MEKELLE UNIVERSITY

Effect of Integrating Maize Varieties and Insecticides against Fall Armyworm (*Spodoptera frugiperda,* J.E. Smith) (Lepidoptera: Noctuidae) in Central Tigray, Ethiopia

By

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DECLARATION AND APPROVAL

I **Fisseha Amaha Gebreslasea** declare that, this thesis is my work and that all sources of material used for the thesis have been properly acknowledged. This thesis is entitled, **'Effect of Integrating maize varieties with Insecticides against Fall Armyworm (*Spodoptera frugiperda*, JE Smith) in Central Tigray, Ethiopia'** for consideration by the Department of Plant and Horticultural Sciences within the College of Dryland Agriculture and Natural Resources at Mekelle University, my thesis in partial fulfillment of the requirements for the degree of Master of Science in Plant Protection (Agricultural Entomology).

I sincerely declare that this thesis is the product of my effort. No other person has published a similar study that I might have copied, and at no stage will this be published without my agreement and that of the Department of Plant and Horticultural Sciences.

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BIOLOGICAL SKETCH

The Author, **Fisseha Amaha Gebreslasea** was born in March 1998 in the rural village of Tanqua Mlash, Central Tigray, Ethiopia. He is the first son of his parents. He began his elementary education at Addisera in 2004 and completed it in 2012. He then attended Agbe-Sele Secondary School from 2012 to 2014, where he successfully passed the Ethiopian General Secondary Education Certificate Examination (EGSECE). Following this, he enrolled at Meles Zenawi Preparatory School from 2014 to 2016, where he excelled in the Ethiopian University Entrance Examination Certificate (EUEEC).

In 2016, Fisseha joined Aksum University, where he pursued a three-year Bachelor of Science (BSc) degree in Plant Science. He graduated with honors in 2019, earning the prestigious title of Gold Medalist for his outstanding academic achievements at Aksum University. Immediately after graduation, he began serving as a Graduate Assistant in the Department of Plant Science at Aksum University.

In 2020/2021, Fisseha advanced his academic journey by enrolling in a Master of Science (MSc) program in Plant Protection, specializing in Agricultural Entomology, at Mekelle University. This program is offered under the Department of Plant and Horticultural Sciences. Fisseha’s academic and professional trajectory demonstrates his passion for plant sciences, exceptional academic performance, and dedication to advancing knowledge in agricultural entomology and plant protection.

DEDICATION

This thesis is dedicated to my beloved little brother, **Dawit Amaha** a life stolen not by fate, but by the brutality of war and the deliberate siege that denied him life-saving medicine. His death was not an accident; it was a crime. In the darkest days of the Tigray siege, when hospitals were looted, pharmacies emptied, and humanitarian aid weaponized, you became one of countless victims of a man-made medical catastrophe. Rabies, a disease with well-established prevention and treatment protocols, claimed your young life simply because those in power decided that medicine was a privilege, not a right.

You were just a child full of curiosity, joy, and boundless potential. You deserved to grow, to learn, to thrive. Instead, you suffered needlessly, abandoned by a world that looked away as an entire region was suffocated by blockade and violence. **Dawit**, your life was a promise one that was crushed under the boots of tyranny and global indifference. But your story does not end here.

I carry you with me in my rage, in my grief, and in my unshakable determination to speak your truth. This thesis is more than academic work; it is my act of defiance, my testimony against the forces that took you. I will never stop fighting for justice for you, for the same victims, and for Tigray.

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Above all, I give all glory and praise to God Almighty, whose divine grace and providence sustained me through every trial and triumph.

LIST OF ABBREVIATIONS AND ACRONYMS

BOARD	Bureau of Agriculture and Rural Development
CD	Critical difference
CSA	Central Statistical Agency
DAS	Days After Spraying
EC	Emulsifiable Concentrate
EIAR	Ethiopian Institute of Agricultural Research
FAOSTAT	Food and Agriculture Organization United Nations Statistical Database
FAW	Fall Armyworm
HSD	Honest Significance Difference
MARC	Melkasa Agriculture Research Centre
SC	Suspension Concentrate
CZH	International Maize and Wheat Improvement Center Zimbabwe hybrid
BH	Bako hybrids

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ABSTRACT

Fall armyworm (Spodoptera frugiperda) is the most devastating insect causing economic losses of maize production and productivity particularly in tropical and subtropical. A field experiment was conducted in 2024 under irrigated conditions to determine the integrated effect of insecticides with maize varieties against naturally occurring fall armyworm infestations. A randomized complete block design with two factors and three replications was used. The first factor included two improved maize varieties (Melkassa-2 and Melkassa-4), and one local variety (Berihu) while the second factor comprised four synthetic insecticides (Chlorfenapyr + Spinosad, Chlorfenapyr, Acetamiprid + Abamectin, Imidacloprid) and one control (water spraying) spraying three times. Data collected includes fall armyworm (FAW) larvae and egg masses count, plant damage, yield, and yield-related attributes analyzed with the Genstat software version 18. The result revealed that all the treatments significantly ($p < 0.05$) affected the FAW population, plant damage, and grain yield compared to the control. The highest larvae mortality (94.74%), lowest leaf incidence (4%), lowest leaf severity (0.993), lowest ear damage(1.667), highest ear length (23.23 cm), highest grain yield (5166 kg ha^{-1}), highest avoidable yield loss (42.35%), and highest Marginal return rate (39071.6%) were obtained from Melkassa -2 treated with Spinosad +Chlorfenapyr, while the untreated Berihu variety showed the lowest larvae mortality (-44.55%), lowest egg masses (1.778), highest leaf incidence (98%), highest leaf severity (8.067), highest ear damage (8.133), shortest ear length (8.9cm) and lowest grain yield (1935 kg ha^{-1}). Furthermore, Melkassa-2 showed the lowest leaf incidence, leaf, tassel, and ear severity, highest larval mortality, highest grain yield, and highest yield loss in comparison to the tested varieties. The minimum days required for tasselling (61.5), silking (65), maturity (99.2), highest plant height (186.4), and egg masses (3.889) were recorded from Spinosad +chlofenapyr insecticide. In conclusion, the highest FAW larvae mortality rate, lowest plant damage, uppermost MRR, lowest yield loss, and grain yield were found when the Melkassa-2 variety was treated with Spinosad+ Chlorfenapyr followed by Chlorfenapyr alone. Thus, it can be recommended that farmers use the integration of the tolerant maize (Melkassa-2) variety with selective insecticides (Spinosad+chlorfenapyr) to reduce the fall armyworm damage thereby enhancing maize productivity.

Keywords: fall armyworm, Insecticides, Maize varieties, integration, Marginal return rate

1. INTRODUCTION

1.1. Background

Maize (*Zea mays* L.) is the third major cereal crop, extensively consumed after rice and wheat and grown in subtropical and tropical regions of the world (Sangle et al., 2020). It is known as the queen of cereals because of its highest genetic yield potential. Every part of the maize plant has economic value (the grain, leaves, stalk, tassel, and cob), and all are used to produce a large variety of food and non-food products (Sravani et al., 2021). It serves as a crucial source of calories, protein, vitamins, and minerals for billions of people. It provides food, feed, and industrial products, particularly in Africa, South America, and Asia (Grote et al., 2021). It is cultivated in nearly 208.234 m ha with a production of 124.156 million tons and productivity of 5962.3 kg ha^{-1} all over the world (FAOSTAT, 2023).

In Ethiopia, cereals accounted for 81 percent of total grain production, with maize sharing 35 percent of cereals production, followed by wheat, teff, and sorghum at 19, 18, and 15 percent, respectively (CSA, 2021). During the 2023/2024 main cropping season, maize production covered 2.55 million hectares of land, resulting in a total production of 10 million tons and a productivity of 3921.6 kg ha^{-1} (FAOSTAT, 2023). While the current maize production and productivity are below their potential, they still exceed those of other major cereal crops. The lower yield is attributed to various biotic and abiotic constraints, primarily the lack of improved production technologies such as pest management practices, moisture stress, low fertility, and poor cultural practices (Hirpa & Bulto, 2016). Similarly, Lobulu et al. (2019) also highlighted those farmers identified several key challenges affecting maize production, with drought being the most significant (97.2%), followed by Striga infestation (93.1%), field insect pests (90.1%), and storage pests (72.7%). Additionally, Singh & Jaglan (2018) noted that insect and pest infestations are among the critical factors leading to reduced maize yields, with approximately 20–25 major insect pests contributing to this issue.

Fall armyworm (FAW) is a highly destructive insect pest of cereals, native to tropical and subtropical regions of the Americas (Kenis et al., 2022). It is a migratory insect pest known to cause serious damage to maize crops under warm and humid conditions in the Americas (Aguirre et al., 2016). The moths' ability to fly up to 100km, their diverse host range, and their lack of diapause make it difficult to control, manage, or eradicate FAW (Anjorin et al., 2022). The larval stage is the most devastating stage of the insect, feeding on 353 species of host plants (Montezano et al., 2018). It feeds on the leaves, stems, and reproductive parts of the maize plants (Tendeng et al., 2019). This insect pest spreads quickly over the continent because it tends to attack a wide range of crops, its ability to produce many eggs, and its preferred major cereal crops, maize (De Groote et al., 2020). Currently, it is distributed to different African countries. Ethiopia is one of the countries that recently confirmed the presence of FAW in 2017 (Assefa &Ayalew, 2018).

The fall armyworm (FAW) has emerged as a major threat to global maize production, with estimated economic losses reaching up to 73% in severe cases, particularly in developing countries (Kenis et al., 2022). In Africa, FAW causes annual yield losses of 9 to 21 million tons enough maize to feed 41 to 101 million people per year (Prasanna, Carvajal-Yepes, et al., 2022) Its impact is especially acute in 12 key maize-producing African nations, where it may reduce annual production by 21–53%, leading to economic losses of US $2.48 to US$6.19 billion (Tambo et al., 2020).

In Ethiopia, the pest has caused an average annual reduction of 36% in maize production and 47% yield loss, equivalent to 0.67 million tons of maize lost between 2017 and 2019. This has led to an economic loss of US$200 million, accounting for 0.08% of the country's GDP (Abro et al., 2021). Recently the BoARD (2023) indicates that FAW has infested nearly all maize and sorghum-growing areas in Tigray, with nine weredas and 54 Tabias (the smallest administrative units) being the most severely affected (unpublished data). Approximately 10,594.8 hectares were impacted, and 2,774.5 liters of chemical Insecticides were used for control efforts irrespective of selectivity and group of insecticides (BoARD, 2023). As a result, Synthetic insecticides remain the primary method for managing FAW, despite limited evidence of their efficacy (Kalyebi et al., 2023). Commonly used insecticides in Ethiopia and other African countries include organophosphates, carbamates, and pyrethroids (Muraro et al., 2021). However, the frequent application of non-selective synthetic insecticides has led to several challenges, including insecticide resistance development, increased production costs, reduced agrobiodiversity, and health risks for farmers and consumers (Ahissou et al., 2021; Safdar et al., 2022). In some cases, farmers have resorted to using highly toxic chemicals and applying lower-than-recommended doses, which can also accelerate resistance development in FAW populations (Otim et al., 2021). To address these issues, newer classes of insecticides, such as diamides, avermectins, spinosyns, neonicotinoids, and benzylureas, have been recommended for FAW control in other regions (Deshmukh et al., 2020).

Host plant resistance is a critical component of integrated pest management (IPM) for controlling fall armyworms (Prasanna et al., 2018). Many efforts are underway to screen maize lines, hybrids, and open-pollinated varieties under artificial or natural FAW infestations to identify and develop cultivars with tolerance to FAW damage (Prasanna et al., 2022; Getu et al., 2024a). Similarly, Amegbor et al.(2025) revealed that significant differences were observed among the hybrids, with the FAW-tolerant hybrids showing reduced leaf and ear damage compared to the commercial hybrid and exhibiting high grain yield performance.

1.2. Statement of the Problem

The productivity of maize, the most important staple crop in Ethiopia, falls below its potential due to various biotic and abiotic factors that negatively impact yield (Hirpa & Bulto, 2016). Among the biotic factors, the fall armyworm (FAW) insect pest has emerged as a significant threat since its introduction to Ethiopia in 2017 (FAO, 2018). Managing fall armyworm infestation is particularly challenging due to the pest's characteristics, including its high reproductive capacity, a wide range of host plants, short life cycle, and rapid development of resistance to insecticides, causing extensive damage to maize crops (Kumela et al., 2019).

It has rapidly spread across all maize-growing regions, leading to severe damage ranging from 20% to 100% in smallholder farmers' fields (Kumela et al., 2019). In Ethiopia, the pest has caused an average annual reduction of 36% in maize production and 47% yield loss (Kumela et al., 2019; Abro et al.,2021). Due to that, different control measures, such as cultural practices, biological control, host plant resistance, bio-pesticides, habitat modification, and the use of insecticides, are necessary to address the challenge posed by fall armyworms.

Despite the lack of a fully effective single control method for fall armyworm (FAW) (Guo et al., 2020), synthetic insecticides remain the most widely used approach in many countries, despite their harmful effects on non-target organisms and the environment (Bhusal & Chapagain, 2020). due to residues and resistance problems associated with the older groups of synthetic insecticides, more environmentally sound and less hazardous insecticides that belong to diamides, avermectins, spinosyns, neonicotinoids, pyrroles, and benzylureas are recommended for fall armyworm management in other parts of the world (Deshmukh et al., 2020). These newer generation and more effective insecticides have not been tested for fall armyworm management in Ethiopia.

In addition to insecticides, integrating host-plant resistance as part of an Integrated pest Management strategy is a viable option. This approach provides an environmentally friendly and cost-effective alternative by reducing reliance on insecticides, as observed in developed countries where they can be used with hybrid and open-pollinated varieties (Soujanya et al., 2025). Currently, various international research centers and national research programs are actively screening maize inbred lines, pre-commercial and commercial hybrids, and improved open-pollinated varieties under artificial or natural fall armyworm infestation to develop resistant or tolerant cultivars (Prasanna et al., 2022; Kasoma et al., 2020). Although limited research has been conducted on host-plant resistance for FAW control in Ethiopia, smallholder farmers have observed that improved maize varieties are relatively less susceptible to FAW compared to local varieties. However, there is still a significant gap in integrating host plant resistance with the newest synthetic insecticides for FAW control in Ethiopia.

Therefore, this study aims to determine the best management option for fall armyworm infestation in maize crops by integrating the use of improved maize varieties with the newest classes of synthetic insecticides under field conditions. The findings and recommendations of this study will provide farmers with effective, environmentally friendly, and economically viable strategies to combat fall armyworm and safeguard maize production and productivity in Ethiopia.

1.3. Objectives

1.3.1. General objective

- To determine the integrated effect of maize varieties and synthetic insecticides on fall armyworm infestations, growth, yield, and yield components of maize.

1.3.2. Specific objectives

- To determine the efficacy of synthetic insecticides on fall armyworm infestation, and growth, yield, and yield components of maize.
- To evaluate the maize varieties against fall armyworm damage
- To investigate the economic feasibility of using varieties and synthetic insecticides for the management of fall armyworms.

2. LITERATURE REVIEW

2.1. Origin and Importance of Maize

Maize (*Zea mays* L.) belongs to the family Poaceae and originated in Mexico and Central America (Moustafa, 2024). It is one of the most widely cultivated cereal crops, holding the third position in global importance after wheat and rice. It serves as a critical source of nutrition for both humans and livestock (Shavanov, 2021). Maize contributes significantly to meeting dietary needs, providing approximately 15% of protein requirements and 19% of calorie intake from plant-based sources, But also, In developing countries, maize is particularly vital as a primary source of dietary protein, helping to meet the nutritional needs of millions of people worldwide (Hossain et al., 2019). Additionally, it is a key source of calories. Populations facing protein and essential amino acid deficiencies rely on maize for 17–60% of their daily protein intake (Muleya et al., 2022). In Ethiopia, maize is the second most cultivated cereal crop and the top crop in total production. It is vital for food, feed, and poultry industries, and a key income source, particularly during the fresh grain stage (Yadesa & Diro, 2023). Approximately 88% of the maize produced in Ethiopia is consumed as food, either as green or dry grain. It is a key source of calories and is prepared in various forms, such as bread, injera, porridge, boiled or roasted maize, and traditional drinks (Abate et al., 2015).

2.2. Production and constraints of maize

Maize (*Zea mays* L.) is the third major cereal crop extensively cultivated in nearly 208.234 million ha with a production of 124.156 million tons and productivity of 5962.3 kg/ha all over the world (FAOSTAT, 2023). Maize cultivation spans both emerging economies and the developed world including 166 countries distributed across the Americas, Asia, Europe, and Africa (FAOSTAT, 2023). The global maize area is primarily located in the Americas and Asia, with over a third each, followed by Africa with a fifth and Europe with a tenth. Maize also shows marked yield differences between regions. The Americas thus contribute half of the global maize production, followed by a third in Asia (32%) and the remainder primarily by Europe (11%) and Africa (7.4 %) (FAOSTAT, 2023).

Ethiopia has the fifth-largest area dedicated to maize cultivation, but it has the second-highest yields after South Africa and the third-largest production area behind South Africa and Nigeria in Sub-Saharan African countries. Not only is it abundantly produced, but it is also the highest-yielding cereal in Ethiopia, ranking first in productivity per hectare, 3.9 tonnes, accounting for 35 percent of cereal production and second in the production area, 2.55 million ha, with a production of 10 million tons (FAOSTAT, 2023). Regionally, maize is mostly grown in the southwestern and western parts of Oromia (56%), western and northwestern parts of Amhara (25%), parts of the Southern Nations, Nationalities, and Peoples' Region (14%), and Benshangul-Gumuz regions (2.4%) and Tigray (2%). Furthermore, Tigray covered 80,151 ha with annual production and productivity of 0.25 million tons and 3.075 tons per ha, respectively (CSA, 2021).

The lower maize yield is primarily due to a combination of biotic and abiotic challenges, including the lack of improved production technologies such as effective pest management practices, moisture stress, poor soil fertility, and inadequate farming techniques (Hirpa & Bulto, 2016). Farmers have identified several major constraints affecting maize production, with drought being the most critical (97.2%), followed by Striga infestation (93.1%), field insect pests (90.1%), and storage pests (72.7%) (Lobulu et al., 2019). Furthermore, Singh and Jaglan (2018) emphasized that insect pest infestations are significant contributors to reduced maize yields, with around 20–25 major insect pests playing a key role in this decline. Among the insect pests, FAW is one of the major insect pests causing substantial yield losses of maize. This is a polyphagous pest causing economic damage through the cost of insecticide and direct eating of maize crops (Day et al., 2017).

2.3. Origin, Distribution, and Status of Fall Armyworm

Fall armyworm (*Spodoptera frugiperda*) is native to the tropical and subtropical regions of the Americas (Bateman et al., 2018). It has also been reported in parts of Europe and the Mediterranean (Aleem et al., 2023). Its distribution is largely influenced by climatic conditions, including temperature and rainfall, with warmer regions being more susceptible to infestations (Goergen et al., 2016; Early et al., 2018). It was first identified on the African continent in 2016 (Goergen et al., 2016; Harrison et al., 2019). Shortly after, outbreaks were reported in West and Central Africa, and by February 2017, the pest had spread to Ethiopia, Tanzania, and Zimbabwe (Midega et al., 2018). The pest's expansion within individual countries and across Africa occurred rapidly. For example, in Ethiopia, infestations were initially reported in the Southern Nations Nationalities and Peoples' States in March 2017 and quickly spread to all regions, becoming an epidemic by June 2017. This means the pest had reached every state of the country within just three to four months (Gebreziher, 2020). It was distributed to 144 districts in six of the main regional states that grow maize namely Benishangul Gumuz, Amhara, Tigray, Gambella, Oromia, and SNNPs and 5230 hectares in Tigray regions have been affected by the armyworm (Assefa & Ayalew, 2019).

2.4. Biology and Morphology of Fall Armyworm

The life cycle of Fall armyworm consists of four developmental stages: egg, larva, pupa, and adult (Badhai et al., 2020; Sagar et al., 2020).

Egg: The eggs of the Fall armyworm are creamy white, dome-shaped, and measure 0.3 mm in height and 0.4 mm in diameter, as described by. Initially light green, they change to golden yellow and then to black before hatching (Deshmukh et al. 2021). The ideal temperature for egg laying is 20–30°C. The eggs are laid in clusters on the underside of leaves near the plant base, leaf junctions, or in whorls (Deshmukh et al. 2021). A female typically lays 100–200 eggs in a mass (Assefa & Ayalew, 2019), and can lay up to 1,500 eggs, with a maximum of 2,000 during her lifetime (Zhang et al., 2021). Most eggs are laid within 4–9 days of female emergence, and the egg stage lasts 2–3 days in summer (20–30°C) (Badhai et al., 2020).

Larva: The larva displays distinct characteristics, including a Y-shaped white stripe on its head and four large, squared black dots. Additionally, three yellow stripes can be observed on the upper part of the larvae. When fully mature, the larva measures between 38 and 51 mm in length (Safder et al., 2024; Badhai et al., 2020). The larva undergoes six different instars, with its color changing from one instar to the next (Deshmukh et al., 2021). Assefa & Ayalew (2019) described the first larval instar, which exhibits a green color with a black head. In the second instar, the color shifts to a greenish-brown hue. From the third instar onwards, the larvae adopt a brown coloration with three lines on their lateral and dorsal sides. The larval stage is the period during which the most damage occurs, as the larvae feed on all developmental stages of the plant (Badhai et al., 2020). and the larva Cannibalism behavior among the larvae is crucial for their survival and successful colonization of new low-nutrient plants (He et al., 2022). The larval stage typically lasts for 14 to 18 days, which can vary depending on the temperature and the host plant. The optimal temperature range for larval development is found to be between 20°C and 30°C, with the lowest mortality and fastest development occurring at a temperature of 30°C (Du Plessis et al., 2020).

Pupa: After reaching full growth, the larvae burrow into the soil and use silk threads to combine the soil particles, creating a cocoon. This cocoon serves as a protective covering during the pupal stage and is typically formed within a depth of 2 to 8 cm in the soil (Day et al., 2017). The pupa itself is oval-shaped and has a reddish-brown coloration (Day et al., 2017). It measures approximately 4.5 mm in width and has a length ranging from 14 to 18 mm (Igyuve et al., 2018). The pupal stage's duration varies depending on the season, with a longer period of 20 to 30 days during winter and a shorter period of 8 to 9 days during summer (Badhai et al., 2020). In cases where the soil is too hard for the larvae to penetrate, they may instead cover themselves with leaf debris for protection (Sharanabasappa et al., 2018).

Adult: The adult form of the insect exhibits several distinct characteristics. In adult males, the forewings are shaded with gray and brown, featuring a triangular bright spot on the apical region. On the other hand, adult females have uniformly greyish-brown forewings. Both males and females have hindwings that are predominantly white with narrow dark borders (Badhai et al., 2020). The wingspan of the adult insect measures approximately 3.2 cm (Sharanabasappa et al., 2018). The adult stage has a lifespan of 9 to 12 days, and the pest completes its life cycle in approximately 30 days during summer and 60 to 90 days during winter when feeding on maize (Deshmukh et al., 2021).

2.5. Host Plants

The fall armyworm is recognized as a destructive global pest, as it is highly polyphagous and can damage approximately 353 host plant species in 76 plant families, especially Poaceae, Fabaceae, and Asteraceae families (Chen et al., 2021). It has evolved into two distinct strains, the C-strain and the R-strain, which are morphologically indistinguishable but exhibit differences in host preferences, mating behaviors, and genetic makeup (Dumas et al., 2015). The C-strain primarily feeds on maize, cotton, and sorghum, but the maize crop is the most preferred host plant (Chimweta et al., 2020b), whereas the R-strain mainly consumes rice and pasture grasses (Dumas et al., 2015). In addition, the pest causes economic damage to wheat, potato, rice, bean, soybean, barley, tomato, lettuce, chickpea, sunflower, millet, cotton, sugarcane, and other crops (Montezano et al., 2018)

2.6. Ecology and Behavioral Pattern of Fall Armyworm

The fall armyworm thrives in humid and warm conditions, which are facilitated by heavy rainfall, as it is crucial for its reproduction and survival (Sagar et al., 2020). However, its development is halted below 10°C and above 33°C, and it cannot endure prolonged cold conditions (Assefa &Ayalew, 2019). The availability of host plants throughout the year, combined with the long-distance migration of fall armyworms, creates a favorable environment for their survival and widespread dispersal (Edosa & Dinka, 2021). To ensure its survival, the fall armyworm is believed to migrate to warmer and moister regions during winter, where host plants are available for overwintering. Environmental conditions play a significant role in the development, distribution, infestation, mortality, and generation numbers of fall armyworms (Sagar et al., 2020). The pest can rapidly spread over distances of more than 500 km using wind currents, while adult pests can travel up to 1,600 km under favorable wind conditions (Badhai et al., 2020; Ge et al., 2021). The neonates disperse between plants through ballooning, while the mature larvae move by crawling. This ability to relocate to uninfested plants is crucial, as larval cannibalism often limits survival, with typically just one or two individuals per plant reaching pupation (Sokame et al., 2020).

High infestation of fall armyworms is typically observed between November and February when maize plants are still in the early stages of growth. Field studies have indicated that the dry season is characterized by a high incidence of pest infestation (Caniço et al., 2021). In Ethiopia, two distinct peaks of fall armyworm infestation have been observed. The first peak occurs in July and August, coinciding with the initiation of the growing phase of the season, while the second peak is observed in February and March, corresponding to the harvest period (Assefa & Ayalew,2019; Niassy et al., 2021).

2.7. Damage and Symptoms

The larvae of the Fall armyworm consume a significant amount of green plant tissue, resulting in characteristic window-pane-like damage on the leaves (Badhai et al., 2020). During the early larval stages, they may feed on one side of a leaf, but larger instars create holes in the leaves (Assefa &Ayalew, 2019). The larvae show the fastest developmental rate when feeding on corn kernels (Badhai et al., 2020). They primarily feed on tender tips, burrow into the stem base, and cause damage to the young leaf whorls, ears, and tassels of maize, leading to reduced yield or complete crop loss (Montezano et al., 2018). In severe cases, the growth of the crop can be stunted, failing to form tassels or cobs. At an advanced stage of damage, the fecal matter of Fall armyworm resembles sawdust and can be found in the funnel or on the leaves of maize (Badhai et al., 2020). The early instars enter the maize cob through the silk, while larger instars bore through the husk and feed on the maize kernels (Deshmukh et al., 2021). Fall armyworms can attack the maize crop at any developmental stage (Tambo et al., 2020). Significant damage occurs when the leaf whorl is destroyed, and feeding by the pest on young plants can destroy the growing point, and prevent cob formation (Day et al., 2017).

2.8. Economic Importance

The fall armyworm is considered economically significant due to its high feeding rate (Chen et al., 2021). This pest causes substantial damage in developing countries where there is limited awareness, research, resources, expertise, and technical support for effective pest management. It affects a wide range of economically important crops such as maize, sorghum, rice, cotton, and vegetables, thereby posing a threat to global food security (Bateman et al., 2021). In the absence of adequate control methods, fall armyworms can damage 100% of maize plants, causing grain yield reductions of up to 73% globally (Yaméogo et al., 2024). Annual yield losses caused by FAW range from 15% to 73%, resulting in economic losses of up to US$9.4 billion in Africa alone (Woolfolk et al., 2025). In 2017 alone, it is estimated that Fall armyworm caused an economic loss of three billion USD in Africa (Day et al., 2017). In twelve African countries, fall armyworms have resulted in annual yield losses of 9 to 21 million tons of maize, which could have fed 41 to 101 million people (Prasanna et al., 2018). It has been projected that Fall armyworm causes losses in maize, sorghum, rice, and sugarcane in sub-Saharan Africa amounting to US$ 13 billion annually, posing significant challenges to the livelihoods of millions of farmers (Harrison et al., 2019).

In Ethiopia, the pest has caused an average annual reduction of 36% in maize production and 47% yield loss (Abro et al., 2021). It poses a significant risk for 9.6 million maize-producing smallholders, resulting in a loss of more than 134,000 tons of maize production losses almost $30 million, and one ton of maize loss per hectare (Kumela et al., 2019; Demis & Jemal, 2024)

2.9. Fall Armyworm Management Options

2.9.1. Cultural methods

Cultural methods play a significant role in minimizing crop losses caused by Fall armyworm (Sagar et al., 2020) and are a key component of integrated pest management (IPM) for this pest (Gebreziher, 2020). Intercropping has been found to have lower pest infestation rates compared to monocropping, resulting in a 30% reduction in pest damage (Houngbo et al., 2020). Ahissou et al. (2021) demonstrated that intercropping maize with legumes effectively suppresses the pest. Cultural control methods also include practices such as early planting to avoid periods of high pest populations and early harvesting to allow maize ears to escape severe Fall armyworm infestations later in the growing season (Harrison et al., 2019). Planting early or using early-maturing cultivars is effective in suppressing Fall armyworms, as higher pest densities tend to occur later in the growing season (Prasanna et al., 2018).

However, the timing of planting significantly affects the level of pest damage, as it needs to be synchronized with the insect's life cycle and host plant (Ahissou et al., 2021). Other cultural methods include handpicking larvae and spraying maize whorls with ash (Badhai et al., 2020; Niassy et al., 2021). Clean plant residues and proper fertilizer use have also been found to reduce ear damage by Fall armyworms (Sagar et al., 2020). Additionally, stubble burning in affected areas can kill unhatched pest stages (Assefa, 2018). Deep ploughing of the soil exposes larvae and pupae to the surface, while frequent weeding helps reduce the pest population (Assefa, 2018; Baudron et al., 2019).

2.9.2. Push-pull technology

The push-pull tactic is a pest management approach that involves using specific plants to repel or attract pests. In the case of fall armyworm control, maize is intercropped with silver-leaf or green-leaf desmodium, which repel the pest, along with Napier, Sudan, or Molasses grasses, which attract the pest (Midega et al., 2018). This push-pull system has shown promising results, with a reported 83% reduction in the number of larvae per plant and an 87% reduction in plant damage per plot compared to maize grown as a sole crop. Additionally, the push-pull system resulted in a 2.7-fold increase in grain yield (Midega et al., 2018). The push-pull technology is considered an environmentally friendly, cost-effective, and effective approach for managing Fall armyworm, significantly reducing pest infestations on maize (Gebreziher & Gebreziher, 2020)

2.9.3. Biological control

Natural enemies, including parasitoids, predators, viruses, nematodes, fungi, and bacteria, play a crucial role in controlling insect pests (Bhusal & Chapagain, 2020). Similarly, Sisay et al. (2018) conducted a study in Ethiopia, Kenya, and Tanzania and identified five native parasitoid species (*Cotesia icipe, Palexorista zonata, Coccygidium luteum, Charops ater*, and *Chelonus curvimaculatus*) that exhibited high levels of parasitism against fall armyworm, reaching up to 45.3%. Predatory insects like ants, ladybird beetles, spiders, and striped earwigs have also demonstrated effectiveness in controlling fall armyworm populations by feeding on their eggs and larvae. Certain entomopathogenic fungi, such as *Beauveria bassiana* and *Metarhizium anisopliae,* have shown efficacy against fall armyworm larvae (Gowda et al., 2021). Similar results were observed. Both *Metarhizium anisopliae* and *Beauveria bassiana* are effective against fall armyworm eggs and second-instar larvae. *Beauveria bassiana* demonstrated 30% mortality against second-instar larvae, while *M. anisopliae* provided 87% and 97% mortality rates for eggs and larvae, respectively (Koffi et al., 2020). Additionally, *Bacillus thuringiensis* (Bt.) is also effective in controlling Fall armyworm, causing over 90% mortality (Dos Santos et al., 2021).

2.9.4. Botanical control

Compared to synthetic insecticides, the use of plant extracts is an environmentally friendly approach to pest management due to their short persistence and repellent or anti-feeding properties (Bhusal & Chapagain, 2020). Plant extracts are an effective, economical, and environmentally friendly method for controlling fall armyworm while also posing minimal risk to human health (Paredes-Sánchez et al., 2021).

These compounds effectively kill fall armyworms retards larval development and suppress growth. Additionally, it can decrease the pest's reproductive capacity by reducing fertility and fecundity (Rioba & Stevenson, 2020). Several plant extracts have shown potential in controlling Fall armyworm, with mortality rates exceeding 75% 72 hours after application. These include *Azadirachta indica*, *Tagetes minuta*, *Phytolacca dodecandra*, *Croton macrostachyus Hochst.*, *Melia curcas L.*, *Melia abyssinica L.*, *Schinus molle L.*, *Jatropha curcas L., and Millettia ferruginea Hochst.* (Sisay et al., 2019). In another study, *Grewinia tenax, Candle bush,* and *Jatropha curcas* extracts exhibited mortality rates of 85%, 81%, and 76.6%, respectively, while *Azadirachta indica* (neem) and *Lantana camara* (wild sage) treatments resulted in moderate larval mortality rates of 71.6% and 65% respectively (Ahmed, 2023).

2.9.5. Host plant resistance

Host plant resistance (HPR) is the most promising, cost-effective, and environmentally friendly alternative pest management approach against FAW, and also reduces the reliance on insecticide applications (Kasoma et al.,2020). It is an essential component of an integrated pest management (IPM) strategy for controlling fall armyworms, particularly in maize, Generally, resistance can be categorized into antixenosis, antibiosis, and tolerance

(Prasanna et al., 2018). In response to the invasion of fall armyworm (FAW) in maize-growing regions, conventional breeding programs have been initiated to develop maize varieties with host resistance to FAW. International and national research programs are currently screening various types of maize lines, hybrids, and open-pollinated varieties under artificial or natural FAW infestation to select breeding lines and develop cultivars with tolerance to FAW damage (Prasanna et al., 2022).

Several morpho-biochemical traits influenced resistance in maize genotypes. Higher trichome density, leaf thickness, cob traits (length, width), husk features (length, width, layers, weight, tightness), and yield parameters reduced leaf damage (Soujanya et al., 2025). Conversely, larger leaf dimensions (length, width) and taller plant architecture (height, node number, internodal distance) increased leaf damage susceptibility (Soujanya et al., 2025). In Zambia and Kenya, screenings of maize landraces, hybrids, and open-pollinated varieties, as well as inbred lines, have been carried out to assess resistance to FAW and yield-related traits. Significant differences in leaf and ear damage caused by FAW, as well as variations in other agronomic traits, have been observed (Kasoma et al.,2020). Similarly, Chiriboga Morales et al. (2021) tested six maize cultivars used by smallholder farmers in Kenya and found no high levels of resistance to FAW feeding but some tolerance in fall armyworm infestations.

Ahmed (2023) reported that among maize cultivars CZH132150, the response of FAW damage was better to tolerate under untreated plot on the parameter of ear damage 2.6% and followed by CZH1261 3.3% moderately tolerant but CZH1270 is highly susceptible to FAW damage in Ethiopia. Similarly, Getu et al. (2024) reported that the hybrid varieties BH-540,546 and local showed a significant difference in fall armyworm leaf damage percentages and severity.

2.9.6. Chemical control

Synthetic insecticides are widely used to control Fall armyworms in many countries (Sisay et al., 2019; Nboyine et al., 2022b). Insecticides applied against Fall armyworms are effective when used at the right time (Sagar et al., 2020). This includes spraying when the larvae are young, spraying in the early morning or late afternoon when the larvae are more active, and directing the spray into the funnel of infested crops (Assefa, 2018). Farmers should have enough knowledge of the life cycle of the pest and the best time for spraying synthetic insecticides, i.e., insecticide application will not be effective once the pest larvae are deeply hidden inside the maize whorls and ears, or during the daytime because larvae come out to feed on crops during night dawn or dusk (Day et al., 2017). Several insecticides have been recommended for managing fall armyworms (Sagar et al., 2020). Therefore, The Fall Armyworm (FAW) has developed resistance to various insecticide groups, including carbamates, organochlorines, organophosphates, and pyrethroids (Prasanna et al., 2018; (Muraro et al., 2021). To effectively manage FAW resistance, it is crucial to select insecticides with distinct modes of action. Recommended chemical classes for pest control include diamides, oxadiazines, pyrroles, avermectins, spinosyns, and benzylureas (Sharanabasappa et al., 2020).

Each of these groups targets pests through unique mechanisms, which can help delay resistance development and enhance the sustainability of pest management strategies. For instance, pyrroles disrupt cellular respiration in pests, significantly reducing the density of eggs and larvae and ultimately leading to their mortality (Hou et al., 2023). Similarly, avermectins target the nervous system of insects, causing paralysis and death (Zhu et al., 2023; Muraro et al., 2021). On the other hand, diamides work by targeting ryanodine receptors in insect muscles, leading to muscle paralysis and death. Their selectivity towards target pests, while minimizing harm to beneficial insects and the environment, makes them a valuable tool in integrated pest management (IPM) strategies. Meanwhile, spinosyns act on nicotinic acetylcholine receptors, while benzylureas function as growth regulators by inhibiting chitin biosynthesis ,These unique modes of action not only help in delaying resistance but also provide longer-lasting control of pest populations (Bajracharya & Bhat, 2024).

However, most African Farmers commonly used other insecticides containing the active ingredients, lambdacyhalotrin, chlorpyriphos, acetamiprid, permethrin, malathion, maltodextrin, cypermethrin, deltamethrin, carbaryl, Chlorpyrifos, carbosulfan, beta cypermethrin and fipronil to combat the pest (Chimweta et al., 2020; Houngbo et al., 2020). The repeated use of insecticides can accelerate the development of resistance (Deshmukh et al., 2021). Due to these reasons, farmers recommend spraying the newer class of insecticides to control the FAW infestations in maize fields. For example, Mallapur et al. (2019) reported a reduction of 98%, 96%, and 96% in the larval population when using spinetoram, emamectin benzoate, and spinosad, respectively, under field conditions. Similarly, Sharma et al.(2023) found that spinetoram, spinosad, emamectin benzoate, and chlorantraniliprole resulted in the lowest damage scores in maize fields. In addition, the Application of the newer classes of insecticides, chlorfenapyr, indoxacarb, emamectin benzoate, and chlorantraniliprole against fall armyworm was effective with a reduction of larvae from 85-90% (Fathy et al., 2024). Furthermore, the selective insecticides, acetamiprid, abamectin, and imidacloprid showed the highest mortality of fall armyworm and the lowest infestation under field conditions (Mukanga et al., 2024; Mumtaz et al., 2024).

2.9.7. Integrated pest management (IPM)

Integrated pest management (IPM) is one of the most preferred and effective management of fall armyworms (Day et al., 2017). Complete elimination of pests from the field is not feasible, thus calling for the emergence of flexible, coordinated, and effective technologies, as a result, the integrated approach includes host plant resistance, biological methods, cultural methods, and suitable doses of pesticides that reduce negative impacts on non-target organisms and control the pest with success (Prasanna et al., 2018; Demis & Jemal, 2024).

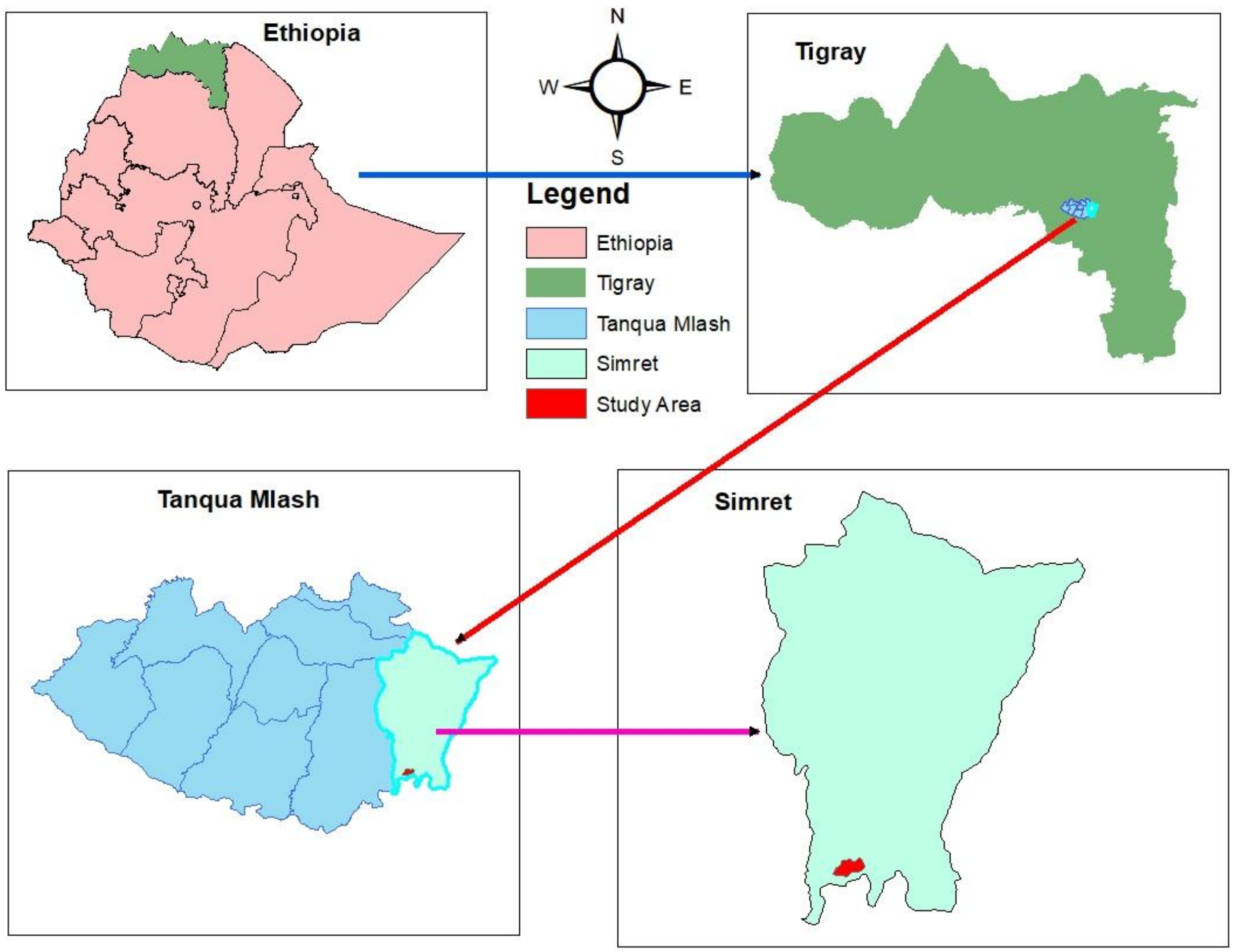
The IPM module showed that integrating host resistance with synthetic chemicals, botanicals, and entomopathogenic fungi markedly reduced yield loss (Ahmed, 2023). In another study, Getu et al. (2024) observed that the integration of chemical insecticides with hybrid maize varieties had a significant effect on the fall armyworm and consequent increase in grain yield. Anilkumar et al.(2024) stated that integrating synthetic insecticides, pheromone traps, botanical insecticides, and biological methods enhanced the natural enemy population, contributing to a more sustainable pest management strategy and also resulted in the highest grain yield among all the treatments, thus underlining its economic viability with high cost-benefit ratio.

3. MATERIALS AND METHODS

3.1. Description of the Study Area

The experiment was conducted at Tanqua Mlash District, Central Tigray, in the year 2024 under irrigation at a farmer's field. The Experimental area is located at 13° 29' 22.38"N - 39° 06' 9.67"E. It is about 855 Km North of Addis Ababa and 76 Km northwest of Mekelle, the capital city of Tigray regional state. The agroecological zone of the study areas is characterized by warm mid-highlands, with a short growing season, and erratic and low amounts of rainfall. The average annual rainfall of the area is 500 - 700 mm, which is concentrated in one season, from June to the beginning of September. The mean annual maximum and minimum temperatures are 29 ^{0}C and 18 ^{0}C respectively. The soils of the study area are broadly categorized as sandy loam (Meresa et al., 2017).

Figure 1. Map of the Experimental Area



3.2. Experimental Design and Treatments

The experiment was laid out in a factorial RCBD (Randomized Complete Block Design) with two factors and replicated three times. Factor one consisted of two improved-maize varieties (Melkasa-2 and Melkasa-4) and one local (Berihu) maize variety, which were currently under production with different potential yields and maturity periods. The tolerance level of the varieties was recorded based on the leaf damage scoring (0-9) described by Prasanna et al. (2018). Factor two had four synthetic insecticides: Tutan 36% SC (Chlorfenapyr), Tutavir 140 SC (Spinosad + Chlorfenapyr), Shooter 50 EC (Abamectin + Acetamiprid), Hortiprid 35 SC (Imidacloprid), and control (only water), which were applied as foliar sprays at the manufacturer's recommended rate.

Spraying was at intervals of 15 days, starting 21 days after planting when plants infested with fall armyworm (FAW) were observed. The infestation threshold is set at 20% of the plants infested or when 1-2 first and second-instar larvae were observed on the whorl of the plant (McGrath et al., 2021). The spraying was applied three times for each type of insecticide used. A Farm knapsack sprayer with a tank capacity of 20 liters was used for spraying, which was carried out during wind-free periods in the early morning or late afternoon. The spacing between plants, rows, plots, and blocks was 30 cm, 60 cm, 75 cm, and 100 cm, respectively. The plot area was 3 m × 3 m = 9 m^2, and the total experimental area was 11 m (width) × 55.5 m (length) = 610.5 m^2. The experiment contained five rows, and data were collected from the three middle rows, except for the phenological data. The two outer rows were considered as border rows to account for border effects. All agronomic practices were applied uniformly to all treatments.

Table 1. List and passport data of improved open-pollinated maize varieties.

Varieties	Year of release	Yield (Qt/ha)	Tolerance	Center of release	Days to maturity
Melkasa-2	2004	45-55	pests	MARC/EIAR	130
Melkasa-4	2006	35-45	pests	MARC/EIAR	105
Berihu(Local)	—	15 -20	—	—	90

Table 2. Description of the Synthetic insecticides used for the experiment

Trade name	Active Ingredient	Chemical class	**Mode of action**	Manufacturer	**Mode of entry**	Rate of application ha^{-1}	
						Insectic ide /ml	Water /L
Tutan 36% SC	Chlorfenapyr 360 g/l	Pyrroles	mitochondrial electron transport inhibitor (METI)	Chico Crop Science Co.Ltd	Contact and Translaminar	500	1000
Tuta vir 140 SC	Chlorfenapyr 115 g/l + spinosad 25 g/l	Pyrroles +spinosyns	nicotinic acetylcholine receptor (nAChR) disruptor in nervous system and **METI**	Hangzhou Leaf Life Chemicals Co. Ltd	Contact and Translaminar	400	800
Shooter 50 EC	Abamectin18+ acetamiprid 32 EC	Avermectins+ neonicotinoids	GABA & nAChR agonists in nervous system	TERRASTEK (SHENZEN) Ltd	Contact and Systemic	500	400
Hortiprid 35 SC	Imidacloprid 350g/l	neonicotinoids	nAChR blocker in nervous system	Jiangsu kesheng Group Co,Ltd	Systemic	1000	400

3.3. Data Collection

Data were collected from 10 randomly sampled plants in the middle three rows of each plot in the experiment. The data recorded included fall armyworm (FAW) larvae mortality, FAW egg masses, maize plant damage incidence and severity, phonological parameters, growth, yield, and yield components. Additionally, 10 FAW-infested plants per plot were randomly pre-tagged for leaf and tassel damage severity assessment. FAW infestation and damage data were recorded both before and after spraying of insecticides at each spray frequency.

3.3.1. FAW and plant damage data

The fall armyworm larvae populations were assessed before and after each synthetic insecticide application. Mortality rates were recorded at one, three, and seven days of the first, second, and third spray treatments each. Data were collected from 10 randomly selected plants in the central rows of each plot. Larva was considered dead if it was unable to move on its own. The percentage mortality (reduction in the insect population after treatment) was calculated by conducting pest scouting before and after treatment using the following formula:

$$M = \frac{(\sum IB - \sum IA)}{\sum IB} \times 100$$

Where M = mortality percentage; IB = Insect population before treatment; IA = Insect population after treatment (Iqbal et al., 2018).

The number of egg masses /10 plants was recorded from the individual 10 randomly selected plants by counting before one day and after fourteen days of each spray.

Leaf Incidence (%): The ratio of FAW-infested plants to the total plants in a plot was calculated using the following equation:

$$\text{LI (\%)} \ \frac{\text{Number of infested plants}}{Total\ number\ of\ plants\ per\ plot} \times 100$$

Leaf incidence was recorded from each of the three consecutive sprays, before one day and 14 days after each spray.

Leaf severity: Data were recorded from 10 pre-tagged infested plants arranged systematically in the middle three rows of each plot. A total of 360 plants were tagged across the entire experimental area (10 plants per plot). The leaf damage severity was evaluated using a 0–9 scoring scale, adapted from the Davis scale as described by Zaman & Patel (2023). The specific criteria for this scale are provided in Table 3. The previously assessed severity of leaves was tagged to track damage. For subsequent sprays, data were collected only from the top newly emerged leaves and the whorl to avoid recounting damage from earlier assessments (Mukanga et al., 2024). Leaf damage severity was recorded from each of the three consecutive sprays, with assessments conducted 14 days after each spray

Table 3. Visual rating of leaf damage severity

Scale	Description	**Response**
0	No visible leaf damages	Highly resistant
1	Only pinhole damage on leaves	Highly resistant
2	Pinhole and shot-hole damage to the leaves	Resistant
3	Small elongated lesions (5-10 mm) on 1-3 leaves	Resistant
4	Midsized lesions (10-30 mm) on 4-7 leaves	Partilally resistant (Tolerant)
5	Large elongated lesions (> 30 mm) or small portions have eaten on 3-5 leaves.	Partially resistant (Tolerant)
6	Elongated lesions (> 30 mm) and large portions have eaten on 3-5 leaves.	Susceptible
7	Elongated lesions (> 30 cm) and 50% of leaves eaten	Susceptible
8	Elongated lesions (>30 cm) and large portions have eaten 70% of leaves.	Highly Susceptible
9	Most leaves with long lesions and complete defoliation observed	Highly Susceptible

Modified Davis scale, Zaman & Patel (2023)

Tassel damage (TD%): Tassel damage was assessed by evaluating 10 randomly selected infested tassels per plot. The severity was visually assessed and assigned a score based on a 0-4 modified Davis scale where 0 represented less than 5% damage; 1 represented 5% to 25% damage; 2 represented 25% to 50% damage;3 represented 50% to 75% damage; and 4 represented 75% to 100% damage (Chimweta et al., 2020a).

Ear damage was recorded at harvest from 10 randomly selected ears of each plot. Ear damage was visually assessed and assigned a score based on the Davis scale (1992), described by (Sugeetha et al. (2024).

Table 4. Assessment of ears and kernel damage of maize varieties specified by Davis and Williams (1992)

Explanation/Definition	Rating
No damage to any ears	1
Tip (<3 cm) damage to 1-3 ears	2
Tip damage to 4-7 ears	3
Tip damage to 7 or more ears and damage to 1-3 kernels below ear tips on 1 to 3 ears	4
Tip damage to 7 or more ears and damage to 1-3 kernels below tips of 4 to 6 ears	5
Ear tip damage on 7-10 ears and damage to 1-4 kernels below tips of 7 to 10 ears	6
Ear tip damage to 7-10 ears and damage to 4-6 kernels destroyed on 7-8 ears	7
Ear tip damage to all ears and 4-6 kernels destroyed on 7-8 ears	8
Ear tip damage to all ears and 5 or more kernels destroyed below tips of 9-10 ears	9

3.3.2. Phenological parameters

Days to 50% emergence: This was recorded when 50% of the expected plants in the plot emerged above the ground.

Days to 50% tasselling: The number of days from sowing to the day when 50% of the maize plants in each plot shed their tassels was counted.

Days to 50% silking: This was recorded as the number of days from planting to when 50% of the maize plants in each plot showed extrusion of silks.

Physiological maturity days: Physiological maturity was recorded when 90% of the plants formed a black layer at the base of the kernel (at the point where the kernel attaches to the cob). All phenological parameters, including days to 50% emergence, days to 50% tasselling, days to 50% silking, and physiological maturity days, were determined through visual observation.

3.3.3. Data on growth, yield, and yield components

Plant height: This was measured in centimeters at maturity from 10 randomly selected plants per plot.

Ear length: This was measured in centimeters at harvest from 10 randomly selected ears per plot.

Number of rows per ear: This was recorded by direct counting from 10 randomly selected ears per plot.

Thousand kernel weights (TKW): Randomly selected kernels from each plot were weighed using a sensitive balance and adjusted to 12-13% moisture content.

Grain yield: Grains were harvested from the three middle rows for each treatment. After threshing the dry cobs, sun-drying to 12-13% moisture content, and winnowing, the yield was recorded and converted to kg/ha.

Avoidable yield loss (%) and grain yield increase (%)

The avoidable yield loss and yield increment over the untreated plot were obtained using the formula suggested by (Srinivasan et al., 2022).

Avoidable yield loss (%) = (Yield of treated -Yield of the untreated plot)/Yield of the treated plot) × 100

Yield increment over control (%) = (Yield of the Treated plot –Yield of the Untreated plot)/Yield of the Untreated plot) × 100

3.4. Economic Analysis

The economic analysis for maize production involved evaluating the costs and benefits associated with different treatments, with a focus on variable costs for the partial budget analysis. The costs included market prices for inputs at planting, while the benefits were based on the market prices for grain yield at harvest. All costs and benefits were expressed in ETB·ha^{-1}. To account for the discrepancy between the experimental area and the anticipated output under farmers' field conditions and management practices, the average yield was adjusted to 10% lower, as suggested by Mesele et al. (2019). Total revenue was calculated by multiplying the adjusted yield by the average price of grain, providing an estimate of the expected revenue for each treatment. The dominance analysis procedure was employed to identify the most profitable treatments among the tested range. This involved comparing the costs and benefits of each treatment to determine economic superiority. Additionally, the marginal rate of return (MRR) was calculated to assess the return per unit of investment when changing field management practices. This analysis considered non-dominated treatments in order of increasing net benefit, ensuring a comprehensive evaluation of the economic viability of each treatment.

3.5. Data Analysis

Data on FAW infestation and damage, phenological parameters, growth, yield, and yield components were subjected to analysis of variance (ANOVA) using GenStat-18 statistical software. Mean comparisons were performed using Tukey's Honest Significant Difference (HSD) test at a 5% probability level to determine significant differences among treatments. The counted number of egg masses was transformed by the logarithmic data transformation method (log10).

4. RESULTS AND DISCUSSIONS

4.1. Integrated Effect of Insecticides and Maize Varieties on Leaf Incidence, Leaf, Tassel, and Ear Damage Severity

4.1.1. Leaf incidence after the first, second, and third spray

After the first spray, the analysis showed a highly significant (<0.001) effect on the incidence of leaves by the main effect of the synthetic insecticides and Maize varieties (Table 5). Among the tested insecticides, the lowest leaf damage incidence was recorded in Spinosad + chlorfenapyr (26.22%), followed by chlorfenapyr (27.33%), abamectin + acetamiprid (32%), and imidacloprid (35.56%). The untreated control plot showed the highest leaf damage (64.89%) across maize varieties. This is probably due to the difference in active ingredients and mode of action of the insecticides tested. This result is in line with the report of Sharma et al.(2023) the highest FAW infestation percentage in maize plants was observed in the control plot (64%) followed by imidacloprid and azadirachtin treated maize plots, with leaves incidence of 63% and 55% respectively. In the present study, the highest (59.6%) and (45.2%) reduction of leaf incidence were from Spinosad + chlorfenapyr treated plots over the Imidacloprid and control plots respectively. This result aligns with the findings of Bajracharya & Bhat (2024) revealed that Spinosad-treated maize plots resulted highest reduction (88.3%) in leaf incidence over the untreated plots. Regarding the varieties, the Melkassa -2 variety had the lowest (29.07%) while the local variety Berihu had the highest (44.4%) incidence of leaves. This might be due to the variation in leaf trichome density, and plant architecture of the varieties. Similarly, Amegbor et al. (2025) revealed that significant differences were observed among the hybrids with the FAW-tolerant hybrids showing reduced leaf damage compared to the commercial maize varieties.

Table 5: The main effect of maize varieties and insecticides on leaf incidence after the first spray

Maize varieties	**AFSI**
Berihu	44.40[a]
Melkassa-2	29.07[c]
Melkassa-4	38.13[b]
CD (5%)	6.11
P- Value	<0.001
Insecticides	
Spinosad +Chlorfenapyr	26.22 [c]
Chlorfenapyr	27.33[bc]
Acetamiprid+ Abamectin	32.00[bc]
Imidacloprid	35.56[b]
Control	64.89[a]
CD (5%)	9.30
P- Value	<0.001
CV (%)	18.2

Note: Means followed with the same letter(s) within the same column are not significantly different.

AFSI: after the first spray incidence

After the second and third sprays, the interaction effect of maize varieties and insecticides had a significant ($p<0.05$) effect on the incidence of leaves (Table 6). The Melkassa-2 variety treated with Spinosad + chlorfenapyr showed the lowest (6%,4%) leaf incidence, followed by chlorfenapyr (11.33%,7.33%), Melkassa-4 treated with Spinosad + chlorfenapyr (13.33%, 10 %) after the respective sprays. In contrast, the untreated Berihu variety had the highest (94.67% and 98.00%) leaf incidence, followed by untreated Melkassa-4 (88.67%). This is possibly the combined effect of the different active ingredients of the insecticides with the different leaf morphology of the tested varieties. This result is in agreement with Bajracharya & Bhat (2024) confirmed a significant effect on the FAW infestation at 2.38% and 1.85% observed from the Spinosad-treated maize variety after the second and third spray, respectively, while 97.92% FAW incidence was recorded from the control after the second and third spray.

In the current study, the highest reduction percentage of leaf incidence over the control was recorded from Spinosad + Chlorfenapyr-treated Melkassa-2 (89.89%, 94.87%), Melkassa-4 (82.46%,88.72%), and Berihu (73.94%, 82.32%) varieties after the second and third sprays. The present study is in line with Dileep & Mohan (2020), who revealed that 83.53% leaf damage reduction from spinosad-treated varieties over the untreated varieties. Besides the local Berihu variety treated with Imidacloprid had the highest (49.33% and 30.00%) leaf infestation after the respective sprays followed by acetamiprid +abamectin treated Melkassa-2 (26%,19.33%), Melkassa-4 (32.67%, 21.33%), and Berihu (40%,26%) after the respective spray. This finding is similar to Mukanga et al. (2024), who observed the highest incidence of maize plants from Imidacloprid-treated variety (33.33% and 26.4%), followed by acetamiprid (29% and 20%) treated maize varieties after the second and third spray, respectively.

Table 6.Interaction effect of maize varieties and insecticides on leaf incidence after the second and third spray

Maize Varieties	Insecticides	ASSI	ATHSI
Berihu	Control	94.67[a]	98.00 [a]
	Spinosad+Chlorfenapyr	24.67[fgh]	17.33[defg]
	Chlorfenapyr	31.33[ef]	20.00[cdef]
	Acetamiprid+Abamectin	40.00[def]	26.00[cd]
	Imidacloprid	49.33[cd]	30.00[c]
Melkassa-2	Control	59.33 [c]	78.00[b]
	Spinosad+ Chlorfenapyr	6.00 [i]	4.00[h]
	Chlorfenapyr	11.33 [hi]	7.33 [gh]
	Acetamiprid+Abamectin	26.00[fgh]	19.33[def]
	Imidacloprid	34.67[def]	26.67[cd]
Melkassa-4	Control	76.00[b]	88.67[a]
	Spinosad +Chlorfenapyr	13.33[ghi]	10.00[fgh]
	Chlorfenapyr	28.67[efg]	15.33[efg]
	Acetamiprid+Abamectin	32.67 [ef]	21.33[cde]
	Imidacloprid	43.33[de]	27.33[cd]
CD (5%		14.88	10.21
CV (%)		12.9	10.4
P value		0.016	0.018

Note: Means followed by the same letter(s) within the same column are not significantly different.

AFSSI- after the second spray incidence, ATHSI- after the third spray incidence,

4.1.2. Leaf damage severity after the first, second, and third spray

The statistical analysis resulted in a significant ($P<0.05$) interaction effect between varieties and synthetic insecticides on FAW leaf damage severity after the first, second, and third sprays (Table 7). After the first, second, and third sprays, the lowest leaf damage severity was recorded from Melkassa-2 treated with Spinosad + Chlorfenapyr ratings of 2.067, 1.633, and 0.933, respectively, followed by the Spinosad Chlorfenapyr-treated Melkassa-4 variety with scores of 2.433,2.067, and 1.56, and Chlorfenapyr-treated Melkassa-2 (2.733,2.267 and 2.00) respectively. The least damage severity of the leaf observed in the Melkassa-2 and Melkassa-4 varieties may be attributed to their rough and textured leaf surfaces. This physical characteristic likely hindered the leaching of synthetic insecticides, thereby enhancing their residual activity on the foliage and prolonged contact toxicity against FAW larvae, This result is in line with the findings of Zaman & Patel (2023), who indicated that Spinosad and chlorfenapyr-sprayed maize scored 1.74 and 1.84 leaf damage severity after the first spray. Similarly, Bajracharya & Bhat (2024) indicated that the Spinosad-treated maize varieties scored with 0.0,0.0, and 0-1 leaf damage severity after the first, second, and third sprays, respectively.

While in the current study, the highest (5.0, 6.3, and 8.067) leaf severity was observed in the untreated Berihu, respectively, followed by untreated Melkassa-4 and Melkassa-2 after the three sprays. Among the treated, the local Berihu variety treated with Imidacloprid showed the highest (3.733, 3.267, and 3.3) leaf severity, followed by Melkassa-4 treated with Imidacloprid after the sprays. Maybe the active ingredient imidacloprid is least effective in the mortality of the late instar larvae, and then with severe feeding on the leaves. This result is in line with the finding of Sharma et al.(2023) reported that among the insecticides, imidacloprid had the highest (6.5) leaf damage severity after the last spray. Among the tested varieties, Melkassa-2 demonstrated tolerance to fall armyworm infestation, whereas both the local Berihu variety and Melkassa-4 exhibited high susceptibility and susceptibility response to FAW, respectively.

Table 7: Interaction effect of maize varieties and insecticides on leaf damage severity

Variety	Insecticides	AFSLDS	ASSLDS	ATHSLDS
Berihu	Control	5.000^{a}	6.300^{a}	8.067^{a}
	Spinosad +Chlorfenapyr	3.167^{def}	2.633^{defg}	2.300^{fg}
	Chlorfenapyr	3.133^{def}	3.000^{cde}	2.367^{fg}
	Acetamiprid + Abamectin	3.500^{cde}	3.167^{cd}	3.100^{de}
	Imidacloprid	3.733^{cd}	3.267^{c}	3.300^{d}
Melkassa-2	Control	3.900^{bc}	4.733^{b}	5.300^{c}
	Spinosad +Chlorfenapyr	2.067^{h}	1.633^{h}	0.933^{i}
	Chlorfenapyr	2.733^{gh}	2.267^{fg}	2.000^{gh}
	Acetamiprid + Abamectin	3.100^{ef}	2.800^{cdef}	2.367^{fg}
	Imidacloprid	3.300^{cdef}	3.067^{cde}	2.933^{de}
Melkassa-4	Control	4.467^{ab}	5.733^{a}	6.900^{b}
	Spinosad +Chlorfenapyr	2.433^{fg}	2.067^{gh}	1.567^{h}
	Chlorfenapyr	3.067^{ef}	2.567^{efg}	2.000^{gh}
	Acetamiprid + Abamectin	3.433^{cde}	3.133^{cde}	2.633^{ef}
	Imidacloprid	3.567^{cde}	3.267^{c}	3.100^{de}
CD (5%		0.6	0.58	0.53
CV (%)		5.6	5.8	5.4
P- value		0.037	<0.001	<0.001

Note: Means followed by the same letter(s) within the same column are not significantly different.

AFSLDS- after the first spray, leaf damage severity, ASSLDS- after the second spray, leaf damage severity, ATHSLDS- after the third spray, leaf damage severity

4.1.3. Tassel and ear damage severity

The tassel damage severity was significantly ($p < 0.05$) influenced due to the interaction effect of maize varieties and synthetic insecticides (Table 8). The highest (4.0) tassel damage severity was recorded from the untreated Berihu and Melkassa-4 variety and Imidacloprid treated Berihu variety while the lowest (0.3333) damage severity was observed from both Spinosad +Chlorfenapyr and Chlorfenapyr treated Melkassa -2 variety and followed (1.00) by Spinosad +Chlorfenapyr treated Melkassa-4 variety This might be because the efficacy of the synthetic insecticides and genetic variation of the maize varieties on the mortality of larvae on leaves reduced the damage of the tassel. This result is consistent with Tanyi et al. (2024) and Chimweta et al. (2020), which indicated a significant effect due to the insecticide-treated plots on tassel damage severity.

The interaction effect between the varieties and synthetic insecticides showed a significant ($p<0.05$) difference in ear damage severity measured by the Davis scale (1-9) (Table 8). The Untreated Berihu variety showed the highest score (8.133) of damaged ears, while the lowest score of damaged ears was recorded from Spinosad + Chlorfenapyr (1.667), followed by Chlorfenapyr-treated Melkassa-2 (2.667). Moderate ear damage was recorded in Berihu treated with Spinosad + Chlorfenapyr (4.667), Melkassa-4 sprayed with Spinosad + Chlorfenapyr (4.067), Chlorfenapyr alone (4.70), and Melkassa-2 treated with abamectin + acetamiprid (5.20). In contrast, the highest ear damage among treated plots was observed in the Berihu (6.567) and Melkassa-4 (6.033) varieties treated with Imidacloprid. It may be due to the efficacy of synthetic insecticides used and the difference in husk tightness, and the number of husk layers of the cobs of the tested varieties. This result is in line with the studies of Yaméogo et al.(2024) and Mohapatra et al. (2023), who confirmed the significant interaction effect of varieties and synthetic insecticides on ear damage.

Table 8.The interaction effect of maize varieties and insecticides on tassel and ear damage severity

Maize varieties	Insecticides	TD	ED
Berihu	Control	4.000[a]	8.133 [a]
	Spinosad+Chlorfenapyr	2.000[cde]	4.667[de]
	Chlorfenapyr	2.667[bcd]	5.433[cde]
	Acetamiprid+Abamectin	3.667[ab]	6.033[cd]
	Imidacloprid	4.000[a]	6.567[bc]
Melkassa-2	Control	2.667[bcd]	6.133[bcd]
	Spinosad+ Chlorfenapyr	0.3333 [f]	1.667[g]
	Chlorfenapyr	0.3333 [f]	2.667[fg]
	Acetamiprid+Abamectin	1.667[de]	5.267 [cde]
	Imidacloprid	2.000[cde]	5.733[cd]
Melkassa-4	Control	4.000[a]	7.767[ab]
	Spinosad +Chlorfenapyr	1.000[ef]	4.067[ef]
	Chlorfenapyr	1.333 [e]	4.700[de]
	Acetamiprid+Abamectin	3.000[abc]	5.900[cd]
	Imidacloprid	3.667[ab]	6.033 [abc]
CD (5%		1.037	1.67
CV (%)		15.8	10.9
P value		0.047	0.009

Note: Means followed with the same letter(s) within the same column are not significantly different.

ED-Ear damage severity, TD- tassel damage severity

4.2. Integrated Effect of Insecticides and Maize Varieties on Fall Armyworm (FAW) Larvae Mortality and Egg Masses

4.2.1. FAW larval mortality after the first, second, and third spray

The interaction effect of maize varieties and synthetic insecticides showed a significant ($p < 0.05$) difference in larval mortality after the first spray on all days but a highly significant ($p <0.001$) difference after the second and third sprays (Table 9).
After the first spray, the Melkassa-2 variety treated with Spinosad +chlorfenapyr showed the highest (74.44%, 83.61%, and 88.61%) FAW larvae mortality after the first, third, and seventh day of spraying, respectively. The second superior result was also observed from the Melkassa-4 variety treated with Spinosad+chlorfenapyr, which recorded 68.94%, 76.19%, and 77.88% FAW larvae mortality after the first, third, and seventh days of the spray, respectively. This might be due to the broad leaf whorls of Melkassa-2 and Melkassa-4 varieties and mode of action of the Spinosad +chlorfenapyr by improving insecticide exposure and retention against fall armyworm larvae. This result is in line with the findings of Mallapur et al.(2019), who reported that 79.20%, 94.53%, and 96.24% of FAW larvae mortality were sprayed with Spinosad after the first, third, and seventh days of spraying, respectively. Similarly, the result also collaborates with the report of Fathy et al.(2024), who observed 82.68% of FAW larvae mortality after one day of spray from the chlorfenapyr-treated maize variety under field conditions.

On the other hand, there was an increase of 2.5%, 12.82%, and 23.50 % FAW larvae population in the untreated Berihu variety after the 1^{st}, $3^{rd,}$ and 7^{th} days of spraying, respectively. Among the treated plots, the lowest FAW larval mortality was recorded from the imidacloprid-treated Melkassa-2 (36.77%-49.12 %), Melkassa-4 (31.92%-46.07%), and Berihu (32.78%-43.75%), but not statistically different between the varieties. These results are consistent with Dahal et al.(2022), who found the lowest (65%) mortality from imidacloprid-treated varieties compared to the insecticides-variety tested, followed by untreated varieties, which increased the larval population by 58% after the seventh day of spray.

The highest mortality percentage was recorded from chlorfenapyr +Spinosad treated Melkasa -2 variety after the second spray of the first (78.35%), third (84.35%), and seventh (90.36 %) days followed by spinosad+chlorfenapyr treated Melkassa-4 variety after first (69.74%), third (75.37%) and seventh (86.72%) days. The Spinosad+chlorfenapyr exhibited the highest larval reduction over the least effective Imidacloprid-treated Melkassa-2, Melkassa-4, and Berihu varieties by 45.78%, 40.98%, and 28.89%, respectively. This could be attributed to the different modes of action of the insecticides interacting with the variation in morphological characteristics of the varieties. This result is supported by the finding of Zaman & Patel (2023), who recorded 82.89% and 77.69% mortality of FAW larvae over the control from Spinosad and Chlorfenapyr insecticides after seven days of the second spray, respectively. Similarly, the spinosad+chlorfenapyr superiority is consistent with the finding of Manoj et al.(2024), who reported 33.33% and 50.17% FAW larval reduction from Spinosad-treated maize varieties compared to imidacloprid-treated varieties after the first and second spray, respectively. In the present study, Moderate FAW larval mortality was observed from the Berihu variety treated with Spinosad+chlorfenapyr (56.06%-65.08%), with chlorfenapyr (51.35% to 62.05%), Melkassa-2 treated with Abamectin+acetamiprid (46.62%-62.05%), and Melkassa-4 treated with Abamectin+acetamiprid (46.58%-56.99%). While the highest population of FAW larvae was recorded from the untreated Berihu variety, which increased by 22.49%, 27.025%, and 29.16% after the first, third, and seventh days, respectively. This result agrees with Thumar et al.(2020) that the FAW larvae population increased by 50.47%, 53.8%, and 58.09% after the first, third, and fifth days of the second spray.

After the third spray, the lowest FAW larvae population was recorded from the Melkassa-2 variety treated with chlorfenapyr +Spinosad decreased by 81.13%, 88.99%, and 94.74% after 1st, the 3rd, and 7th of spraying respectively compared to all tested treatments followed by chlorfenapyr treated Melkassa-2 variety (81.66% and 87.14%) after the third and seventh days of spray but not statistically different with chlorfenapyr +Spinosad treated Melkassa-4 variety. Increased spray frequency enhances FAW mortality due to the lowest resistance of the tested insecticides, while delayed mortality after a single spray reflects residual and translaminar insecticide effects over time. This result is in line with the finding of Mallapur et al.(2019) reported that chlorfenapyr and Spinosad-treated maize varieties caused 86.61% and 98.64 % FAW larvae mortality after the third spray on the 7th day at field conditions. In this study, the imidacloprid-treated varieties showed the lowest mortality percentage of FAW, causing 44.64% to 48.35% compared to the tested insecticides and statistically similar between the varieties, followed by the abamectin-treated Berihu (45.75%-52.39%) and Melkassa-4 (46.47%-58.90%) after the spray. This result is similar to the finding of Mukanga et al.(2024) recorded 69.51% mortality of FAW larvae from imidacloprid-treated maize varieties after the third spray. This finding also found that the lowest mortality of larvae was recorded from the untreated Berihu variety, with increased FAW larval populations by 29.74%, 36.04%, and 44.55% after the first, third, and seventh days of spray, respectively. The current finding is strongly supported by the finding of Dahal et al.(2022), who reported the lowest mortality rate of fall armyworm larvae was -85% in the untreated plot after the third spray.

Table 9. Interaction effect of insecticides and varieties on FAW larvae mortality

Treatments		1st spray			2nd spray			3rd spray		
Varieties	Insecticides	1DAS	3DAS	7DAS	1DAS	3DAS	7DAS	1DAS	3DAS	7DAS
Berihu	Control	-2.56^{g}	-12.82^{f}	-23.50^{j}	-22.49^{h}	-27.02^{j}	-29.16^{g}	-29.74^{i}	-36.04^{j}	-44.55^{j}
	Spinosad +Chlorfenapyr	50.88^{c}	57.81^{bcd}	65.03^{cd}	53.06^{cd}	60.44^{cd}	65.86^{c}	57.80^{cd}	66.56^{cd}	73.25^{cd}
	Chlorfenapyr	47.05^{cd}	56.28^{cd}	62.18^{de}	51.85^{cde}	57.42^{de}	61.08^{cd}	54.34^{de}	60.95^{de}	67.56^{de}
	Acetamiprid + Abamectin	41.25^{de}	46.02^{cde}	50.79^{fgh}	42.04^{ef}	47.34^{fg}	52.65^{de}	45.75^{fg}	52.39^{efg}	52.39^{fg}
	Imidacloprid	32.78^{f}	37.96^{e}	43.15^{h}	37.28^{f}	43.39^{g}	46.94^{e}	40.01^{g}	44.64^{g}	49.27^{g}
Melksa2	Control	0.00^{g}	0.00^{f}	1.75^{i}	-4.94^{g}	-6.00^{h}	-12.85^{f}	-14.69^{h}	-14.69^{h}	-23.80^{h}
	Spinosad +Chlorfenapyr	74.44^{a}	83.61^{a}	88.61^{a}	78.35^{a}	84.35^{a}	90.36^{a}	81.13^{a}	88.99^{a}	94.74^{a}
	Chlorfenapyr	60.18^{b}	71.71^{ab}	76.19^{b}	62.26^{bc}	73.80^{b}	82.01^{ab}	72.38^{b}	81.66^{ab}	87.14^{ab}
	Acetamiprid+ Abamectin	43.32^{de}	51.51^{cde}	56.67^{def}	46.62^{def}	53.22^{def}	62.08^{cd}	50.88^{def}	56.56^{ef}	62.17^{e}
	Imidacloprid	36.77^{ef}	42.90^{de}	49.12^{fgh}	38.85^{f}	46.25^{fg}	52.07^{de}	43.31^{fg}	48.78^{fg}	52.97^{fg}
Melkassa4	Control	-2.38^{g}	-7.15^{f}	-17.20^{j}	-10.23^{g}	-14.67^{i}	-19.78^{fg}	-23.89^{i}	-24.89^{i}	-33.33^{i}
	Spinosad +Chlorfenapyr	68.94^{a}	76.19^{a}	77.88^{b}	69.74^{ab}	75.37^{b}	86.72^{ab}	76.31^{ab}	78.40^{b}	85.66^{ab}

	Chlorfenapyr	51.11^{c}	58.75 ^{bc}	72.78 ^{bc}	58.04^{c}	67.83^{bc}	77.63 ^{b}	64.05^{c}	73.89^{bc}	80.04^{bc}
	Acetamiprid+ Abamectin	41.43^{de}	48.15^{cde}	54.86^{efg}	46.55^{def}	51.77^{efg}	56.99^{cde}	46.47^{efg}	51.86^{efg}	58.90^{ef}
	Imidacloprid	31.92 ^{f}	39.88 ^{e}	46.07 ^{gh}	38.11^{f}	43.62^{g}	49.12^{e}	40.06^{g}	45.07^{g}	50.08^{fg}
CD (5%)		7.43	15.20	10.0	10.58	8.48	10.93	7.88	9.95	9.12
CV (%)		6.4	11.6	7.0	9.0	6.4	7.5	6.4	7.3	6.3
P-value		<0.001	0.023	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

Note: Means followed with the same letter(s) within the same column are not significantly different.

DAS- Days After Spraying, CD- critical difference

4.2.2. FAW egg masses after the first, second, and third spray

The Analysis of variance revealed that the interaction of maize varieties with insecticides did not show a statistically significant ($p < 0.05$) effect on the abundance of FAW egg masses (Table 10). The main effect of maize varieties did not show a statistically significant effect on the number of FAW egg masses ($p < 0.05$). The highest number of egg masses was recorded from Melkassa-2 (3.533,3.733, and 2.667) while the lowest number of egg masses was from the local Berihu (2.867,3.067, and 2.267) after the first, second, and third sprays, respectively. The lowest number of egg masses is probably due to the severe damage to leaves, as the moth does not prefer to deposit eggs.

The main effect of synthetic insecticides showed a highly significant ($P<0.001$) difference in the number of FAW egg masses. The highest number of egg masses was recorded from the treated plots in comparison to the untreated plots. After the first, second, and third sprays, the highest number of egg masses was recorded from the Spinosad + chlorfenapyr treated plots, 5.333,5.889,3.889 per 10 plants in the following sprays, followed by the chlorfenapyr treated varieties with 4.111,4.556, and 2.556 per 10 plants, but statistically similar to Spinosad+ chlorfenapyr treated plots. The least damaged maize leaves obtained the highest number of egg masses; this might be because female moths may find it easier to lay eggs on smooth, unbroken surfaces of leaves. In contrast, the lowest number of egg masses was recorded from the untreated plots (2.222,2.000 and 1.778 per 10 plants) followed by the Imidacloprid-treated plots with 2.222,2.000 and 1.889 per 10 plants with the respective sprays. The reduction in egg masses observed in untreated plots is due to severe leaf damage, which makes the environment less suitable for female moths to lay their eggs, the larvae hatching from the eggs need adequate feeding. And might be due to the egg parasitoid natural enemies in the control plots being the highest. Similarly, He et al.(2021) and Bakry & Abdel-Baky (2024) supported this result by addressing Leaf damage on maize plants caused by Fall Armyworm (FAW) can significantly reduce the number of egg masses laid by female FAW moths, as they tend to prefer healthy, undamaged leaves for oviposition, meaning more severe leaf damage leads to fewer egg masses being deposited on the plant.

After the third spray, in all insecticides, relatively decreased egg masses were observed, which were from Spinosad + chlorfenapyr (3.889), chlorfenapyr (2.556), acetamiprid + abamectin (2.111), and imidacloprid (1.889) treated plots. This might be due to the growth stages of the maize plant and the timing of synthetic insecticide applications. The female moth tends to prefer laying eggs on younger plants, resulting in higher egg mass counts during these early stages. This result is in line with the findings of Nboyine et al.(2021), who revealed regarding the spraying regimes, the one and two times spraying of insecticides recorded the highest number of egg masses in comparison to the last spraying.

Table 10.The main effect of maize varieties and insecticides on FAW egg masses

Maize varieties	BSEM	AFSEM	ASSEM	ATHSEM
Berihu	3.733 (0.5579)^{a}	2.867 (0.423)^{a}	3.067 (0.446)^{a}	2.267 (0.3162)^{a}
Melkassa-2	3.733 (0.5650)^{a}	3.533 (0.502)^{a}	3.733 (0.504)^{a}	2.467 (0.3730)^{a}
Melkassa-4	4.133 (0.6075)^{a}	3.333 (0.488)^{a}	3.467 (0.478)^{a}	2.667 (0.3946)^{a}
CD (5%)	0.087	0.1135	0.1257	0.081
P- Value	0.151	0.221	0.547	0.067
Insecticides				
Spinosad+ Chlorfenapyr	3.556 (0.5346)^{a}	5.333 (0.718)^{a}	5.889 (0.757)^{a}	3.889 (0.5851)^{a}
Chlorfenapyr	3.889 (0.5851)^{a}	4.111 (0.67)^{a}	4.556 (0.649)^{a}	2.556 (0.3989)^{b}
Acetamiprid+ Abamectin	4.444 (0.6451)^{a}	2.333 (0.36)^{b}	2.333 (0.34)^{b}	2.111 (0.3206)^{bc}
Imidacloprid	3.889 (0.5788)^{a}	2.222 (0.34)^{b}	2.000 (0.287)^{b}	1.889 (0.2676)^{c}
Control	3.556 (0.5403)^{a}	2.222 (0.326)^{b}	2.000 (0.326)^{b}	1.778 (0.2341)^{c}
CD (5%)	0.135	0.147	0.193	0.1249
P- Value	0.674	<0.001	<0.001	<0.001
CV (%)	17	28.1	29.7	25.2

Note: Means followed with the same letter(s) within the same column are not significantly different. The values in parenthesis are logarithmic (Log10) transformed

AFSEM: after the first spray egg masses, ASSEM: after the second spray egg masses, ATHSEM: after the third spray egg masse

4.3. Integrated Effect of Insecticides and Maize Varieties on Phenological and Growth Parameters

4.3.1. Days to 50% emergence

The analysis showed a highly significant (p<0.001) difference between the studied maize varieties on days to 50% emergence (Table 11). The late-emerged variety was recorded from Melkassa -4 (6.2 days) after sowing, and the earliest-emerged variety was Berihu after 5.13 days. This might be due to genetic variation of the varieties.

4.3.2. Days to 50 % tasseling

The analysis of variance revealed that the main effect of varieties and insecticides showed a highly significant (P<0.001) difference on days to 50% tasseling (Table 11). The maximum number of days to tassel was recorded from the Melkassa-2 variety (70.53 days), while the minimum number of days to 50% tasseling was observed from the Berihu variety (63.07 days). This might be due to inherent genetic differences in the tested varieties. The results are consistent with the findings of Legesse et al.(2023a) and Kinfe et al. (2017), who reported the days to 50% tasseling attained ranges from 67-76.08 days from the Melkassa varieties. The result also showed a highly significant (p<0.001) effect due to insecticides on days to 50 % tasselling. The minimum days required to attain 50% tasselling was observed from Spinosad+ Chlorfenapyr (61.56 days), while the maximum number of days was observed from control (69.78) followed by Imidacloprid (67 days). This possibly due to the effectiveness of the insecticides on the mortality of larvae facilitates or delayed the days to tasseling. A study by Beato (2018) noted that Insecticides had a significant effect on days to 50 % tasseling, 50% silking, and maturity of maize.

4.3.3. Days to 50% silking

As described in Table 11, the Analysis of variance revealed that days to 50 % silking was significantly (P<0.001) affected due to the main effect of varieties and insecticides. But did not show an interaction effect. The highest prolonged duration of silking was recorded from the Melkassa-2 variety (76.13 days), and the minimum duration was observed from the Berihu variety (68.27 days). This might be due to genetic variation among different varieties of maize. This result is in line with Kusa et al.(2022), who reported variations in days to 50% silking on maize varieties. In addition to this, there was a highly significant difference obtained among the insecticides. The lowest number of days taken for 50 % silking was seen in the Spinosad Chlorfenapyr (65 days), followed by chlorfenapyr (68.67 days. In contrast to this, the maximum number of days required for silking was obtained from the control (78.56 days), followed by the Imidacloprid (75.33 days). This result disagrees with the finding of Kashetti et al.(2020), who reported that the tested insecticides did not show a significant difference in days to 50% silking.

4.3.4. Days to 90 % physiological maturity

The result indicated that days to 90% physiological maturity were a highly significant ($p<0.001$) effect by the main effect of varieties and insecticides (Table 11). The earliest variety to physiological maturity was recorded from the Berihu variety (102.3 days), while the latest variety to attain physiological maturity was observed from the Melkasa-2 variety (112.1 days). The varieties have different genetic backgrounds, which might be a reason for variation in days to tasseling, silking, and maturity duration among the tested varieties. Similarly, Yadete et al.(2024) and Bekis (2024) confirmed the significant variability of maize varieties for days to maturity and plant height due to the genetic variability of the genotypes. In addition to this, the insecticides showed a highly significant effect for days to 90% maturity; the longest days to maturity were recorded from the control (114 days), next by imidacloprid (110.4 days) treated varieties. Whereas the shortest days to attain maturity were recorded from the Spinosad +chlorfenapyr (99.2 days), followed by Chlorfenapyr (104.9 days) treated maize varieties. This might be the effective synthetic insecticides that facilitate the growth of the maize plants by reducing the damage to the maize by the FAW larvae. This result confirmed the finding of El-Tokhy et al.(2024), who reported that insecticides had a significant effect on different growth stages of maize varieties.

4.3.5. Plant height

The Analysis showed, there is no interaction ($p<0.05$) effect of varieties and insecticides on plant height (Table 11). However, plant height was highly influenced by the main effect of synthetic insecticides and Maize varieties. The longest (172.7 cm) plant height was measured from the Melkassa-2 variety, while the shortest (157.8 cm) plant height was recorded from the Berihu variety. Possibly due to genetic differences between the varieties. This result is consistent with those who reported a significant difference in maize varieties on plant height (Legesse et al.,2023). Among the synthetic insecticides, the highest plant height was recorded from Spinosad + chlorfenapyr (186.4 cm), followed by chlorfenapyr (174.9 cm), Acetamiprid + abamectin (161.5 cm) treated maize varieties, while the shortest (140.4 cm) plant height was measured from the control plots next to imidacloprid (151.1 cm) treated varieties. Similarly, Ochoa et al.(2023) and Bakry & Abdel-Baky (2024) reported that Synthetic insecticides against fall armyworms showed a highly significant effect on plant height. Those findings disagree with the findings of Bhandari et al.(2024) and Sisay et al.(2019) indicated that synthetic insecticides did not show a significant effect on the plant height of the maize varieties.

Table 11. The main effect of maize varieties and insecticides on phenological, growth, and yield component parameters.

Maize varieties	DTE	DTT	DTS	DTM	PH	TKW
Berihu	5.133[b]	63.07 [b]	68.27[c]	102.3[c]	157.8[b]	274.9[c]
Melkassa-2	6.133[a]	70.53 [a]	76.13[a]	112.1[a]	172.7[a]	297.4[a]
Melkassa-4	6.200[a]	64.40 [b]	71.93[b]	107.9[b]	158.0[b]	287.1[b]
CD (5%)	0.67	2.15	2.59	2.93	7.66	9.78
P- Value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Insecticides						
Spinosad +Chlorfenapyr	5.889[a]	61.56[c]	65.00[c]	99.2[d]	186.4[a]	315.[a]
Chlorfenapyr	6.111[a]	64.56[bc]	68.67[c]	104.9[c]	174.9[a]	300.5[ab]
Acetamiprid+ Abamectin	5.556[a]	67.11[ab]	73.00[b]	108.7[bc]	161.5[b]	285.8[bc]
Imidacloprid	5.778[a]	67.00[ab]	75.33[ab]	110.4[ab]	151.1[bc]	274.1[c]
Control	5.778[a]	69.78[a]	78.56 [a]	114.0[a]	140.4[c]	257.0[d]
CD (5%)	1.04	3.32	3.99	4.51	11.81	15.08
P- Value	0.64	<0.001	<0.001	<0.001	<0.001	<0.001
CV (%)	13.00	3.70	4.00	3.10	5.3	3.8

Note: Means followed by the same letter(s) within the same column are not significantly different.

Where: DTE: days to emergence, DTT: days to 50% tasselling, DTS: days to 50% silking, DTM: days to 90% physiological maturity, PH: plant height, TKW: Thousand kernel weight

4.4. Integrated Effect of Insecticides and Maize Varieties on Yield and Yield Components

4.4.1. Row number per ear

Significant (p<0.05) differences between treatments in row number per ear due to the interaction of maize varieties and insecticides were revealed by the Analysis of variance (Table 12). The Melkassa-2 variety treated with Spinosad + chlorfenapyr gave the maximum number of rows per ear (18.75 rows) and was followed by chlorfenapyr-treated Melkassa-2 varieties (17.75 rows), but they were statistically similar. Whereas the minimum number of rows per ear was recorded from the untreated Berihu variety (8.30), next to the imidacloprid-treated Berihu variety (10.20 rows). The local Berihu variety treated with Spinosad + chlorfenapyr, untreated Melkassa-2, and imidacloprid-treated Melkassa-4 showed no statistically significant differences in the number of rows per ear. The maximum row number per ear might be due to the genetics of maize varieties, particularly the Melkassa-2 variety has a wider ear diameter than the other tested varieties, resulting in a maximum row number per ear. In addition to the varieties, synthetic insecticides increased the row number per ear due to the reduction of damage in growth parameters by the FAW larvae. The present study is consistent with the findings of Ochoa et al.(2023) observed a significant difference in row number per ear from insecticide-treated maize varieties recorded (14.48 rows) and from untreated varieties (12.25 rows), but also a significant difference due to maize varieties.

4.4.2. Ear length

The analysis indicated that there is a highly significant (p<0.001) difference in ear lengths caused by the interaction between maize varieties and insecticides (Table 12). The longest ear was measured from the Melkassa-4 variety treated with Spinosad + chlorfenapyr (23.23 cm), followed by Spinosad + chlorfenapyr treated Melkassa -2 varieties (22.93) and chlorfenapyr Melkassa-4 (21.73 cm) while the shortest ear length was measured from untreated Berihu variety (8.9 cm) next to Imidacloprid treated Berihu variety (11.37 cm) and Abamectin +acetamiprid treated Berihu (11.73cm) variety. The length of the ear can be due to genetic differences in the maize varieties and the efficacy of the insecticides on the FAW larvae, which reduced damage to the maize ears. This result is supported by Getu et al. (2024a) showed a highly significant interaction effect of maize varieties and synthetic insecticides on the ear length of maize varieties.

4.4.3. Thousand kernel weight

The main effect of maize varieties and synthetic insecticides was demonstrated with a very highly significant ($p<0.001$) difference in the thousand kernel weight (Table 11 above). The thousand kernel weights recorded the highest amount based on variety Melkassa-2 (297.4 g), while the lowest thousand kernel weight was recorded in variety Berihu (274.9 g). The thousand kernel weight can be different due to the size of the grain of the tested varieties. This result correlates with Asefa et al. (2022), who observed a highly significant effect due to maize varieties on thousand-kernel weight. Regarding the insecticides, the lowest (257 g) thousand kernel weight was recorded from untreated maize varieties, whereas the highest (315 g) thousand kernel weight was recorded from Spinosad +chlorfenapyr treated plots, followed by chlorfenapyr(300.5 g) sprayed maize plots. This might be because the synthetic insecticides make the maize plant healthy, resulting in undamaged and larger grains being produced. Bhandari et al.(2024) have reported similar results, which indicated a significant effect on thousand kernel weights due to synthetic insecticides, with Spinosad recording the highest thousand kernel weight from Spinosad (382 g) while the lowest (257 g) was from untreated plots.

4.4.4. Grain yield

The interaction effect of Insecticides and maize varieties exhibited a significant (<0.05) difference in grain yield (Table 12). The maximum (5166 kg ha^{-1}) grain yield was obtained from the Melkassa -2 variety treated with Spinosad +Chlorfenapyr followed by Chlorfenapyr (4441 kg ha^{-1}) alone, Melkassa-4 treated with Spinosad +Chlorfenapyr (3957 kg ha^{-1}) while the lowest (1935 kg ha^{-1}) grain yield was attained from water sprayed Berihu variety followed by water sprayed Melkassa -4 (2151 kg ha^{-1}), Berihu treated with imidacloprid (2620 kg ha^{-1}). Melkassa-4 was treated with imidacloprid (2698 kg ha^{-1}) and untreated Melkassa-2 (2978 kg ha^{-1}). The observed variation in grain yield may be attributed to the inherent genetic differences among the varieties as well as the varying efficacy of the tested insecticides against fall armyworms. These findings aligned with the studies by Getu et al. (2024b) and Nboyine et al. (2021) indicated noticeable differences in grain yield due to the interaction effect of maize varieties and synthetic insecticides. The Chlorfenapyr-treated Berihu, Imidacloprid-treated Melkassa-2, and Abamectin + acetamiprid-treated Melkassa-4 produced moderate yields among the treated plots, ranging (from 3010- 3271kg ha^{-1}). This showed a strong interaction effect of maize varieties with synthetic insecticides on grain yield reduced by the fall armyworm damage. This result is contrary to the findings of Mukanga et al.(2024) and Sharma et al. (2023) recorded the lowest grain yield from imidacloprid and acetamiprid-treated varieties in comparison to the tested maize varieties in combination with other insecticides that were statistically similar to the grain yield obtained from Azadirachtin-treated maize varieties.

4.4.5. Avoidable yield loss and yield increment of grain yield

The avoidable yield loss and yield increment of grain yield are presented in Table 12 below. The highest grain yield (5166 kg/ha) was harvested from Melkassa-2 treated with Spinosad Chlorfenapyr, while the lowest (1935 kg) was from the untreated Berihu variety. The avoidable yield loss and yield increment are calculated over the untreated plot of each variety. The result indicates that the greatest avoidable yield loss (46.32%) was obtained from untreated Berihu compared to Spinosad + Chlorfenapyr-treated Berihu variety due to fall armyworm damage. In contrast, a yield advantage (86.3%) over the control was obtained from Spinosad +chlorfenapyr-treated plots of the Berihu variety. Additionally, the maximum estimated yield loss (45.6%) was calculated from untreated Melkassa-4 in comparison to Spinosad + Chlorfenapyr-treated Melkassa-4 variety, which was attributed to the fall infestation. However, the yield increment (83.96%) over the control was calculated from Spinosad + Chlorfenapyr. Similarly, in the Berihu variety, the highest yield advantage (86.3%) was calculated from the Spinosad + Chlorfenapyr over untreated plots.

Overall, the yield loss was minimized by 42.35%,45.6%, and 46.32% from Melkassa-2, Melkassa-4, and Berihu varieties, respectively, when treated with Spinosad + Chlorfenapyr insecticide sprayed three times. This result is consistent with the finding of Mukanga et al.(2024) indicated that an increase in yield from 40.2%-71.1 % was obtained from the insecticide-treated maize varieties over untreated maize varieties. Similarly, Bhandari et al.(2024) revealed that the Spinosad-treated varieties resulted in an 80.6% yield increment over untreated varieties. Additionally, Ahmed (2023) reported that from 12.71% to 32% yield loss is minimized due to fall armyworm infestation by the integration of insecticides and maize varieties. This result also collaborates with Karki et al.(2023) reported that the estimated yield loss was 30.80% from the synthetic insecticides treated over the untreated plots.

Table 12. Interaction effect of varieties and insecticides on yield components and grain yield

Varieties	Insecticides	EL	RN	GY	Yield increment over control (%)	GY loss (%)
Berihu	Control	8.90^{e}	8.30^{g}	1935^{g}	0	0
	Spinosad+Chlorfenapyr	15.17^{c}	13.03^{bcd}	3605^{cd}	86.3	46.32
	Chlorfenapyr	13.97^{cd}	12.47^{cde}	3271^{cde}	69.04	40.84
	Acetamiprid+Abamectin	11.73^{de}	10.67^{ef}	3046^{de}	57.41	36.47
	Imidacloprid	11.37^{de}	10.20^{fg}	2620^{efg}	35.4	26.15
Melkassa-2	Control	13.20^{cd}	12.60^{cde}	2978^{def}	0	0
	Spinosad+ Chlorfenapyr	22.93^{a}	18.57^{a}	5166^{a}	73.47	42.35
	Chlorfenapyr	20.07^{b}	17.57^{a}	4441^{ab}	49.12	32.94
	Acetamiprid+Abamectin	15.17^{c}	14.43^{bc}	3417^{cde}	14.74	12.85
	Imidacloprid	14.67^{c}	13.67^{bcd}	3010^{de}	10.78	10.63
Melkassa-4	Control	13.30^{cd}	10.70^{ef}	2151^{fg}	0	0
	Spinosad +Chlorfenapyr	23.23^{a}	14.83^{b}	3957^{bc}	83.96	45.6
	Chlorfenapyr	21.73^{ab}	13.63^{bcd}	3730^{bcd}	73.40	42.33
	Acetamiprid+Abamectin	15.80^{c}	12.33^{de}	3135^{cde}	45.74	31.39
	Imidacloprid	15.27^{c}	12.10^{def}	2698^{efg}	25.43	20.27
CD (5%)		2.84	1.98	829.35		
P-value		<0.001	0.032	0.016		
CV (%)		6.0	5.0	8.4		

Note: Means followed with the same letter(s) within the same column are not significantly different.

Where EL: is ear length, RN: is row number per ear, and GY: is grain yield.

4.4.6. Association of FAW data with growth, yield, and yield attributes

The results of correlation analysis indicated the FAW infestation had a significant positive correlation with maize leaf damage severity (r = 0.98***), Tassel damage (r = 0.96***), and ear damage (r = 0.80***). However, a strong negative association with every parameter was assessed, including the mortality percentage of larvae, egg masses, plant height, row number, ear length, and thousand kernel weight (Table 13). Additionally, grain yield had a highly significant negative correlation with the percentage of plants infested (r = -0.8**), leaf damage severity (r = -0.82***), Tassel damage (r =-86***), and ear damage (r = -0.90***). Additionally, the grain yield was highly significant and positively correlated with mortality of larvae (r=0.77***), plant height (r=0.84***), ear length (r=0.78***), row number (r=0.87***), and thousand kernel weight (r=0.85***). This result strongly correlates with the findings of Bhandari et al.(2024) and Mukanga et al. (2024), who reported that foliar damage severity was negatively correlated with mortality rate, plant height, ear height, cob length, cob diameter, and thousand-grain weight, and grain yield

Table 13: Correlation of FAW, plant damage, yield and yield attributes

Variables	ASI	ASLDS	AFSM	ASSM	ATSM	ASEM	TD	PH	EL	RN	ED	TKW	GY
ASI	1.00												
ASLDS	0.98	1.00											
AFSM	-0.97	-0.98	1.00										
ASSM	-0.97	-0.97	0.99	1.00									
ATSM	-0.97	-0.97	0.99	1.00	1.00								
ASEM	-0.56	-0.60	0.59	0.58	0.57	1.00							
TD	0.96	0.96	-0.96	-0.95	-0.95	-0.60	1.00						
PH	-0.77	-0.79	0.80	0.77	0.76	0.66	-0.83	1.00					
EL	-0.70	-0.72	0.71	0.71	0.68	0.63	-0.71	0.72	1.00				
RN	-0.76	-0.76	0.73	0.69	0.68	0.52	-0.77	0.81	0.82	1.00			
ED	0.80	0.82	-0.81	-0.79	-0.78	-0.65	0.84	-0.86	-0.77	-0.88	1.00		
TKW	-0.78	-0.80	0.80	0.77	0.75	0.75	-0.83	0.84	0.71	0.78	-0.81	1.00	
GY	-0.80	-0.82	0.80	0.78	0.77	0.67	-0.86	0.84	0.78	0.87	-0.90	0.85	1.00

All the results of correlation analysis showed that highly significant P≤0.001(***)

Where, ASI: after spray incidence, ASLDS: after spray leaves damage severity, AFSM: after first spray mortality, ASSM: after second spray mortality, ATSM: after third spray mortality, ASEM: after the spray egg masses TD: tassel damage, PH: plant height, EL: ear length, RN: row number, ED: ear damage, TKW: thousand kernel weight, GY: grain yield

4.5. Economic Analysis

The grain yield was considered for sale, and except for the cost of seed and synthetic insecticides, all other costs were assumed to be zero. The partial budget analysis indicates that the treated plots, particularly those treated with Spinosad + chlorfenapyr, demonstrated a significantly higher net benefit compared to the untreated plots. Specifically, the Melkassa variety treated with Spinosad + chlorfenapyr yielded the maximum net benefit of ETB 202,923 per hectare, which is notably higher than the net benefits from other treatment combinations (Table 14).

Additionally, the Spinosad + chlorfenapyr treatment on the Melkassa-2 variety resulted in the highest marginal return rate of (39,071.6%), followed by the chlorfenapyr-treated Melkassa-2 (22936%). These results suggest that the combination of Spinosad +chlorfenapyr and chlorfenapyr is highly effective in enhancing both yield and economic returns for the Melkassa-2 variety, making it a potentially optimal choice for farmers looking to maximize their profits while managing pest issues effectively. This result is in line with the previous findings of Ahir et al.(2021a) and Panigrahi et al.(2023) reported that the maximum return rate was obtained from spinosad, chlorantraniliprole, and Emamectin benzoate insecticides treated maize varieties. Similarly, Nboyine et al.(2022) revealed that the highest marginal return rate was obtained from the insecticide-treated plots in comparison to the untreated varieties. Additionally, Kusi et al.(2024) showed that the integration of synthetic insecticides with intercropped maize resulted in the highest marginal rate of return.

Table 14. Partial budget analysis of insecticides and varieties to control FAW on maize

Varieties	Insecticides	ADY Kgha^{-1}	SR ETBha^{-1}	TVC ETBha^{-1}	NB ETBha^{-1}	Dominance	MRR %
Berihu	Control	1741.5	60952.5	1050	59902.5	-	
	Spinosad+Chlorfenapyr	3244.5	113557.5	5850	107707.5	D	
	Chlorfenapyr	2943.9	103036.5	6450	96586.5	D	
	Acetamiprid+Abamectin	2741.4	95949	4650	91299	D	
	Imidacloprid	2358	82530	7050	75480	D	
Melkassa-2	Control	2680.2	120609	1500	119109	N	19694.8
	Spinosad+ Chlorfenapyr	4649.4	209223	6300	202923	N	39071.6
	Chlorfenapyr	3996.9	179860.5	6900	172960.5	N	22936.4
	Acetamiprid+Abamectin	3075.3	138388.5	5100	133288.5	N	9036.8
	Imidacloprid	2709	121905	7500	114405	N	10008.8
Melkassa-4	Control	1935.9	87115.5	1375	85740.5	N	7950.1
	Spinosad +Chlorfenapyr	3561.3	160258.5	6175	154083.5	N	1934.42
	Chlorfenapyr	3357	151065	6775	144290	N	-12343.8
	Acetamiprid+Abamectin	2821.5	126967.5	4975	121992.5	N	82.9
	Imidacloprid	2428.2	109269	7375	101894	N	-14961.4

ADY: Adjustable yield, SR: sale revenue, TVC: total variable cost, NB: net benefit, MRR: marginal return rate, $ETBha^{-1}$: Ethiopian Birr Per Hectare

The price of the grain per kilogram was 35 for Berihu but 45ETB for Melkassa-2 and Melkassa -4 during the harvesting.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

The results of this study demonstrate that the integration of maize varieties with selective synthetic insecticides is a highly effective strategy for managing the devastating fall armyworm (FAW) pest in the study area. The Melkassa-2 variety treated with the Chlorfenapyr+Spinosad and Chlorfenapyr insecticide combination exhibited the most promising performance, with the lowest FAW incidence, leaf, tassel, and ear damage severity, the highest larvae mortality rate, maximum grain yield, the highest marginal return rate, and minimum yield loss. In contrast, the untreated local Berihu variety showed the highest FAW infestation, with the highest leaf, tassel, and ear damage severity, lowest grain yield, and maximum yield loss.

The Abamectin + Acetamiprid insecticide showed moderate efficacy against fall armyworm, resulting in moderate reductions in leaf and ear damage severity across the Berihu, Melkassa-2, and Melkassa-4 varieties, whereas Imidacloprid was the least effective in controlling FAW, resulting in higher pest infestations and lower yields compared to the other tested insecticides across the varieties. Among the maize varieties, Melkassa-4 exhibited moderate tolerance to FAW, while the Berihu variety was the most susceptible, resulting in the highest pest damage and lowest grain yields. Furthermore, the minimum days to tasselling, silking, maturity, highest plant height, maximum thousand kernel weight, and highest egg masses were recorded from Spinosad chlofenapyr among the tested insecticides. Additionally, the grain yield was highly negatively correlated with the percentage of leaf infestation, leaf damage severity, tassel, and ear damage. However, the grain had a strong positive association with plant height, FAW larval Mortality percentage, ear length, row number, and thousand-grain weight.

The partial budget analysis revealed that the Spinosad + Chlorfenapyr and Chlorfenapyr alone treated Melkassa-2 variety resulted in the highest marginal return rate, which is significantly higher than the net benefits from other treatment combinations. These results suggest that the combination of the Melkassa-2 variety with Spinosad +chlorfenapyr and chlorfenapyr alone is highly effective in enhancing both yield and economic returns, making it a potentially optimal choice for farmers looking to maximize their profits while managing FAW damage effectively.

5.2. Recommendations

Based on the findings from the study, the integration effect of synthetic insecticides (Spinosad + Chlorfenapyr and Chlorfenapyr alone) and tolerant improved varieties (Melkassa-2) has proven to significantly increase FAW larval mortality, reduce plant damage, and thus increase yield as well as overall substantial profits. Therefore, it can be recommended that maize growers (small-scale farmers, private sectors, and other state enterprises) should adopt and use the integration of Spinosad + chlorfenapyr and chlorfenapyr with the Melkassa-2 variety to effectively manage fall armyworm (FAW) and thereby boost the maize yield. Further research should be conducted to elucidate the specific morphological, biochemical, and genetic factors underlying the Melkassa-2 variety's enhanced resistance. While the study results are promising, it is also important to recognize its limitations, as it has used a few improved varieties coupled with the latest and better environmentally friendly insecticides. Moreover, since the research was conducted in a single location and season, the findings may not be universally effective and efficient without further validation across diverse regions and different seasons.

6. REFERENCES

Abate, T., Shiferaw, B., Menkir, A., Wegary, D., Kebede, Y., Tesfaye, K., Kassie, M., Bogale, G., Tadesse, B., & Keno, T. (2015). Factors that transformed maize productivity in Ethiopia. *Food Security*, *7*, 965–981.

Abro, Z., Kimathi, E., De Groote, H., Tefera, T., Sevgan, S., Niassy, S., & Kassie, M. (2021). Socioeconomic and health impacts of fall armyworm in Ethiopia. *PLoS One*, *16*(11), 1–19.

Aguirre, L. A., Hernández-Juàrez, A., Flores, M., Cerna, E., Landeros, J., Frías, G. A., & Harris, M. K. (2016). Evaluation of foliar damage by Spodoptera frugiperda (Lepidoptera: Noctuidae) to genetically modified corn (Poales: Poaceae) in Mexico. *Florida Entomologist*, *99*(2), 276–280.

Ahir, K. C., Mahla, M. K., Sharma, K., Babu, S. R., & Kumar, A. (2021). Bio-efficacy of insecticides against fall armyworm. *The Indian Journal of Agricultural Sciences*, *91*(12), 1796–1800.

Ahissou, B. R., Sawadogo, W. M., Bokonon-Ganta, A., Somda, I., & Verheggen, F. (2021). Integrated pest management options for the fall armyworm Spodoptera frugiperda in West Africa: Challenges and opportunities. A review. *Biotechnologie, Agronomie, Société et Environnement*, *25*.

Ahmed, S. (2023). Integrated Management of Fall Armyworm (Spodoptera Frugiperda)(JE Smith)(Lepidoptera: Noctuidae) in Maize. *American Journal of Entomology*, *7*(3), 109–119.

Aleem, K., Imran, M., Bashir, S., Pernia, A., Manzoor, M., Anwar, M. S., Akbar, M., & Munawar, I. (2023). Integrated pest management strategies for invasive fall armyworm. *Agrobiological Records*, *12*(2708–7182), 53–59.

Amegbor, I. K., Adu, G. B., Nelimor, C., Prasanna, B. M., Beyene, Y., Chivasa, W., Gethi, J. G., Togola, A., Jamal-Deen, A., & Adogoba, D. S. (2025). Assessment of fall armyworm tolerant maize hybrids for sustainable maize production in sub-Saharan Africa. *Phytoparasitica*, *53*(2), 29.

Anilkumar, G., LakshmiSoujanya, P., Kumar, D. V, Kumar, V. M., Yathish, K. R., Sekhar, J. C., & Jat, H. S. (2024). Integrated approaches for the management of invasive fall armyworm, Spodoptera frugiperda (JE Smith) in maize. *Journal of Plant Diseases and Protection*, *131*(3), 793–803.

Anjorin, F. B., Odeyemi, O. O., Akinbode, O. A., & Kareem, K. T. (2022). Fall armyworm (Spodoptera frugiperda)(JE Smith)(Lepidoptera: Noctuidae) infestation: maize yield depression and physiological basis of tolerance. *Journal of Plant Protection Research,* 12–21.

Asefa Kusa, K., Alemu, S., & Teshome, G. (2022). Evaluation of Drought Tolerant Maize Varieties (Zea mays L.) For Low Land of Guji Zone, Southern Oromia, Ethiopia. *Journal of Agronomy*, *21*(1), 8–13. https://doi.org/10.3923/ja.2022.8.13

Assefa, F. (2018). Status of fall armyworm (Spodoptera frugiperda), biology and control measures on maize crop in Ethiopia: a review. *International Journal of Entomological Research*, *6*(2), 75–85.

Assefa, F., & Ayalew, D. (2019). Status and control measures of fall armyworm (Spodoptera frugiperda) infestations in maize fields in Ethiopia: A review. *Cogent Food & Agriculture*, *5*(1), 1641902.

Badhai, S., Gupta, A. K., & Koiri, B. (2020). Integrated management of fall armyworm (Spodoptera frugiperda) in maize crop. *Reviews in Food and Agriculture*, *1*(1), 27–29.

Bajracharya, A. S. R., & Bhat, B. (2024). Evaluation of chemical insecticides against Fall Armyworm, Spodoptera frugiperda (JE Smith) in maize. *Journal of Nepal Agricultural Research Council*, *10*, 97–104.

Bakry, M. M. S., & Abdel-Baky, N. F. (2024). Impact of the fall armyworm, Spodoptera frugiperda (Lepidoptera: Noctuidae) infestation on maize growth characteristics and yield loss. *Brazilian Journal of Biology*, *84*, 1–16. https://doi.org/10.1590/1519-6984.274602

Bateman, M. L., Day, R. K., Luke, B., Edgington, S., Kuhlmann, U., & Cock, M. J. W. (2018). Assessment of potential biopesticide options for managing fall armyworm (Spodoptera frugiperda) in Africa. *Journal of Applied Entomology*, *142*(9), 805–819.

Bateman, M. L., Day, R. K., Rwomushana, I., Subramanian, S., Wilson, K., Babendreier, D., Luke, B., & Edgington, S. (2021). Updated assessment of potential biopesticide options for managing fall armyworm (Spodoptera frugiperda) in Africa. *Journal of Applied Entomology*, *145*(5), 384–393.

Baudron, F., Zaman-Allah, M. A., Chaipa, I., Chari, N., & Chinwada, P. (2019). Understanding the factors influencing fall armyworm (Spodoptera frugiperda JE Smith) damage in African smallholder maize fields and quantifying its impact on yield. A case study in Eastern Zimbabwe. *Crop Protection*, *120*, 141–150.

Beato, L. (2018). Planting Corn the Earth-Friendly Way: Use of Bio-Fertilizers and Plant-Based Insecticides in Cultivating Green Corn At Laguna, Philippines. *International Journal of Advanced Research*, *6*(2), 1740–1756. https://doi.org/10.21474/ijar01/6614

Bekis, D. (2024). Evaluation of Maize (Zea mays L.) Varieties for Irrigation Season at Fogera District of South Gondar Zone, Northwestern Ethiopia. *J Plant Genet Breed*, *8*(206), 2.

Bhandari, G. S., Bhandari, P., & Sah, L. (2024). Efficacy of Insecticides against Fall Armyworm, Spodoptera frugiperda (JE Smith) in Maize Field in Chitwan, Nepal. *Journal of Nepal Agricultural Research Council*, *10*, 50–60.

Bhusal, S., & Chapagain, E. (2020). Threats of fall armyworm (Spodoptera frugiperda) incidence in Nepal and it's integrated management-A review. *Journal of Agriculture and Natural Resources*, *3*(1), 345–359.

BoARD. (2023). Beaureu of Agriculture and Rural Development Workshop. *The Outbreak of Locust and Fall Armyworm Damage Status in Tigray Region Ethiopia,Mekelle December 22-25*.

Caniço, A., Mexia, A., & Santos, L. (2021). Farmers' knowledge, perception and management practices of fall armyworm (Spodoptera frugiperda Smith) in Manica province, Mozambique. *NeoBiota*, *68*.

Chen, Q., Liu, X., Cao, S., Ma, B., Guo, M., Shen, J., & Wang, G. (2021). Fine structure and olfactory reception of the labial palps of Spodoptera frugiperda. *Frontiers in Physiology*, *12*, 680697.

Chimweta, M., Nyakudya, I. W., Jimu, L., & Bray Mashingaidze, A. (2020a). Fall armyworm [Spodoptera frugiperda (J.E. Smith)] damage in maize: management options for flood-recession cropping smallholder farmers. *International Journal of Pest Management*, *66*(2), 142–154. https://doi.org/10.1080/09670874.2019.1577514

Chimweta, M., Nyakudya, I. W., Jimu, L., & Bray Mashingaidze, A. (2020b). Fall armyworm [Spodoptera frugiperda (JE Smith)] damage in maize: management options for flood-recession cropping smallholder farmers. *International Journal of Pest Management*, *66*(2), 142–154.

Chiriboga Morales, X., Tamiru, A., Sobhy, I. S., Bruce, T. J. A., Midega, C. A. O., & Khan, Z. (2021). Evaluation of African maize cultivars for resistance to fall armyworm Spodoptera frugiperda (JE Smith)(Lepidoptera: Noctuidae) larvae. *Plants*, *10*(2), 392.

CSA. (2021). *Central Statistical Agency (CSA)(2020/21). Reports on area and crop production forecasts for major grain crops (For private peasant holding, Meher Season). The FDRE Statistical Bulletins (1990–2021), CSA, Addis Ababa, Ethiopia*.

Dahal, A., Dahal, K., Koirala, S., & Wagle, P. (2022). Effect of Different Insecticides against Fall Armyworm, Spodoptera frugiperda (JM Smith) in Maize at Belaka Municipality, Udayapur, Nepal. *Asian Journal of Research in Agriculture and Forestry*, *2*(10), 1–6.

Day, R., Abrahams, P., Bateman, M., Beale, T., Clottey, V., Cock, M., Colmenarez, Y., Corniani, N., Early, R., & Godwin, J. (2017). Fall armyworm: impacts and implications for Africa. *Outlooks on Pest Management*, *28*(5), 196–201.

De Groote, H., Kimenju, S. C., Munyua, B., Palmas, S., Kassie, M., & Bruce, A. (2020). Spread and impact of fall armyworm (Spodoptera frugiperda JE Smith) in maize production areas of Kenya. *Agriculture, Ecosystems & Environment*, *292*, 106804.

Demis, E., & Jemal, A. (2024). Biology, Distribution and Management of Fall Army Worm Spodoptera frugiperda (JE Smith) in Ethiopia. *Indian Journal of Entomology*, 1–9.

Deshmukh, S., Pavithra, H. B., Kalleshwaraswamy, C. M., Shivanna, B. K., Maruthi, M. S., & Mota-Sanchez, D. (2020). Field efficacy of insecticides for management of invasive fall armyworm, Spodoptera frugiperda (JE Smith)(Lepidoptera: Noctuidae) on maize in India. *Florida Entomologist*, *103*(2), 221–227.

Dileep, K., & Mohan, M. (2020). Bio-efficacy of selected insecticides against fall armyworm , Spodoptera frugiperda (J . E . Smith) (Noctuidae: Lepidoptera), in maize. *Journal of Entomology and Zoology Studies*, *8*(4), 1257–1261.

Dos Santos, C. A. M., do Nascimento, J., Gonçalves, K. C., Smaniotto, G., de Freitas Zechin, L., da Costa Ferreira, M., & Polanczyk, R. A. (2021). Compatibility of Bt biopesticides and adjuvants for Spodoptera frugiperda control. *Scientific Reports*, *11*(1), 5271.

Du Plessis, H., Schlemmer, M.-L., & Van den Berg, J. (2020). The effect of temperature on the development of Spodoptera frugiperda (Lepidoptera: Noctuidae). *Insects*, *11*(4), 228.

Dumas, P., Legeai, F., Lemaitre, C., Scaon, E., Orsucci, M., Labadie, K., Gimenez, S., Clamens, A.-L., Henri, H., & Vavre, F. (2015). Spodoptera frugiperda (Lepidoptera: Noctuidae) host-plant variants: two host strains or two distinct species? *Genetica*, *143*, 305–316.

Early, R., González-Moreno, P., Murphy, S. T., & Day, R. (2018). *Forecasting the global extent of invasion of the cereal pest Spodoptera frugiperda, the fall armyworm. NeoBiota 40: 25–50* (pp. 25–50).

Edosa, T. T., & Dinka, T. D. (2021). Current and future potential distribution, risk and management of Spodoptera frugiperda. *J Innov Agric*, *8*, 14–23.

El-Tokhy, A. I., Ibrahim, K. M., & El-Sheikh, W. (2024). Impact of Insecticide on Fall Armyworm Infestation at Different Maize Growth Stages: Insights from a Field Study in a Subtropical Region. *New Valley Journal of Agricultural Science*, *4*(4), 55–72.

FAO. (2018). Integrated Management of the Fall Armyworm on Maize. In *A guide for Farmer Field Schools in Africa* (pp. 1–133). http://www.grainsa.co.za/upload/FAO---FAW-Guide.pdf

FAOSTAT. (2023). Food and Agriculture Organization of the United Nations. In *https://www.fao.org/faostat/ accessed Feburary 26,2025*.

Fathy, M., Aziz, A., Saad, H. M., & Mousa, E. A. M. (2024). The efficacy of some insecticides against fall Armyworm , Spodoptera frugiperda (Lepidoptera : Noctuidae), in maize fields. *I Nternational Journal of Entomology Research*, *9*(8), 175–179.

Ge, S.-S., He, L.-M., Wei, H. E., Ran, Y. A. N., Wyckhuys, K. A. G., & Wu, K.-M. (2021).

Laboratory-based flight performance of the fall armyworm, Spodoptera frugiperda. *Journal of Integrative Agriculture*, *20*(3), 707–714.

Gebreziher, H. G. (2020). Review on management methods of fall armyworm (Spodoptera frugiperda JE Smith) in Sub-Saharan Africa. *International Journal of Entomology Research*, *5*(2), 9–14.

Gebreziher, H. G., & Gebreziher, F. G. (2020). Effect of integrating night-time light traps and push-pull method on monitoring and deterring adult fall armyworm (Spodoptera frugiperda). *International Journal of Entomology Research*, *5*(1), 28–32.

Getu, A., Jenber, A. J., Tesfaye, A., & Wubshet, B. (2024a). Survey and Management of Fall Armyworm (Spodoptera Frugiperda JE, Smith) on Maize (Zea Mays L.), Ethiopia. *Entomology and Applied Science Letters*, *11*(1), 30–39. https://doi.org/10.51847/8ojgsxgjn0

Getu, A., Jenber, A. J., Tesfaye, A., & Wubshet, B. (2024b). Survey and Management of Fall Armyworm (Spodoptera Frugiperda JE, Smith) on Maize (Zea Mays L.), Ethiopia. *Entomology and Applied Science Letters*, *11*(1–2024), 30–39.

Goergen, G., Kumar, P. L., Sankung, S. B., Togola, A., & Tamò, M. (2016). First report of outbreaks of the fall armyworm Spodoptera frugiperda (JE Smith)(Lepidoptera, Noctuidae), a new alien invasive pest in West and Central Africa. *PloS One*, *11*(10), 1–9.

Gowda, G. B., Sahu, M., Ullah, F., Patil, N. B., Adak, T., Pokhare, S., Mahendiran, A., & Rath, P. C. (2021). Insecticide-induced hormesis in a factitious host, Corcyra cephalonica, stimulates the development of its gregarious ecto-parasitoid, Habrobracon hebetor. *Biological Control*, *160*, 104680.

Grote, U., Fasse, A., Nguyen, T. T., & Erenstein, O. (2021). Food security and the dynamics of wheat and maize value chains in Africa and Asia. *Frontiers in Sustainable Food Systems*, *4*, 617009.

Guo, J., Wu, S., Zhang, F., Huang, C., He, K., Babendreier, D., & Wang, Z. (2020). Prospects for microbial control of the fall armyworm Spodoptera frugiperda: a review. *BioControl*, *65*, 647–662.

He, H., Zhou, A., He, L., Qiu, L., Ding, W., & Li, Y. (2022). The frequency of cannibalism by

Spodoptera frugiperda larvae determines their probability of surviving food deprivation. *Journal of Pest Science*, *59*, 145–157.

He, L., Zhao, S., Gao, X., & Wu, K. (2021). Ovipositional responses of Spodoptera frugiperda on host plants provide a basis for using Bt-transgenic maize as trap crop in China. *Journal of Integrative Agriculture*, *20*(3), 804–814.

Hirpa, K., & Bulto, T. (2016). Effects of different termite management practices on maize production in Assosa district, Benishangul Gumuz Region, Western Ethiopia. *Journal of Biology, Agriculture and Healthcare*, *6*(1), 23.

Hossain, F., Sarika, K., Muthusamy, V., Zunjare, R. U., & Gupta, H. S. (2019). Quality protein maize for nutritional security. *Quality Breeding in Field Crops*, 217–237.

Hou, R., Li, C., Tan, Y., Wang, Y., Huang, S., Zhao, C., & Zhang, Z. (2023). Eco-friendly O-carboxymethyl chitosan base chlorfenapyr nanopesticide for effective pest control and reduced toxicity to honey bees. *International Journal of Biological Macromolecules*, *224*, 972–983.

Igyuve, T. M., Ojo, G. O. S., Ugbaa, M. S., & Ochigbo, A. E. (2018). Fall army worm (Spodoptera frugiperda); it's biology, impact and control on maize production in Nigeria. *Nigerian Journal of Crop Science*, *5*(1), 70–79.

Iqbal, M., Hussain, M. M., urRehman, K., Shah, M., Iqbal, M. F., Hussain, M., Iqbal, Z., & Sikandar, A. (2018). Evaluation of new chemistry insecticides for controlling invasive pest in citrus orchard. *International Journal of Advanced Research in Biological Sciences*, *5*, 100–105.

Kalyebi, A., Otim, M. H., Walsh, T., & Tay, W. T. (2023). Farmer perception of impacts of fall armyworm (Spodoptera frugiperda JE Smith) and transferability of its management practices in Uganda. *CABI Agriculture and Bioscience*, *4*(1), 9.

Karki, N., Soti, A., Katel, S., Bhandari, R., Thapa, N., & Yadav, S. P. S. (2023). Field efficacy of different insecticides against fall armyworm (Spodoptera frugiperda JE Smith) in spring maize (Zea mays L.). *AgroEnvironmental Sustainability*, *1*(2), 93–104.

Kashetti, S., . P., Siddaraju, R., & M.S, H. (2020). Effect of new insecticide molecule on insect management and seed quality attributes in maize (Zea mays L.). *International Journal of Chemical Studies*, *8*(2), 2844–2846. https://doi.org/10.22271/chemi.2020.v8.i2ar.9181

Kasoma, C., Shimelis, H., Laing, M., Shayanowako, A. I. T., & Mathew, I. (2020). Screening of inbred lines of tropical maize for resistance to fall armyworm, and for yield and yield-related traits. *Crop Protection*, *136*, 105218.

Kenis, M., Benelli, G., Biondi, A., Calatayud, P.-A., Day, R., Desneux, N., Harrison, R. D., Kriticos, D., Rwomushana, I., & Van den Berg, J. (2022). Invasiveness, biology, ecology, and management of the fall armyworm, Spodoptera frugiperda. *Entomologia Generalis*, *43*(2), 187–242.

Kinfe, H., Tsehaye, Y., Redda, A., Welegebriel, R., Yalew, D., Gebrelibanos, W., & Seid, H. (2017). Evaluating adaptability and yield performance of open pollinated maize varieties in North Western Tigray. *Advances in Crop Science and Technology*, *5*(6), 316.

Koffi, D., Kyerematen, R., Eziah, V. Y., Agboka, K., Adom, M., Goergen, G., & Meagher, R. L. (2020). Natural enemies of the fall armyworm, Spodoptera frugiperda (JE Smith)(Lepidoptera: Noctuidae) in Ghana. *Florida Entomologist*, *103*(1), 85–90.

Kumela, T., Simiyu, J., Sisay, B., Likhayo, P., Mendesil, E., Gohole, L., & Tefera, T. (2019). Farmers' knowledge, perceptions, and management practices of the new invasive pest, fall armyworm (Spodoptera frugiperda) in Ethiopia and Kenya. *International Journal of Pest Management*, *65*(1), 1–9.

Kusa, K. A., Alemu, S., & Teshome, G. (2022). Research Article Evaluation of Drought Tolerant Maize Varieties (Zea mays L.) For Low Land of Guji Zone, Southern Oromia, Ethiopia. *Jornal of Agronomy*, *21*(2), 8–13.

Kusi, F., Nboyine, J. A., Adjebeng-Danquah, J., Agrengsore, P., Seidu, A., Quandahor, P., Sugri, I., Adazebra, G. A., Agyare, R. Y., & Asamani, E. (2024). Effect of insecticides and intercropping systems on fall armyworm (Spodoptera frugiperda (JE Smith)) infestations and damage in maize in northern Ghana. *Crop Protection*, *186*, 106909.

Legesse, Z., Gudeta, J., Tadesse, F., & Diribsa, B. (2023a). Performance Evaluation of Drought Tolerant Hybrid Maize (Zea mays) Varieties in East Hararghe Zone, Ethiopia. *American*

Journal of Plant Biology, *8*(4), 93–96.

Legesse, Z., Gudeta, J., Tadesse, F., & Diribsa, B. (2023b). Performance Evaluation of Drought Tolerant Hybrid Maize (Zea mays) Varieties in East Hararghe Zone, Ethiopia. *American Journal of Plant Biology*, *8*(4), 93–96. https://doi.org/10.11648/j.ajpb.20230804.13

Lobulu, J., Shimelis, H., Laing, M., & Mushongi, A. A. (2019). Maize production constraints, traits preference and current Striga control options in western Tanzania: farmers' consultation and implications for breeding. *Acta Agriculturae Scandinavica, Section B—Soil & Plant Science*, *69*(8), 734–746.

Mallapur, C., Kumar Naik, A., Hagari, S., & Naik, M. (2019). Laboratory and field evaluation of new insecticide molecules against fall armyworm, Spodoptera frugiperda (J. E. Smith) on maize. *~ 729 ~ Journal of Entomology and Zoology Studies*, *7*(5), 729–733. http://www.entomoljournal.com

Manoj, M. S., Sharma, K. C., & Baskaran, R. M. (2024). Evaluation of biopesticides against the fall armyworm, Spodoptera frugiperda in maize. *International Journal of Advanced Biochemistry Research*, *8*(8S), 1000–1007. https://doi.org/10.33545/26174693.2024.v8.i8sn.1971

McGrath, D. M., Huesing, J. E., Jepson, P. C., Prasanna, B. M., & Krupnik, T. J. (2021). Fall armyworm scouting, action thresholds, and monitoring. In *A guide for integrated pest management* (pp. 21–57).

Meresa, H., Gebreselassie, T., Belay, F., Kelelew, H., & Gebreslassie, A. (2017). Yield improvement in hot pepper through demonstration of improved variety (Melkashote) with improved production technologies under irrigation scheme, Abergelle, Tigray, Ethiopia. *Journal of Horticulture and Forestry*, *9*(9), 74–79.

Mesele, T., Dibaba, K., & Mendesil, E. (2019). Farmers' perceptions of Mexican bean weevil, Zabrotes subfasciatus (Boheman), and pest management practices in Southern Ethiopia. *Advances in Agriculture*, *2019*(1), 8193818.

Midega, C. A. O., Pittchar, J. O., Pickett, J. A., Hailu, G. W., & Khan, Z. R. (2018). A climate-adapted push-pull system effectively controls fall armyworm, Spodoptera frugiperda (JE

Smith), in maize in East Africa. *Crop Protection*, *105*, 10–15.

Mohapatra, A. R., Sisodiya, D. B., Parmar, R. G., Thumar, R. K., & Patel, N. B. (2023). Evaluation of bio-intensive, chemical intensive and integrated pest management modules against fall armyworm, Spodoptera frugiperda (JE Smith) infesting maize. *Pharma Innovation Jounal*, *12*(9), 513–520.

Montezano, D. G., Sosa-Gómez, D. R., Specht, A., Roque-Specht, V. F., Sousa-Silva, J. C., Paula-Moraes, S. V. de, Peterson, J. A., & Hunt, T. E. (2018). Host plants of Spodoptera frugiperda (Lepidoptera: Noctuidae) in the Americas. *African Entomology*, *26*(2), 286–300.

Moustafa, K. (2024). Maize's origin to be revisited. *Plant Signaling & Behavior*, *19*(1), 2332017.

Mukanga, M., Matimelo, M., Lwinya, K., Machuku, O., Chilipa, L., Lupapula, M., Tembo, S. M., & Chipabika, G. (2024). Efficacy of Selected Pesticides against the Fall Armyworm Infestation in Small Holder Maize Production in Zambia. *International Journal of Agriculture and Biosciences*, *13*(2), 237–249. https://doi.org/10.47278/journal.ijab/2024.105

Muleya, M., Tang, K., Broadley, M. R., Salter, A. M., & Joy, E. J. M. (2022). Limited supply of protein and lysine is prevalent among the poorest households in Malawi and exacerbated by low protein quality. *Nutrients*, *14*(12), 2430.

Mumtaz, H., Majeed, M. Z., Afzal, M., Arshad, M., Mehmood, A., & Qasim, M. (2024). The Efficacy of Selected Synthetic Insecticide Formulations against Fall Armyworm Spodoptera frugiperda (J.E. Smith) Under Laboratory, Semi-Field and Field Conditions. *Pakistan Journal of Zoology*, *56*(1), 147–155. https://doi.org/10.17582/journal.pjz/20220822120846

Muraro, D. S., de Oliveira Abbade Neto, D., Kanno, R. H., Kaiser, I. S., Bernardi, O., & Omoto, C. (2021). Inheritance patterns, cross-resistance and synergism in Spodoptera frugiperda (Lepidoptera: Noctuidae) resistant to emamectin benzoate. *Pest Management Science*, *77*(11), 5049–5057.

Nboyine, J. A., Asamani, E., Agboyi, L. K., Yahaya, I., Kusi, F., Adazebra, G., & Badii, B. K. (2022a). Assessment of the optimal frequency of insecticide sprays required to manage fall armyworm (Spodoptera frugiperda J.E Smith) in maize (Zea mays L.) in northern Ghana. *CABI Agriculture and Bioscience*, *3*(1), 1–11. https://doi.org/10.1186/s43170-021-00070-7

Nboyine, J. A., Asamani, E., Agboyi, L. K., Yahaya, I., Kusi, F., Adazebra, G., & Badii, B. K. (2022b). Assessment of the optimal frequency of insecticide sprays required to manage fall armyworm (Spodoptera frugiperda JE Smith) in maize (Zea mays L.) in northern Ghana. *CABI Agriculture and Bioscience*, *3*(1), 3.

Nboyine, J. A., Kusi, F., Yahaya, I., Seidu, A., & Yahaya, A. (2021). Effect of cultivars and insecticidal treatments on fall armyworm, Spodoptera frugiperda (JE smith), infestation and damage on maize. *International Journal of Tropical Insect Science*, *41*(2), 1265–1275.

Niassy, S., Agbodzavu, M. K., Kimathi, E., Mutune, B., Abdel-Rahman, E. F. M., Salifu, D., Hailu, G., Belayneh, Y. T., Felege, E., & Tonnang, H. E. Z. (2021). Bioecology of fall armyworm Spodoptera frugiperda (JE Smith), its management and potential patterns of seasonal spread in Africa. *PloS One*, *16*(6), 1–24.

Ochoa, M. A. B., Sánchez-Mora, F. D., & Torres, D. T. C. (2023). Can fall armyworm damage decrease depending on the season, maize hybrid, and type of pesticides? *Scientia Agropecuaria*, *14*(3), 313–320. https://doi.org/10.17268/sci.agropecu.2023.027

Otim, M. H., Fiaboe, K. K. M., Akello, J., Mudde, B., Obonyom, A. T., Bruce, A. Y., Opio, W. A., Chinwada, P., Hailu, G., & Paparu, P. (2021). Managing a Transboundary Pest: The Fall Armyworm on Maize in. In *Moths and caterpillars* (pp. 1–24).

Panigrahi, C. K., Mahapatra, S., & Mishra, B. K. (2023). Economic assessment of chemical treatments against the invasive fall armyworm , Spodoptera frugiperda on rabi Maize (Zea mays L .) under Prayagraj region of India. *The Pharma Innovation Jornal*, *12*(7), 2762–2765.

Paredes-Sánchez, F. A., Rivera, G., Bocanegra-García, V., Martínez-Padrón, H. Y., Berrones-Morales, M., Niño-García, N., & Herrera-Mayorga, V. (2021). Advances in control strategies against Spodoptera frugiperda. A review. *Molecules*, *26*(18), 5587.

Prasanna, B. M., Bruce, A., Beyene, Y., Makumbi, D., Gowda, M., Asim, M., Martinelli, S., Head, G. P., & Parimi, S. (2022). Host plant resistance for fall armyworm management in maize: relevance, status and prospects in Africa and Asia. *Theoretical and Applied Genetics*, *135*(11), 3897–3916.

Prasanna, B. M., Carvajal-Yepes, M., Kumar, P. L., Kawarazuka, N., Liu, Y., Mulema, A. A., McCutcheon, S., & Ibabao, X. (2022). Sustainable management of transboundary pests requires holistic and inclusive solutions. *Food Security*, *14*(6), 1449–1457.

Rioba, N. B., & Stevenson, P. C. (2020). Opportunities and scope for botanical extracts and products for the management of fall armyworm (Spodoptera frugiperda) for smallholders in Africa. *Plants*, *9*(2), 207.

Safdar, U., Ahmed, W., Ahmed, M., Hussain, S., Fatima, M., & Tahir, N. (2022). A review: pesticide application in agriculture and its environmental consequences. *International Journal of Agriculture and Biosciences*, *11*(2), 125–130.

Safder, A., Bukero, A. A., Hyder, M., Rana, S., Sohail, A., Hanif, M., Shamshar, S. A., Imam, A., & Ramzan, M. (2024). Biology, Ecology and IPM of Fall Army Worm Spodoptera frugiperda (JE Smith): A Review. *Indian Journal of Entomology*, *86*(2), 663–667.

Sagar, G. C., Aastha, B., & Laxman, K. (2020). An introduction of fall armyworm (Spodoptera frugiperda) with management strategies: a review paper. *Nippon Journal of Environmental Science*, *1*(4), 1010.

Sangle, S. V, Jayewar, N. E., & Kadam, D. R. (2020). Efficacy of insecticides on larval population of fall armyworm, Spodoptera frugiperda on maize. *J. Entomol. Zool. Stud*, *8*(6), 1831–1834.

Sharanabasappa, S. D., Kalleshwaraswamy, C. M., Maruthi, M. S., & Pavithra, H. B. (2018). Biology of invasive fall army worm Spodoptera frugiperda (JE Smith)(Lepidoptera: Noctuidae) on maize. *Indian Journal of Entomology*, *80*(3), 540–543.

Sharma, S., Thapa, R. B., Pokhrel, S., Neupane, S., Tiwari, S., & Adhikari, C. (2023a). Evaluation on the Efficacy of Synthetic insecticides for the Management of Fall Armyworm, Spodoptera frugiperda (J.E. Smith (Lepidoptera: Noctuidae) in Maize. *Journal of the Plant Protection Society*, 14–21. https://doi.org/10.3126/jpps.v8i1.56444

Sharma, S., Thapa, R. B., Pokhrel, S., Neupane, S., Tiwari, S., & Adhikari, C. (2023b). Evaluation on the Efficacy of Synthetic insecticides for the Management of Fall Armyworm, Spodoptera frugiperda (JE Smith (Lepidoptera: Noctuidae) in Maize. *Journal of the Plant Protection Society*, *8*(1), 14–21.

Shavanov, M. V. (2021). The role of food crops within the Poaceae and Fabaceae families as nutritional plants. *IOP Conference Series: Earth and Environmental Science*, *624*(1), 12111.

Singh, G., & Jaglan, M. S. (2018). Seasonal incidence of different insect-pests in Kharif maize. *Journal of Pharmacognosy and Phytochemistry*, *7*(3), 3666–3669.

Sisay, B., Tefera, T., Wakgari, M., Ayalew, G., & Mendesil, E. (2019). The efficacy of selected synthetic insecticides and botanicals against fall armyworm, Spodoptera frugiperda, in maize. *Insects*, *10*(2), 45.

Sokame, B. M., Subramanian, S., Kilalo, D. C., Juma, G., & Calatayud, P. (2020). Larval dispersal of the invasive fall armyworm, Spodoptera frugiperda, the exotic stemborer Chilo partellus, and indigenous maize stemborers in Africa. *Entomologia Experimentalis et Applicata*, *168*(4), 322–331.

Soujanya, P. L., Kumar, D. V. S. R., Kumar, V. M., Yathish, K. R., Venkateswarlu, R., Karjagi, C. G., Singh, S. B., Sekhar, J. C., & Jat, H. S. (2025). Resistance in diverse maize genotypes to invasive fall armyworm Spodoptera frugiperda (JE Smith) reveals potential morpho-biochemical traits. *Crop Protection*, *187*, 106956.

Sravani, D., Guddeti, M., & Rajanikanth, E. (2021). Boquet Ears in Maize. *Biotica Researh Today*, *3*(1), 70–71.

Srinivasan, T., Shanmugam, P. S., Baskaran, V., Kavitha, Z., Yasodha, P., Ravi, M., Sathiah, N., Rabindra, R. J., Krishnamoorthy, S. V, & Muthukrishnan, N. (2022). Estimation of avoidable yield loss in Maize Zea mays L. caused by the fall armyworm Spodoptera frugiperda (JE Smith)(Noctuidae: Lepidoptera). *Ecol Environ Conserv*, *28*(4), 1946–1957.

Sugeetha, G., Adwaith, M. V, Reddy, K. S., Mahadevu, P., & Mahadeva, J. (2024). Guarding maize: screening leaf, ear and kernel damage against infestation of fall armyworm, spodoptera frugiperda (je smith). *Plant Archives (09725210)*, *24*(2), 1311–1317.

Tambo, J. A., Day, R. K., Lamontagne-Godwin, J., Silvestri, S., Beseh, P. K., Oppong-Mensah, B., Phiri, N. A., & Matimelo, M. (2020). Tackling fall armyworm (Spodoptera frugiperda) outbreak in Africa: an analysis of farmers' control actions. *International Journal of Pest Management*, *66*(4), 298–310.

Tendeng, E., Labou, B., Diatte, M., Djiba, S., & Diarra, K. (2019). The fall armyworm Spodoptera frugiperda (JE Smith), a new pest of maize in Africa: biology and first native natural enemies detected. *International Journal of Biological and Chemical Sciences*, *13*(2), 1011–1026.

Thumar, R. K., Zala, M. B., Varma, H. S., Dhobi, C. B., Patel, B. N., Patel, M. B., & Borad, P. K. (2020). Evaluation of insecticides against fall armyworm, Spodoptera frugiperda (JE Smith) infesting maize. *International Journal of Chemical Studies*, *8*(4), 100–104.

Woolfolk, S. W., Jeffers, D., Hawkins, L. K., Uhdre, R., Ni, X., & Warburton, M. L. (2025). Integrated approaches to maximizing maize resistance to fall armyworm. *CABI Reviews*, *20*(1), 1–13.

Yadesa, L., & Diro, D. (2023). Nutritional and Specialty Maize Production, Consumption, and Promising Impact on Ethiopia's Food and Nutrition Security: A Review. *EAS Journal of Nutrition and Food Sciences*, *5*, 142–157.

Yadete, E., Gurmu, S., & Biya, M. (2024). Effects of Time and Rate of Nitrogen Fertilizer Application on Phenology, Growth and Yield of Maize at Jimma, Southwestern Ethiopia. *World Journal of Agricultural Science and Technology*, *2*(4), 185–197.

Yaméogo, I. S., Latévi, K., Ouattara, D., Agboyi, L. K., Dabiré, R. A., Zallé, S., Kenis, M., Gnankiné, O., & Nacro, S. (2024). Level of damage and yield losses associated with the fall armyworm (Spodoptera frugiperda) on maize (Zea mays), millet (Pennisetum glaucum) and sorghum (Sorghum bicolor) on station in Burkina Faso. *Crop Protection*, *182*, 106743.

Zaman, M. I., & Patel, L. C. (2023). Comparative efficiency of some novel insecticides against fall army worm, Spodoptera frugiperda in maize. *International Journal of Bio-Resource and Stress Management*, *14*(10), 1350–1359.

Zhang, Z., Batuxi, Jiang, Y., Li, X., Zhang, A., Zhu, X., & Zhang, Y. (2021). Effects of different wheat tissues on the population parameters of the fall armyworm (Spodoptera frugiperda). *Agronomy*, *11*(10), 2044.

Zhu, F., Zhang, H., Chen, C., Long, Y., Liao, G., Chen, M., Qin, L., Chen, X., He, Y., & Chen, Z. (2023). Controlled-release alginate-bentonite polymer gel granules of emamectin benzoate and control efficacy against Spodoptera frugiperda. *Pest Management Science*, *79*(1), 324–335.

7. APPENDIX

Appendix Table I.ANOVA of Leaf Incidences

Where, d.f. - Degrees of Freedom, **s.s.** - Sum of Squares, **m.s**. - Mean Square, **v.r.** - Variance Ratio, **F pr.** - F-test p-value, **Rep** - Replication, **Chem** - Chemical Treatment, **Var** - Variety, **Chem.Var** - Chemical×Variety Interaction

Variate: AFSI (after the first spray incidence)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	115.73	57.87	1.26	
Chem	4	9128.53	2282.13	49.76	<.001
Var	2	1782.93	891.47	19.44	<.001
Chem.Var	8	811.73	101.47	2.21	0.057
Residual	28	1284.27	45.87		
Total	44	13123.20			

Variate: ASSI (after the second spray incidence)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	144.18	72.09	2.98	
Chem	4	20748.98	5187.24	214.49	<.001
Var	2	3000.71	1500.36	62.04	<.001
Chem.Var	8	572.62	71.58	2.96	0.016
Residual	28	677.16	24.18		
Total	44	25143.64			

Variate: ATHSI (after the third spray incidence)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep	2	173.51	86.76	7.60	
Chem	4	36461.69	9115.42	798.04	<.001
Var	2	940.98	470.49	41.19	<.001
Chem.Var	8	262.58	32.82	2.87	0.018
Residual	28	319.82	11.42		
Total	44	38158.58			

Appendix Table II. ANOVA of Larval Mortality

After the first spray

Variate: 1DAS (one day after spraying)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep	2	7.542	3.771	0.63	
Chem	4	22851.384	5712.846	948.46	<.001
Var	2	616.500	308.250	51.18	<.001
Chem.Var	8	626.842	78.355	13.01	<.001
Residual	28	168.653	6.023		
Total	44	24270.921			

Variate: 3DAS (three days after spraying)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep	2	20.82	10.41	0.41	
Chem	4	33717.07	8429.27	333.97	<.001
Var	2	1248.30	624.15	24.73	<.001
Chem.Var	8	552.82	69.10	2.74	0.023
Residual	28	706.70	25.24		
Total	44	36245.72			

Variate: 7DAS (seven days after spraying)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	13.75	6.87	0.63	
Chem	4	45889.25	11472.31	1050.45	<.001
Var	2	1754.12	877.06	80.31	<.001
Chem.Var	8	609.79	76.22	6.98	<.001
Residual	28	305.80	10.92		
Total	44	48572.70			

After the second spray

Variate: 1DAS (one day after spraying)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	36.79	18.39	1.50	
Chem	4	34381.61	8595.40	702.89	<.001
Var	2	1104.86	552.43	45.17	<.001
Chem.Var	8	582.63	72.83	5.96	<.001
Residual	28	342.40	12.23		
Total	44	36448.29			

Variate: 3DAS (three days after spraying)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep	2	6.461	3.230	0.41	
Chem	4	44969.889	11242.472	1429.88	<.001
Var	2	1493.654	746.827	94.99	<.001
Chem.Var	8	534.756	66.845	8.50	<.001
Residual	28	220.151	7.863		
Total	44	47224.911			

Variate: 7DAS (seven days after spraying)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep	2	38.66	19.33	1.71	
Chem	4	59091.75	14772.94	1306.98	<.001
Var	2	1743.58	871.79	77.13	<.001
Chem.Var	8	479.34	59.92	5.30	<.001
Residual	28	316.49	11.30		
Total	44	61669.82			

After the third spray

Variate: 1DAS (one day after spraying)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep	2	1.576	0.788	0.12	
Chem	4	50086.471	12521.618	1844.28	<.001
Var	2	1263.750	631.875	93.07	<.001
Chem.Var	8	548.629	68.579	10.10	<.001
Residual	28	190.104	6.789		
Total	44	52090.530			

Variate: 3DAS (three days after spraying)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	6.98	3.49	0.32	
Chem	4	61473.61	15368.40	1420.05	<.001
Var	2	1589.94	794.97	73.46	<.001
Chem.Var	8	576.94	72.12	6.66	<.001
Residual	28	303.03	10.82		
Total	44	63950.50			

Variate: 7DAS (seven days after spraying)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	26.958	13.479	1.48	
Chem	4	81538.589	20384.647	2244.37	<.001
Var	2	1714.089	857.045	94.36	<.001
Chem.Var	8	392.363	49.045	5.40	<.001
Residual	28	254.313	9.083		
Total	44	83926.312			

Appendix Table III. ANOVA of Egg Masses

Variate: BSEM (before spraying egg masses)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep	2	0.005725	0.002863	0.30	
Chem	4	0.070675	0.017669	1.83	0.152
Var	2	0.021612	0.010806	1.12	0.341
Chem.Var	8	0.055579	0.006947	0.72	0.674
Residual	28	0.270747	0.009670		
Total	44	0.424338			

Variate: AFSEM (after first spray egg masses)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication	2	0.01154	0.00577	0.36	
Chem	4	1.39113	0.34778	21.41	<.001
Var	2	0.05353	0.02677	1.65	0.211
Chem.Var	8	0.06681	0.00835	0.51	0.836
Residual	28	0.45489	0.01625		
Total	44	1.97790			

Variate: ASSEM (after second spray egg masses)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep	2	0.05565	0.02782	1.39	
Chem	4	1.62019	0.40505	20.31	<.001
Var	2	0.02456	0.01228	0.62	0.547
Chem.Var	8	0.09694	0.01212	0.61	0.764
Residual	28	0.55854	0.01995		
Total	44	2.35588			

Variate: ATHSEM (after third spray egg masses)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep	2	0.006983	0.003491	0.42	
Chem	4	0.702825	0.175706	21.24	<.001
Var	2	0.049201	0.024601	2.97	0.067
Chem.Var	8	0.068133	0.008517	1.03	0.438
Residual	28	0.231677	0.008274		
Total	44	1.058820			

Appendix Table IV. ANOVA of Leaf, Tassel, and Ear Damage Severity

Variate: AFSLDS (after the first spray leaf damage severity)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.12133	0.06067	1.51	
Chem	4	17.62578	4.40644	109.64	<.001
Var	2	4.32533	2.16267	53.81	<.001
Chem.Var	8	0.79022	0.09878	2.46	0.037
Residual	28	1.12533	0.04019		
Total	44	23.98800			

Variate: ASSLDS (after the second spray leaf damage severity)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.08578	0.04289	1.16	
Chem	4	64.86978	16.21744	439.06	<.001
Var	2	4.52978	2.26489	61.32	<.001
Chem.Var	8	1.89689	0.23711	6.42	<.001
Residual	28	1.03422	0.03694		
Total	44	72.41644			

Variate: ATHSLDS (after the third spray leaf damage severity)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.09244	0.04622	1.52	
Chem	4	149.44311	37.36078	1224.62	<.001
Var	2	9.41511	4.70756	154.31	<.001
Chem.Var	8	6.26489	0.78311	25.67	<.001
Residual	28	0.85422	0.03051		
Total	44	166.06978			

Variate: ED (ear damage)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.4858	0.2429	0.80	
Chem	4	86.1480	21.5370	71.11	<.001
Var	2	28.3658	14.1829	46.83	<.001
Chem.Var	8	7.9587	0.9948	3.28	0.009
Residual	28	8.4809	0.3029		
Total	44	131.4391			

Variate: TD (tassel damage)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	1.2444	0.6222	4.26	
Chem	4	42.0889	10.5222	72.05	<.001
Var	2	26.8444	13.4222	91.91	<.001
Chem.Var	8	2.7111	0.3389	2.32	0.047
Residual	28	4.0889	0.1460		
Total	44	76.9778			

Appendix Table V. ANOVA of Phenological and Growth Parameters.

Variate: DTE (days to emergence)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.5778	0.2889	0.50	
Chem	4	1.4667	0.3667	0.64	0.640
Var	2	10.7111	5.3556	9.32	<.001
Chem.Var	8	3.7333	0.4667	0.81	0.598
Residual	28	16.0889	0.5746		
Total	44	32.5778			

Variate: DTT (days 50% to tasselling)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep	2	192.400	96.200	16.40	
Chem	4	345.111	86.278	14.71	<.001
Var	2	475.733	237.867	40.55	<.001
Chem.Var	8	46.489	5.811	0.99	0.464
Residual	28	164.267	5.867		
Total	44	1224.000			

Variate: DTS (days 50% to silking)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	33.911	16.956	2.01	
Chem	4	1036.222	259.056	30.64	<.001
Var	2	464.844	232.422	27.49	<.001
Chem.Var	8	88.711	11.089	1.31	0.278
Residual	28	236.756	8.456		
Total	44	1860.444			

Variate: DTM (days to 90% maturity)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	181.91	90.96	8.41	
Chem	4	1148.44	287.11	26.55	<.001
Var	2	715.91	357.96	33.11	<.001
Chem.Var	8	98.09	12.26	1.13	0.372
Residual	28	302.76	10.81		
Total	44	2447.11			

Variate: PH

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep	2	272.00	136.00	1.84	
Chem	4	12089.35	3022.34	40.82	<.001
Var	2	2184.78	1092.39	14.76	<.001
Chem.Var	8	533.27	66.66	0.90	0.530
Residual	28	2072.91	74.03		
Total	44	17152.31			

Appendix Table VI.ANOVA of Yield And Yield Components

Variate: EL (ear length)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep	2	34.9773	17.4887	19.86	
Chem	4	467.3889	116.8472	132.69	<.001
Var	2	285.2280	142.6140	161.96	<.001
Chem.Var	8	33.6098	4.2012	4.77	<.001
Residual	28	24.6560	0.8806		
Total	44	845.8600			

Variate: RN (row number)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep	2	2.9453	1.4727	3.44	
Chem	4	143.4458	35.8614	83.67	<.001
Var	2	149.2573	74.6287	174.11	<.001
Chem.Var	8	8.6982	1.0873	2.54	0.032
Residual	28	12.0013	0.4286		
Total	44	316.3480			

Variate: TKW (thousand kernel weight)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep	2	1880.2	940.1	7.79	
Chem	4	18316.4	4579.1	37.93	<.001
Var	2	3826.6	1913.3	15.85	<.001
Chem.Var	8	1719.2	214.9	1.78	0.124
Residual	28	3380.5	120.7		
Total	44	29122.8			

Variate: GY (grain yield)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	303753.	151877.	2.02	
Chem	4	20979720.	5244930.	69.84	<.001
Var	2	6617013.	3308507.	44.06	<.001
Chem.Var	8	1775062.	221883.	2.95	0.016
Residual	28	2102667.	75095.		
Total	44	31778216.			

Appendix Figure I .pictures in the growth stages of maize.

Appendix Figure II. Ears of maize variety pictures

Berihu variety

Melkassa -2 variety

Melkassa-4 variety