{**}	0.65^{**}	0.95^{*}	0.93^{*}	1		
TKW	0.33^{NS}	0.36^{*}	0.35^{*}	0.81^{*}	0.79^{*}	0.82^{***}	0.80^{*}	0.38^{**}	0.92^{**}	0.75^{*}	0.87^{*}	0.87^{**}	0.84^{**}	1	
HI	0.24^{NS}	0.19^{NS}	0.19^{NS}	0.27^{*}	0.21^{NS}	0.33^{*}	0.25^{*}	0.03^{NS}	0.47^{**}	0.46^{*}	0.48^{*}	0.60^{**}	0.29^{***}	0.47^{*}	

Conclusion

Maize (*Zea mays* L.) is one of the oldest cultivated grains and the leading crop in terms of productivity among cereals. In tropical regions, the fall armyworm is a primary pest of maize. A survey of 1,006 farmers in maize fields found that approximately 72.92% had been affected by fall armyworm, a notable increase compared to the 2019 growing season.

The experimental data indicate that both maize variety and pesticide use significantly influence various aspects of the crop, including vegetative growth, pest management, and yield. The BH-546 variety, when treated with Agrolambasin supper 315, displayed the highest plant height, ear length, grain yield, and harvest index. Similarly, this treatment resulted in the highest biomass yield and thousand kernel weight for the BH-546 variety. In contrast, control plots, which received no pesticide treatment, showed the lowest values for all measured parameters, including plant height, ear length, biomass, thousand kernel weight, grain yield, and harvest index. Although this study found that the fall armyworm caused significant damage to all maize varieties during the peak growing season, the use of improved cultivars in combination with Agrolambasin supper 315 insecticide application proved effective in reducing yield loss. Therefore, integrating this pest control strategy into broader pest management programs is recommended.

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