Addis Ababa University

College of Natural and Computational Sciences

Department of Zoological Sciences (Insect Science Stream)

Assessment of possible integrated management alternatives for fall armyworm (*Spodoptera frugiperda* Smith: Lepidoptera: Nocutidae) on maize at Melkassa

By

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A thesis presented to Addis Ababa University, Department of Zoological Sciences, (Insect Sciences Stream) in partial fulfillment of the requirements for the degree of Master of Science in Zoology (Insect sciences)

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ASSESSMENT OF POSSIBLE INTEGRATED MANAGEMENT ALTERNATIVES FOR FALL ARMYWORM (*SPODOPTERA FRUGIPERDA* SMITH: LEPIDOPTERA: NOCUTIDAE) ON MAIZE AT MELKASSA

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A Thesis Presented to the School of Graduate Studies of the Addis Ababa University in Partial Fulfillment of the Requirements for the MSc in Zoological Science (Insect Science Stream)

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Declaration

I, the undersigned, hereby declare and affirm this thesis is my original work and has not been submitted to any institute. All sources of materials used for this work have been acknowledged.

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Dedication

This work is dedicated to my mother (Tsehay Beyene), my father (Degife Hailu) and my sister (Hawi Degife).

List of Abbreviations/Acronyms

FAW	Fall Armyworm
SSA	Sub Saharan Africa
IPM	Integrated pest management
IITA	International Institute for Tropical Agriculture
CABI	Centre for Agriculture and Bioscience International
CIMMYT	International maize and wheat improvement center
CSA	Central statistical agency
EIAR	Ethiopian Institution Agricultural Research
SPSS	Statistical Package for the Social Sciences
MAEZ	Maize agro ecology zones
MARC	Melkassa Agricultural Research Center

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Abstract

Maize is an important crop that is produced in Ethiopia but still falls short of its potential due to biotic and abiotic factors. Fall armyworm (Spodoptera frugiperda Smith) has been one of the yield limiting factors in Ethiopia since its introduction in 2017. This experiment was conducted at Melkasa Research Centre to asses an integrated management of fall armyworm during the 2020 rainy season. The experimental design was split plot design where the two maize varieties (Melkassa 2 and Melkasa 4) were main plot treatments, while different control options were sub-plot treatments which include T1 (Sole maize), T2 (Neem), T3 (Avaunt 150 SC), T4 (intercropping with haricot bean), T5 (Neem +intercropping with haricot bean), T6 (Avaunt 150 SC + intercropping with haricot bean), T7 (Avaunt 150 SC +Neem and T8 (Avaunt 150 SC +Neem + intercropping with haricot bean). The result obtained indicated that there was no significant difference (P>0.05) between the maize varieties in all measured parameters across all maize growth stages. Treatments such as T3, T6, T7 and T8 which contain Avaunt were effective in reducing egg and larval densities of S. frugiperda. In terms of percent infestation, plant score damage and cob damage score, treatments which also contain Avaunt had the least infested, less damaged maize plants and cobs. In a field survey for natural enemies, lady bird beetles and ear wigs were detected. Earwigs were only found from seedling to tasseling stages, while lady bird beetles were detected throughout the growth stages. In laboratory analysis the parasitoids Telenomus remeus Nixon *(Platygastridae) (egg parasitoid) and Cotesia icipe* Fiaboe, Fernández-Triana, Nyamu, & Agbodzavu *(Braconidae) (larval parasitoid) were found at seedling stage, while C. icipe and Charops ater* Szépligeti *(Ichneumonidae) both larval parasitoid were found at vegetative stage. The highest yield was obtained in T7 (Avant +neem) with the yield of 7555.08 Kg/ha, followed by T3 (Avaunt) which was 7208.4Kg/ha. From the study, it can be concluded that all control measures with Avaunt (T3, T6, T7 & T8) can be used as S. frugiperda control methods and Avaunt (indoxcarb) 150 SC can be recommended to be farmers to integrated with other controls alterenatives.*

Key words/phrases: Botanical, chemical, cereal, East Shewa, Environmentally friendly, FAW, intercropping,

1. Introduction

1.1. Background

Maize (*Zea mays* L.) is one of the most important cereal crops in the world which is cultivated widely in a broad range of agro-ecological environments (Shah *et al.,* 2006).It is the third major crop grown throughout the world after wheat and rice (Nuss & Tanumihardjo, 2010). Maize serves as an important cereal crop for millions of people in Asia, Latin America and Africa where it is used as a subsistence crop (Kumar, 1997). It is also a very important component in animal feed (Thorne *et al.*, 2003) and industries where it is used to extract bio-fuel and other products like plastics, fabrics and adhesive (Marichelvam *et al.*, 2019).

Now days, Maize can be found in different parts of the world and plays a major role in food security. It was first introduced in Africa in the 16th century (McCann 2005; Olaniyan, 2015) and is now the second most important food crop after Cassava (Yimenu Kassa, 2017). From global production, Africa accounts for 7.5% or (49MMT) with an average yield of 4.9 tons/ha (Olaniyan, 2015). Maize is cheaper than other crops which provide about 35% of calories and 34% of protein for more than 330 million people in Africa (IITA, 2020).

Maize was introduced to Ethiopia around the 16th to 17th century (McCann, 2005). Maize is the cheapest source of calories compared to other cereal crops, which makes it important for insuring food security in Ethiopian households. According to Dowswell et al. (1996), maize is the second cultivated crop next to Teff (*Eragristis teff* Zucc, Trotter) among the cereals produced in Ethiopia and its demand is ever more increasing. However, the production of maize has many limitations, among which the recently introduced insect, *S. frugiperda*, is the most important one which contributes to the low productivity of maize in Ethiopia.

S. frugiperda is native to the Americas and is a highly polyphagous. It has a migratory behavior with a high dispersal rate. *S. frugiperda* feeds on more than 80 different plant species, including maize. *S. frugiperda* was first detected in Nigeria from Africa in 2016. Then it quickly spread to South and East Africa. To date, the existence of *S. frugiperda* has been confirmed in 28 African countries (Day *et al.,* 2017). *S. frugiperda* has become the most damaging insect pest in decreasing maize production in Africa where it has the potential to cause maize yield losses of

8.3 to 20.6 million metric tons per year, which accounts for 21-53% of the annual maize production averaged over three years, in just 12 of Africa's maize producing countries (CABI, 2017).

S. frugiperda was first reported in Ethiopia in 2017, in the Bench Maji Zone of southern Ethiopia and has spread to most parts of the country (Fenta Assefa & Dereje Ayalew, 2017). According to Teshome Kumela *et al.* (2018), 93% of Ethiopian farmers encountered damage by *S. frugiperda* with an estimated 32% crop damage which poses a huge risk to the food security and livelihood of millions of farming household in the country

Currently, different methods are employed to control *S. frugiperda* such as chemical, biological, cultural and introducing maize genotypes with high ability to resist and/or tolerate *S. frugiperda*. But to properly control *S. frugiperda*, it is suggested to apply effective control measure within 30 days of damage detection to avoid additional damage (Fernandez, 2002).

For these reasons, effective control methods must be explored and put forward. In Africa, the vast majority of control is done by chemicals (Prasanna *et al.*, 2018). Though this method is effective, it comes with side effects on human health and the ecosystem. A healthy agricultural system which produces healthy crops and reduces the damage to the ecosystem can help curb this problem. This is why integrated pest management (IPM) is the best approach to *S. frugiperda* control. This method combines all the best control measures out there. It is cheap and can benefit many small scale farmers. It has the potential to reduce the impact of chemical pesticides while keeping pests below the economic threshold level (FAO, 2018).

1.2. Objective

1.2.1. General objective

- To assess an integrated management alternative for *S. frugiperda* on maize in Ethiopia

1.2.2. Specific objectives

- To evaluate the efficacy of various *S. frugiperda* control options.
- To assess the compatibility between *S. frugiperda* control options for development of integrated pest management
- To assess the effect of the treatments on natural enemies (predators) and parasitoids active against *S. frugiperda*.

2. Literature review

2.1. Overview of Maize

Maize is classified under the family Poaceace (Gramineae), which is a grass family that includes most other agriculturally important crops like wheat, rice, barley, sorghum and oats. Archeological records suggest, these major grass lineages arose from a common ancestor around 55-70 million years ago (Buckler & Stevens, 2005). The genus *zea* further classifies maize into four species, which include *Zea mays* L. (domesticated maize) is economically important and teosinte (which includes the other *Zea* sp), a large wild grass that is native to Mexico (Kumar *et al.,* 2012).

Maize is an important cereal crop in the world after rice and wheat. It provides important nutrients for humans and animals and is used as a basic raw material for the production of starch, alcoholic beverages, food sweeteners and fuel (Thorne *et al.,* 2020). Maize can be grown in a variety of agro ecologies and is adaptable to a wide range of environments. Around 72 million metric tons of maize is produced in sub Saharan Africa where it serves as a strategic food for 48 countries and millions of people insuring food security in the continent (Tsedeke Abate *et al.,* 2017).

Maize is a tall plant which can grow up to 3 meters. The stem is cylindrical, and divided into nodes and internodes. It has 8 to 21 internodes. The leaves are 9 cm in width and 120 in length which grow from each node alternately on opposite sides of the stalk. Maize is a monecious plant, which means the male and female grow on the same plant as separate inflorescence. Male flowers are borne in the tassel and female flowers on the ear. The tassel is located at the apex of the stem and in favorable condition it releases its pollen aided by wind. The ear is usually located laterally halfway up the stem. It is covered with bracts and the silk is situated on the upper part of the ear and used as pollen receptors (Plessis, 2003; Tollenaar & Dwyer, 1999).

Based on some archeological evidence, maize is believed to have been first cultivated in Mexico between 7000 and 10,000 years ago (Tollenaar & Dwyer, 1999; Ranum *et al.,* 2014) but other theories suggest that maize originated in the Himalayas (Ranum *et al.,* 2014). Maize spread to different parts of the world at a remarkable pace with respect to its evolution as a cultivated crop and type of food product. The wide spread migration of indigenous tribes of Central America introduced maize to different parts of Latin America, modern USA, Canada and the Caribbean. After European explorers discovered continental America, maize was able to spread to Europe and Asia via trade (Neumann *et al.*, 2010; Tollenaar & Dwyer; Gong *et al.*, 2015; Vollbrecht & Sigmon, 2005). Maize was first introduced to the continent of Africa in the 16th century (McCann 2005; Olaniyan, 2015).

Maize responds well to high temperatures since it originates in a subtropical environment. But in order to cultivate maize, it has been modified by selection to grow in various ecosystems. It germinates at an optimum temperature of 16 to 18^0 c while the minimum temperature required is 10^0c. Maize requires a large amount of water for a greater yield, but it is highly efficient. Around 450 to 600 mm of water per season in temperate areas and 900 mm or more in irrigated areas, depending upon evaporative demand, is required to cultivate maize. Maize grows best on moist and fertile soil planted at effective depth on sandy clam (loam), loamy and silty clay soils (Plessis, 2003; Nafziger, 2009).

Maize is cultivated all around the world across temperate and tropical zones spanning all continents. According to (FAOSTAT, 2020) in 2018, more than 192 million hectares of land were covered in maize producing around 1.5 billion tons, with 34.2% and 22.4% being produced by the USA and China, making them the top two global producers respectively. In Africa (FAOSTAT, 2020), it is stated that approximately 38 million hectares of land were cultivated, producing approximately 78 million tons. Over all, maize production is dominated by a few countries, like the USA, China, Brazil, Mexico and Argentina, which produce nearly 75% of global production (Nafziger, 2009). Africa only contributes around 7.5% of the global production in which Nigeria is the leading country with more than 33 million tons, followed by South Africa, Egypt and Ethiopia (IITA, 2020).

Maize’s nutritional content includes 72% starch, 10% protein, 4% fat, vitamin B, essential minerals and fibers, providing an energy density of 365Kcal/100g (Ranum *et al.*, 2014). It can be consumed off the cob, parched, boiled, fried, roasted, ground, and fermented for use in breads, porridges, gruel, cakes, and alcoholic beverages (Nuss & Tanumihardjo 2010). Maize is an important food for 1.2 billion people in the world where more than 330 million are sub-Saharan African. (IITA, 2020). It also accounts for over 25% of the total calories consumed per capita annual consumption of 58 kg in east Africa. (Hailegebrial Kinfe *et al.*, 2017). Some predictions also state that the demand for maize is expected to double in the developing nations between now and 2050 (Rosegrant *et al.,* 2009).

Maize is a primary source of energy in animal feed which accounts for 30% protein, 60% energy and 90% starch. Around 70-80% of the global maize production is used as an ingredient in animal feed (Dado, 1999). In the United States, 75% of the total maize production is used for these purposes (Tollenaar & Dwyer, 1999). Its low cost compared to other cereal crops makes maize preferable as animal feed. (Olaniyan, 2015). Over the past 10 years, the demand for maize has grown due to an increase in the population in Latin America and the Middle East, resulting in higher demand for livestock and poultry (Delgado, 2003). Maize can also be used in ethanol production (Eckert *et al.,* 2018) and serve as a component in the manufacturing of biodegradable plastic for commercial and industrial application (Marichelvam *et al.,* 2019).

2.2. Maize in Ethiopia and its economic importance

Maize was first introduced to Ethiopia in the 1600s and 1700s, and it was known as "*yabaher mashela*," which means "sorghum from the sea" in Amharic (McCann 2005). Maize is cultivated at 4 different maize agro ecology zones (MAEZs) classified primarily by their altitude and precipitation; high altitude sub humid (1800-2400 masl), mid-altitude sub-humid (1000-1800 masl), low altitude sub-humid (< 1000 masl) and low-moisture stress (500-1800 masl) (Mossisa Worku & Habtamu Zeleke, 2002). It is one of the most produced and consumed crops in Ethiopia. It accounts for 14.96% of the total grain crop area covered, second only to Teff, and 27.43% of total cereal production, the highest in the country (CSA, 2017/18). Ethiopia is a major maize producer in east Africa with 2 million hectares of land covered, producing more than 73 million hectares with an average yield of 32.9 quintal per hectare (FAO STATS, 2020). More than 10 million farmers in Ethiopia produce maize, by far the largest number of farmers compared to the other cereal crops in which around 4.9 million are found in the Oromia region, making it the top producer with 46 million quintal (40.78 Qt/Ha) followed by Amhara and SNNP with 20 million quintal (39.83Qt/Ha) and 11 million quintal (38.06Qt/Ha) respectively (CSA, 2017/18). The production of maize has been increasing over the past few years in Ethiopia. Between 2005 and 2012, the area under maize production increased by 32% while its yield increased by 41% and total production increased by 84% (Demeke Mulatu and Di Marcantonio, 2013).

Maize provides the cheapest calories compared to other major cereal crops, which makes it essential for food security in millions of house hold in Ethiopia (Hailegebrial Kinfe et al, 2017). The majority of Ethiopian farmers are small scale, with 94% relying on land less than 5 hectares in size, and the highest yield of maize benefits this situation (Rashid *et al.,* 2010). Maize is also used for making local beverages, fuel, construction and animal feed. The use of maize in livestock and poultry feed is very small but it is expected to grow as the demand for both is every more increasing in the country (Dawit Alemu, *et al.,* 2014; Yimenu Kassa, 2017).

2.3. Production constraints of maize in Ethiopia

Maize is an important food crop in Ethiopia. But despite its importance, the average yield of the country is still lower than the world average (FAOSTAT, 2020). There are many biotic and abiotic factors that can contribute to this. Abiotic factors include drought, heat, soil acidity, and low soil fertility, particularly in nitrogen and phosphorus (Tolera Keno *et al.,* 2018). The major biotic factors include diseases, parasitic weeds, rodents and insect pests (Mosisa Worku *et al.,* 2012). Among these, insect pest fall army worm (*Spodoptera frugiperda*) is among the main factors that are responsible for the low productivity of maize in Ethiopia (Assefa Fenta & Ayalew Dereje, 2019).

2.4. Fall Army worm

S. frugiperda is native to America and has been prevalent for more than a century. It is a highly invasive and destructive agricultural pest (Nagoshi *et al.,* 2007). FAW’s ability to consume different types of crop, spread over large areas quickly and persist throughout the year makes them very dangerous (Prasanna *et al.,* 2018). This invasive pest was first recorded in Africa in Nigeria in 2016 (Goergen, 2016). And now it is spreading to the rest of the continent at an alarming rate and threating the food security of millions (Sisay Birhanu *et al.,* 2018).

Fall army worm is also called fall army moth. Its scientific name is derived from the Latin word “frugis; frux" which means fruit and "perdere" which means to lose or to ruin indicating the pest ability to destroy crop (Bug Guide, 2020).

The adults usually have wing which is 32 to 40 mm in length. *S. frugiperda* are nocturnal and are active during humid and warm evenings. They are sexually dimorphism where the male fore wing are generally is shaded brown and grey, with triangular white spots at the tip and near the center of the wing and the female females are less distinctly marked, ranging from a uniform grayish brown to a fine mottling of brown and grey. The adult moth may live 7-12 days with an average lifespan of 10 days. Their primary source of food is flower nectar. *S. frugiperda* usually prefers warm temperatures as it is effective in producing more generations than temperate, which may result in fewer generations (Capinera, 2000).

Reproduction is usually initiated by the female emitting sex pheromones. The male then responds to the female by traveling at a slanted angle to the wind. They usually mate at dusk and can last up to 130 minutes. (Spark, 1979; Simmons & Marti, 1992). Then the eggs are spread and attached to the leaf of the plant, deposited in a layer of grayish scale between and over the egg mass. The eggs are generally dome shaped where they are rounded at the apex and flat at the base. They are 0.3 mm in height and 0.4 mm in diameter and last 2-3 days in warm seasons. A female *S. frugiperda* may lay 100-200 eggs at one time and up to 1500-2000 in her life time (Padhee & Prasanna 2019).

S. frugiperda has six larval stages. The 1st instar has a greenish body with a black head that turns to orange at the 2nd instar. The body then turned brownish and a lateral white line began to form at the 3rd instar. From 4th to 6th instar, the body is brownish with white sub dorsal and lateral line while the head is reddish brown with spots of white dots. An inverted "Y" is also observed on the face of mature larvae. In general, the head capsule width ranges from 0.3 mm (1st instar) to 2.6 mm (6th instar) and larval length in the range of about 1 mm (1st instar) to 45 mm (6th instar) (Capinera, 2000). At an optimum temperature of 25°C, the mean development time is 3.3, 1.7, 1.5, 1.5, 2.0, and 3.7 days for 1st to 6th instar (Pitre and Hogg 1983). Among all the growth stages, the larvae are the ones who are responsible for crop destruction and yield loss and can consume 140 cm^2 of maize leaf (Assefa Fenta & Ayalew Dereje, 2019).

The pupal stage begins when the sixth instar falls from the plant and digas 2-8 cm deep in the soil. *S. frugiperda* is usually 14-18mm in length and 4.5mm in width with a reddish brown color. During harsh conditions like the cold or dry season, the pupae cannot enter the diapause period

(Spark, 1979). The pupae usually mature in 8-9 days in the summer and 20-30 days in the winter (Silva *et al.*, 2017).

S. frugiperda worm has a wide range of hosts. Different publications predict different figures of plants when it comes to the total number. For example (Juarez *et al.*, 2012) estimate there to be around 186 species while (Montezano *et al.,* 2018) estimates around 353 species of host plant belonging to 76 families, mainly in Poaceae, Asteraceae and Fabaceae. Wide varieties of crops are consumed by *S. frugiperda* which includes cotton, millet, rice, peanut, sorghum, maize, sugar beet, soybean, sugarcane, tobacco, wheat, etc. But amongst these crops, the most frequently damaged are maize, sorghum, Bermuda grass and crab grass (Capinera, 2000). Besides these, when there are limited resources, fall army worm larvae prey on their own kind or other smaller caterpillars which increase their fitness (Chapman *et al.*, 1999).

Temperature, humidity and diet can affect the development of *S. frugiperda* larvae. Generally, high temperatures are usually favorable for *S. frugiperda* with the optimum temperature for larval development being 28^0c (Simmons, 1993). Besides these plant varieties, plant growth stage, soil type and tillage method can affect fall army work infestation (FAO and CABI. 2019).

2.5. Distribution of fall army worm

S. frugiperda originated in the Americas where it has been a major agriculture problem for both North and South America countries (Early *et al.*, 2018). Its existence was first confirmed in Africa in January 2016 in Nigeria (Goergen et al. 2016). According to (Day *et al.*, 2017), FAW entered from the Americas to Africa as stowaways on commercial aircraft, either in cargo containers or airplane holds, before subsequent widespread dispersal by the wind. Now, it has spread throughout Africa where it has been confirmed to exist in 30 countries (Feldmann *et al.*, 2019).

Fall army worm was discovered in an irrigated maize field in the Bench Maji zone of southern Ethiopia in February 2017. To date, it exists in most parts of the country which are major maize producing areas, including Tigray, Amhara, Oromia, SNNPs, Gambela and Beninshangul (Fenta Assefa & Ayalew Dereje, 2019). According to (Simmons, 1993), FAW is a tropical species that thrives in warm climates ranging from 10.9 to 30 degrees Celsius, in which case the minimum average temperature in Ethiopia remains above 10^0 degrees Celsius, with the exception of certain highland areas that provide favorable conditions for FAW.

2.6. Fall army worm infestation on maize and its economic impact

S. frugiperda infestation on maize is initiated at a young stage and can last long up to tasseling, but it can harm nearly all growth stages (FAO and CABI. 2019). The larvae are always responsible for crop damage. Damage is usually initiated during the first instar, when they only feed on one side of the leaf. During the 2nd and 3rd instar, the larvae start to make a hole in the leaves and eat from the edge of the leave, which produces a characteristic row of perforation in the leave. As the larvae get older, the extent of the damage increase something leaving the stalk or ribs of maize plant. The larva can also burrow through bud, whorl and husk on the side of the ear and feed on the kernels and destroying the growing potential of the plant. (Deole & Paul, 2018; Marenco *et al.,* 1992).

S. frugiperda was the 2nd most destructive insect pest in continental America, resulting in a total loss of 39-297 million dollars before it spread around the world (Spark, 1986). In Brazil, FAW is a major pest of maize, causing an estimated annual yield loss of between 19-100%, which is around 400 million dollars (Cruz & Turpin 1982). In Argentina, the yield loss by FAW ranges between 17-72% (Willink *et al.,* 1993).

In Africa, it is estimated that *S. frugiperda* has the potential to result in maize yield losses of 8.5 to 21 million metric tons, ranging from 21-53% annual production, with a value loss estimated between US $2.48 billion and US $6.19 billion each year in just 12 African maize producing countries, with Nigeria ranking first, losing around 2.1 to 5.2 million metric tons, valued at 1.8 billion dollars. (CABI, 2017). In a survey done in West Africa (Ghana and Togo) for 3 years, estimated 68.46% in 2016, 55.82% in 2017, and 17.76% in 2018, infestation level of FAW was detected on maize fields (Koffi *et al.,* 2020). In Kenya around 1 million tons of maize is lost to FAW which is roughly one third of the total countries production (Groote *et al.,* 2020).

In Ethiopia, there are different figures about FAW infestation. For example, (Day *et al.,* 2017) estimates a yield loss between around 1,227 to 3,057 tons of maize, which is about 293-728 million dollars. According to various sources, including (Teshome Kumela, *et al.,* 2018) an estimates that 93% of Ethiopia farmer encounter FAW which cause a 32% crop damage reducing the yield between 0.8 to 1 tonne/ha. These poses a huge risk to the food security and livelihood of millions of farming house hold in sub-Saharan Africa if proper control measures are not implemented.

2.7. Management options

FAW can be damaging to maize plants. Therefore, it has to be controlled to minimize its economic impact on maize and the millions of people who depend on it. The first key step in controlling FAW infestation is detection of the pest before they cause extensive damage. During maize growth, if 20% of small plants are infested during the first 30 days, it is advised to use good control options to avoid additional damage (Fernandez, 2002). Today there are different control measures that can be implemented, which include cultural, botanical, host plant (varietal resistance), biological and chemical control.

2.7.1. Cultural control

Cultural control is a method that is based on the knowledge about the relationship between organisms and their ecosystem to reduce pest populations (FAO and PPD, 2020). Its main purpose is to make the environment less ideal for the pest. Cultural control has been in use for many years since the dawn of agriculture and is still an important component in pest control (Haftay Gebreziher, 2020). Cultural control is cheap and target specific and doesn’t contaminate the environment, create pesticide resistance or kill non target organisms like chemical control. It requires long term planning to be successful and needs proper timing and takes too much labor. Cultural control may be successful in controlling a specific pest but not in controlling a closely related species. The efficiency of cultural control is hard to predict since they don’t always produce complete economic control of pests (Van Emden, 1989). Today there are different methods that can be used as cultural control.

Tillage depth can be a good factor in reducing FAW infestation. Damage to maize can greatly decrease in tillage fields compared to non-tillage fields in 10-15 days of planting (All, 1988). Practices such as frequently weeding and enhancing ecosystem by planting trees or shrubs between crops, especially neem, *Tephrosia, Gliricidia*, etc., can increase the species diversity of natural enemies, useful insects and predator birds (Wyckhuys & O’Neil 2006; Hay-Roe et al.

2016). Other common cultural practices like removing plant residue and adjusting planting dates produce no significant impact on FAW infestation but can be useful in controlling other lepidoptean pests (Baudron *et al.,* 2019). Further investigation is needed to clarify if removing plant residue and adjusting plant date could be used as a FAW control measure.

Hand picking is the simplest and most direct method of pest control. It operates by handpicking the adults and crashing their eggs to prevent larvae population building from 1500 to 2000 in less than four weeks (FAO & PPD, 2020). Hand picking is practiced in Africa. According to (Kansiime *et al.,* 2019), a survey conducted in Zambian farmers perception of FAW concluded that hand picking is considered an effective method by 38% of the farmers. Hand picking can sometimes be combined with other control methods to produce excellent results. For instance, a survey from Ghana and Zambia conducted on small scale farmers concluded that the use of hand picking in combination with chemical pesticide produced a yield gain of 125% (Tambo *et al.,* 2020). In Ethiopia, around 26% of farmers combine handpicking with pesticide spray while 15% only practice handpicking to control FAW infestation (Teshome Kumela *et al.,* 2018).

Intercropping is another major method of pest control. It is a practice of farming two or more crops at the same time which affects pest infestation by a push-pull strategy where crops are planted with pest repellent plant species (push) and plants that are attractive to the pest (pull). Intercropping maize with common bean, French bean and ground nut can reduce *S. frugiperda* ovipositon by 30% in Uganda (Girma Hailu et al *et al.,* 2018). Similarly, it is also recommended to intercrop maize with cow pea, Gliricidia, pigeon pea, and lablab bean (Prasanna *et al.,* 2018). When it comes to Ethiopia, there isn't much data about the impact of intercropping on FAW infestation. According to (Menale Kassie, 2020), maize legume intercropping was not effective in controlling FAW damage in which it contradicted (Girma Hailu *et al.,* 2018), but further research can help put the benefit of intercropping to light.

2.7.2. Varietal resistance

Varietal resistance is those features that allow plants to avoid or withstand or recover from attacks of pests where it can cause great injury to the plant. Varietal resistance is the most farmer friendly pest control method (Nwanze, 1997). Historically, the *S. frugiperda* resistant genotype started to develop in the US and was soon introduced to Brazil and Mexico. The technology operates by identifying certain strains that are resistant to *S. frugiperda* and cross breeding them to produce highly resistance strains. Nowadays, this technology is adapted in the US, Argentina, and Brazil, which account for 85% of maize production (Hruska, 2019).

There are many stains that are resistant to FAW, but currently in Africa, there are no maize strains adapted for these purposes. To address these issues, the International Maize and Wheat Improvement Center (CIMMYT) has been working in Africa to identify maize varieties resistant to *S. frugiperda* (Prasanna et al., 2018).

2.7.3. Botanical control

Botanical control is the application of plant derived compounds which include essential oils, fatty acids, esters glycosides, alkaloids and flavonoids to control pest infestation. It has a broad range of modes of action which includes contact poisons, ingestion positions, repellents, feeding deterrents, and oviposition deterrents. Botanical control is generally less toxic to natural enemies, easily biodegradable, does not accumulate in the ecosystem, and poses little risk of pest resistance development. (FAO, 2018; Hikal *et al.,* 2017; Islam *et al.,* 2013).

Botanical control can be a good tool to control *S. frugiperda* infestation in Africa, but it is not used to the fullest extent. According to (Houngbo *et al.,* 2020), a survey done in Benin indicates that only 1.9% of farmers use botanicals compared to 91.4% of farmers who only use pesticides. Several plant extracts have been identified with insecticidal property in Africa. These include Neem (*Azadirachta indica*), Persian lilac (*Melia azedarach*) and Pyrethrum (*Tanacetum cinerariifolium*) (Ogendo et al. 2013; Mugisha-Kamatenesi et al. 2008).

The neem plant, *Azadirachta indica* A. Juss. (Meliaceae) originates from Asia and up to date, can be found in America, Africa, and Australia (Schmutterer, 1990). It is one of the most important plants with insecticide property that can be used to control FAW. For instance, according to (Tavares et al 2010), application of bio-pesticide with 0.25% neem oil under laboratory condition showed 80% mortality of the larva. (Silva *et al.,* 2015) also recorded a higher larval percentage of mortality by applying seed cake extract of neem. In Ethiopia, (Birhanu Sisay, *et al.,* 2019B) reports that neem has one the highest percent of larval mortality compared to other 11 bio pesticides used in his experiment. The main drawback of neem is its shorter residual life under field conditions due to its high photosensitivity, which breaks down faster under the sun (Fenta Assefa & Dereje Ayalew, 2019).

Melia azadirachata (belongs to the family Meliaceae) is another good example of botanical control that has been tested against FAW and shows some promise. For instance (Scapinello *et al.*, 2014), were able to conclude that higher concentration of *M, azadirachata* extract increases FAW mortality. Bullangpoti *et al.,* (2012) also concluded that *M, azadirachata* has an anti-feeding effect on FAW larvae when presented in their food and can be considered an environmentally friendly approach.

Other bio pesticides can also be used to control FAW. In Cameroon, for example, black pepper extract together with bean intercropping proved to be a good control for *S. frugiperda* (Tanyi *et al.,* 2020). Salinas-Sanchez et al. (2012) found that hexane, acetone and ethanol extracts of *Tagetes erecta* caused 48%, 60% and 72% mortality respectively of FAW larvae, while other like, (Franco et al. 2006) demonstrated 100% FAW larval mortality with water extracts of seed of *Carica papaya* at 10% concentration.

2.7.4. Biological control

Biological control is the use of natural enemies to decrease damage caused by pests to an acceptable level. It is environmentally friendly, cheap, safe for non-target vertebrates and suitable for plant protection, which makes it an ideal tool for pest control. Understanding the adaptation and establishment of bio control agents in agro ecology is essential for the use of biological control agents. Though biological control methods may not replace pesticides any time soon, several arthropods and pathogens have been used successfully. Nowadays there are various options from natural predators, parasitoids and pathogens which can attack different growth stages of FAW (Fenta Assefa & Dereje Ayalew, 2019; Birhanu Sisay, 2019A).

2.7.4.1. Parasitoids

Various insect species have been reported to parasitize against *S. frugiperda* and are classified depending on growth stage. FAW parasitoids are usually common in the USA, Central and South America (Ashley, 1979). Among these, egg parasitoids are considered one of the most important control agents. They can prevent FAW infestation on the host plant. In some developed countries, egg parasitoids can also be reared on a large scale and sold on the market (Prasanna *et al.*, 2018). There are various egg parasitoids which include *Telenomus remus* (Nixon) (Hymenoptera: Scelionidae), *Trichogramma pretiosum* (Riley) (Trichogrammatidae) and *Trichogrammatoidea armigera* (Nagaraja) (Trichogrammatoidea) are good examples (FAO, 2018).

Though most of these species originated from the South, Central and North America, nowadays some of them can be found in different parts of the world, including Africa. For example, in a survey conducted in Ghana and Benin, *Telenomus remus* was discovered in both countries, while *Trichogramma* spp was only discovered in Benin (Agboyi *et al.*, 2020). Other survey conducted in five African countries, including South Africa, Kenya, Benin, Niger and Cote d'Ivoire concluded the presence of *Telenomus remus* (Kenis *et al.*, 2019). Similarly, a different survey in east Africa found *Telenomus remus* and *Chelonus curvimaculatus* in Kenya and Tanzania (Birhanu Sisay *et al.*, 2019A).

There are various larval parasitoids which mostly originated from continental America. In the United States, *Chelonus texanus* and *Cotesia marginiventris* (both Hymenoptera: Braconidae), are the most commonly reared larval parasitoids (Capinera 2000). In Africa, there are several species that have been discovered across the continent. According to (Agboyi *et al.*, 2020), a survey conducted in Ghana and Benin found five larval parasitoids which include *Cotesia icipe* Fernandez, *Charops* sp, *Coccygidium luteum* (Brullé), *Drino quadrizonula* (Thomson) and *Pristomerus pallidus* (Kriechbaumer). According to a survey conducted in east Africa (Ethiopia, Kenya and Tanzania), *Cotesia icipe* is the main parasite with a 37.6% rate of parasitism (Birhanu Sisay *et al.*, 2019A). Similarly, a survey conducted in Ethiopia by (Sisay Birhanu, 2018) discovered parasitoids like *Cotesia icipe*, *Charops ater* and *Palexorista zonata* where *Cotesia icipe* has a higher parasitism percentage.

2.7.4.2. Predators

There are predators that attack FAW eggs and larvae that are good biological control options. For example, in the US, the most common predators include the spined soldier bug, *Podisus maculiventris* (Say) (Hemiptera: Pentatomidae); ground beetles (Coleoptera: Carabidae), the insidious flower bug, *Orius insidiosus* (Say) (Hemiptera: Anthocoridae) and the striped earwig, *Labidura riparia* (Pallas) (Dermaptera: Labiduridae) (Capinera, 2000). In Africa, predators like predatory bugs, predatory wasps, ladybird beetles, spiders and earwigs are common in maize fields (FAO, 2018).

2.7.5. Chemical control

Chemical control is the application of pesticides, which are substances used for killing or repelling harmful and invasive insects that can cause damage to crops. It is the most effective control measure out there for conserving time and energy compared to the other methods. Though it is effective, it can possibly damage the ecosystem (including non-target organisms, pollinators, natural enemies and bystanders) and promote the development of pesticide resistance resulting in pest resurgence (Crowe & Booty, 1995). Chemical control is usually applied at dawn or dusk to be successful because those are the time to pick up FAW larvae feeding activity (Day *et al.*, 2017). They are also applied based on threshold level to reduce plant injury and pesticide resistance (Togola *et al.*, 2018).

For decades now, chemical control has been used as a tool to control the FAW population. In the US, for example, (Pitre, 1986) indicates the use of Diazino. Trichlorfon, Methyl parathion, and Carbaryl. Similarly, more recent data (Hardke et al, 2011) indicates the use of Flubendiamide, Cyantraniliprole, Chlorantraniliprole, indoxacarb, Spinetoram, and many others. In Mexico, most of the chemicals tend to older products in two modes of action groups: the acetylcholinesterase (AChE) inhibitors chlorpyrifos (an organophosphate) and methomyl (a carbamate), or the sodium channel modulators cypermethrin, permethrin and lambda-cyhalothrin (all pyrethroids) (Albert 2006).

Though FAW is very recent in Africa, governments are deploying massive insecticide spray programs in affected areas to prevent FAW from spreading. The extent to which these differ varies by country. For instance, in a survey done in Benin, about 91.4% of farmers use synthetic pesticides (Houngbo *et al.*, 2020). A similar survey done in Zambia revealed 60% of farmers apply synthetic pesticides (Kansiime *et al.*, 2019).

Pesticides can produce good results in Africa, but it comes with its own set of problems. Many of the low-priced and broadly used insecticides are usually unsuccessful because FAW has already developed resistant in Continental America (3A, Pyrethroids-Pyrethrins and 1B, Organophosphates) (Day *et al.*, 2017). Other issues include the purchase and use of very toxic, inexpensive, and old insecticides with no practical support from the supplier or producer, a lack of personal protective equipment (PPE), a lack of information concerning calibration, time of application, chemical and equipment handling, and a lack of personnel and facilities to handle and dispose of pesticides (Jepson *et al.*, 2014).

In Ethiopia, chemical control method is a major way of controlling FAW infestation. According to a survey done by (Teshome Kumela *et al.,* 2018), around 46% of farmers think chemical control measures are effective. Though these methods are commonly practiced, there are no registered chemicals for FAW control, but several insecticides such as pyrethroids, carbamates and organophosphates are being applied in the country. (Fenta Assefa & Dereje Ayalew, 2019). Nowadays, some researchers are testing different chemicals against FAW. For instance (Birhanu Sisay *et al.*, 2019B) tested 9 chemical pesticides and concluded that, under laboratory condition, Radiant, Tracer, Karate, and Ampligo caused over 90% larval mortality while Malathion and Carbaryl have moderate activity and are less effective with 51.7% and 28% larval mortality respectively. Under green conditions, all pesticides reduce foliar damage to maize compared to the untreated control and under field conditions they are highly efficient against FAW larvae.

2.7.6. Integrated pest management

In today's world, it is essential to meet production demand while improving the production resources based for future generations. For these reasons, integrated pest management (IPM) is the best way of approaching the FAW problem. In general, it is difficult to control FAW with a single control method. It is highly recommended to consider an integrated approach which keeps the pest below the threshold level (Haftay Gebreyesus Gebreziher, 2020). The goal of IPM is to suppress the pest population by employing methods that reduce the damage to the ecosystem and human beings (Prasanna *et al.,* 2018). To properly implement IPM, it is important to understand its basic principles, which include cultivating healthy crops in a healthy farming system, conserving natural enemies, monitoring field constantly and enhancing farmer's knowledge (FAO, 2018). In the developed world, especially in the USA, Brazil and Argentina, IPM strategies are implemented by incorporating innovative technology like genetically enhanced crops and the latest generation of pesticides (Hruska, 2019). IPM has the potential to limit pesticide damage to the environment and promote a healthy agricultural practice which is very important to small scale farmers in Africa (Day *et al.,* 2017).

3. Material and Methods

3.1. Description of the study site

This study was conducted at Melkassa Agricultural Research Centre (MARC) located in East Shewa zone of Oromia region of Ethiopia which is 117 km away from Addis Ababa to the East. The center is found at an altitude of 1550 meters above sea level at the latitude and longitude of 8º24’ N and 39º21’E, respectively. The ecology of the area range from arid to semi-arid which receives an annual rain fall of 763 mm with its maximum and minimum temperature of 28.4ºC and 14ºC, respectively. The soil type is Andosol of volcanic origin with pH ranging from 7 to 8.2.

3.2. Study design

The experiments were designed in a split plot design with three replications. It was conducted during the 2020 rainy season (June, July and August). The main plot treatments were maize varieties (Melkassa 2 (M2) and Melkassa 4 (M4)) andthe sub plot were 8 treatments (Sole maize (T1), Neem (T2), Avaunt 150 SC(T3), intercropping with haricot bean(T4), Neem + intercropping with haricot bean(T5), Avaunt 150 SC + intercropping with haricot bean(T6), Avaunt 150 SC + Neem (T7) and Avaunt 150 SC + Neem + intercropping with haricot bean(T8)). Initially, a land with a width of 88 meters and length of 22 meters was prepared. The main plot size was 43m X 6m and the sub-plot size was 4.5m by 6 meters, respectively. The main plots were spaced 2 meters from each other while the subplots were spaced 1 meter apart were each subplot contains a total of 144 maize plants. The spacing used was 25 cm between plants and 75 cm between rows (Plessis, 2003).

The treatments began by intercropping the maize with haricot bean (Awash 2) in a ratio of 2 rows of maize by 1 row of beans two weeks after planting the maize. Avaunt 150 SC (Indoxacarb) was applied at a rate of 200ml per 600L. According to the Ministry of Agriculture's website, it is a registered pesticide against stalk borer on maize and other pests. It was applied two times with in a gap of 10 day apart during the seeding stage in the morning. Neem (*Azadirachta indica*) (leaf powder) was applied at a rate of 5kg per hectare (Tsedeke Abate, *et* *al.*, 2006) mixed with sand with a ratio of 2 parts neem and one part sand. Neem was also applied two times with a 10 gap.

3.3. Data Collection

Data collection was initiated 10 days after the haricot bean was planted, the percentage of infestation was taken by counting all infected plant from each of the subplots and calculating the percentage. Similarly, one non border row was randomly selected and each plant in the row was ranked for foliar damage infestation using a 1-9 scale (Davis and Williams 1992) where 1 means no visible damage and 9 means completely damaged. Larval density was calculated by distractively sampling two plants each taken from both sides of a border row. Egg density was taken by surveying 5 non border plants. Each of the above parameters were taken before the treatments were applied and after in all maize growth stages where number time various data collected also differ from stage to stage (seedling (2X), vegetative (2X), tasseling (2X), grain filling (2X), maturity (2X), and harvest stages (1X)).

After treatment, when larvae were detected in the sampling unit, they were taken to (MARC) Entomology laboratory for further examinations. The different stages of larvae were separately placed in petri dishes to prevent cannibalism. They were kept for two weeks by giving them fresh leaves of maize and cleaning their waste (frass). The eggs that were collected in the field were put in a vial and left for a week. After the duration of the specific time, both the egg and larvae were checked for parasitoids. Those with parasites were then identified using insect identification key. (Goulet & Huber, 1993; Fernández-Triana *et al.*, 2014; Polaszek & Kimani, 1990; Fiaboe *et al.*, 2017). Then the percentage of parasitism was calculated for both egg and larva based on (pair *et al.*, 1986) formula.

$$\%\ \text{parasitism} = \frac{\text{Number of parasitoid}}{\text{Number of laravae collected}} * 100$$

Similarly, in the field, five plants were randomly selected from non-border rows and thoroughly checked for the presence of natural enemies. This data was taken in all maize growth stages. At maturity and harvest stage, 2 plants from both sides of the border from each subplot were selected and cob damage score was taken and were rated based on the 1-9 scale in (Prasanna *et* *al.*, 2018). Finally, the entire maize cob from the non-border row were collected, shelled and weighted to calculate the yield. The yield was calculated using the following formula (Ullah et al. 2011).

$$\text{Grain yield/ha} = \frac{\text{Grain yield per plot}}{\text{Plot size}} \times 100$$

$$(1 \text{ ha} = 10000 \text{ m}^2)$$

3.4. Data Analysis

Both percentage and count, which includes egg density, larval density, larval percent mortality, natural enemies' density, percent of parasitism and percent of mortality were converted to their square roots to normalize variance (Gomez & Gomez, 1984). Analysis was done using ANOVA table with two level of error for main and sub plots. Level of significance was set at 0.05 for both main and sub plot interaction. Significant means ($P< 0.05$) were separated using Turkey's Honestly Significant Difference test. All data analyses were done using IBM SPSS data editor version 26.

4. Results

4.1. Egg density

Eggs were available from seedling to tasseling stage. Before any treatment was applied, no significant difference was reordered. After the treatments were applied, the two maize varieties (Melkassa 2 and Melkassa 4) showed no significant difference (P> 0.05) (Table 1) while the different treatments applied showed significant variation (Table 1). At seedling stage, T1 (Sole maize) showed the highest egg density followed by T2 (neem) and T4 (intercropping) while T6 (Avaunt +intercropping with Awash) showed the lowest egg density followed by T7 (Avuant + neem). At vegetative stage, egg density was also higher in T1 (sole maize) while it was lower in T3 (Avaunt). At the tasseling stage (F = 5.22; df = 7; P = 0.001), all chemical control treatments (T3 (Avaunt), T6 (Avaunt + intercropping with awash 2, T7 (Avaunt + neem), and T8 (Avaunt + neem + intercropping with awash 2) had no egg mass while T2 (neem) has the smallest egg density, whereas T4 (intercropping with Awash 2) had the highest egg density

Table 1: Mean (± SE) density of eggs per plant across three growth stage of maize

Treatments	pretreatment	Seedling	Vegetative	Tasseling
Sole maize	115.45±9.79^{a}	89.67±11.84^{a}	48.26±3.522^{a}	12.67±4.029^{ab}
Neem	86.37±8.89^{a}	81.93±9.57^{ab}	18.59±2.99^{abc}	4.53±4.53^{b}
Avaunt	88.5±8.09^{a}	61.5±8.69^{abc}	4.35±1.99^{c}	0^{b}
Intercropping	88.87±5.820^{a}	78.93±7.22^{ab}	38.76±5.89^{a}	21.97±4.95^{a}
Intercropping+neem	85.17±6.230^{a}	72.88±14.17^{abc}	20.57±3.58^{ab}	11.28±8.45^{ab}
Avaunt+intercropping	85.27±8.90^{a}	32.06±8.15^{c}	8.63±3.51^{bc}	0^{b}
Avaunt+neem	85.2±6.89^{a}	41.12±11.04^{bc}	13.1±4.85^{bc}	0^{b}
Avaunt+neem+intercropping	85.67±11.67^{a}	45.25±6.43^{abc}	5.47±2.73^{bc}	0^{b}

Mean followed with the same letter (s) within a column are not significantly different from each other at $P < 0.05$ (HSD, 5%).

4.2. Larval density and percent mortality

Similarly, larva was only available from seedling to tasseling stage. The density was obtained by the number larvae per plant and to normalize variation the count are then converted to square root. Here at each growth stage, the maize varieties showed no significant difference ($P > 0.05$) in terms of larval density. During the pretreatment, seedling stage and vegetative stage, the different treatments showed no significant difference in larval density (Table 2). However, at tasseling stage ($F = 9.048$; $df = 7$; $P < 0.001$), significant differences was observed in the treatments. Here, T5 (neem + intercropping with awash 2) showed the highest larval density while T3 (Avaunt), T6 (Avaunt + intercropping with awash 2) and T8 (Avaunt +neem +intercropping with awash 2) showed zero larval density.

Table 2: Mean (± SE) density of larvae per plant across the three maize growth stages

Treatments	Pretreatment	Seedling	Vegetative	Tasseling
Solemaize	2.95 ± 0.27^{a}	1.86 ± 0.25^{a}	1.54 ± 0.05^{a}	0.82 ± 0.18^{ab}
Neem	2.97 ± 0.29^{a}	2.11 ± 0.24^{a}	1.56 ± 0.06^{a}	0.28 ± 0.18^{bc}
Avaunt	2.88 ± 0.45^{a}	1.95 ± 0.08^{a}	1.40 ± 0.11^{a}	0^{c}
Intercropping	2.98 ± 0.35^{a}	2.14 ± 0.26^{a}	1.36 ± 0.07^{a}	0.33 ± 0.21^{bc}
Intercropping+neem	2.89 ± 0.31^{a}	1.67 ± 0.21^{a}	1.54 ± 0.14^{a}	1.10 ± 0.10^{a}
Avaunt+intercropping	2.86 ± 0.28^{a}	1.91 ± 0.20^{a}	1.39 ± 0.08^{a}	0^{c}
Avaunt+neem	3.27 ± 0.18^{a}	1.41 ± 0.19^{a}	1.32 ± 0.11^{a}	0.12 ± 0.12^{c}
Avaunt+neem+intercropping	2.73 ± 0.25^{a}	1.59 ± 0.33^{a}	1.36 ± 0.15^{a}	0^{c}

Mean followed with the same letter in a column are not significantly different from each other at $P < 0.05$ (Tukey test).

Across the three growth stages, the percentage of dead larvae varies between treatments. As significant differences was observed only in the treatment applied while the maize varieties (Melkassa 2 and Melkassa 4) showed no significant difference. Here the percentage larval mortlity are converted to square root to normalize variation. At seedling stage, T1 (sole maize) showed no larval mortality while T6 (Avaunt + intercropping with awash 2) showed the highest larval mortality. Likewise, in the vegetative stage T1 (sole maize) had the lowest larval mortality and T6 (Avaunt + intercropping with awash 2) had the highest larval mortality. At tasseling stage, T7 (Avaunt + neem) showed the highest larval mortality while T4 (intercropping) showed the lowest mortality (Table 3).

Table 3: Mean (± SE) percentage of larval mortality across the three maize growth stages

Treatments	Seedling	Vegetative	Tasseling
Sole maize	0.00 ± 0.00^{b}	1.02 ± 0.65^{d}	0.58 ± 0.58^{ab}
Neem	0.65 ± 0.65^{b}	37.33 ± 2.36^{abc}	4.29 ± 1.95^{ab}
Avaunt	7.35 ± 0.45^{a}	47.84 ± 3.47^{a}	0^{b}
Intercropping	1.67 ± 1.05^{b}	16.28 ± 7.92^{bcd}	0^{b}
Intercropping+neem	0.53 ± 0.53^{b}	15.78 ± 5.55^{cd}	1.51 ± 0.96^{ab}
Avaunt+intercropping	7.46 ± 0.83^{a}	51.61 ± 9.62^{a}	0.00 ± 0.0^{b}
Avaunt+neem	6.57 ± 1.42^{a}	44.51 ± 7.13^{ab}	4.77 ± 1.62^{a}
Avaunt+neem+intercropping	6.85 ± 1.52^{a}	48.25 ± 6.06^{a}	0^{b}

Mean followed with the same letter in a column are not significantly different from each other at $P < 0.05$ (Tukey test).

4.3. Percentage of infestation

Percentage of infestation was obtained in all growth stages. The percentage of infested plants showed different degrees of significance across each growth stage. In all the growth stages, percentage of infestation was converted to square roots to normalize variation. Here significant differences were observed between treatments with exception to when no treatments were applied. At seedling stage, T4 (intercropping with awash 2) had the highest infestation while T6 (Avaunt + intercropping with awash 2) had the lowest infestation. At vegetative stage, the highest infestation was recorded in T5 (neem + intercropping with awash 2) while the lowest was recorded in T7 (Avaunt + neem). Here treatments that contains T2 (neem) and T4 (intercropping) also had some the highest percentage of infestation. At tasseling, grain filling and maturity stage, T1 (sole maize) has the highest infestation while T7 (Avaunt + neem) had the lowest infestation where similarly T6 (Avaunt + intercropping) and T7 (Avaunt + neem) had the some of the lowest infestation (Table 4).

Table 4: Mean (± SE) percentage of infestation of fall army worm across all growth stages of maize

Treatments	Pre treatment	Seedling	Vegetative	Tasseling	Grain filling	Maturity
Sole maize	6.79±0.07^{a}	9.17±0.14^{a}	9.66±0.08^{a}	9.57±0.07^{a}	9.17±0.10^{a}	8.72±0.07^{a}
Neem	6.39±0.07^{a}	8.55±0.26^{ab}	9.33±0.11^{a}	9.11±0.11^{a}	7.84±0.37^{b}	7.61±0.19^{a}
Avaunt	6.72±0.11^{a}	7.81±0.14^{bc}	7.34±0.11^{b}	6.24±0.12^{b}	5.02±0.13^{c}	4.22±0.07^{b}
Intercropping	6.69±0.12^{a}	9.23±0.18^{a}	9.63±0.08^{a}	9.49±0.10^{a}	8.76±0.08^{ab}	8.33±0.08^{a}
Intercropping + neem	6.67±0.07^{a}	9.03±0.22^{a}	9.67±0.04^{a}	9.52±0.07^{a}	8.82±0.12^{ab}	8.27±0.10^{a}
Avaunt + intercropping	6.63±0.11^{a}	7.48±0.17^{c}	6.68±0.20^{bc}	5.88±0.21^{b}	4.55±0.28^{c}	3.75±0.28^{b}
Avaunt + neem	6.62±0.12^{a}	7.59±0.11^{c}	6.59±0.23^{c}	5.47±0.34^{b}	4.10±0.41^{c}	3.31±0.37^{b}
Avaunt + neem +intercropping	6.69±0.08^{a}	7.72±0.09^{c}	6.68±0.24^{bc}	5.59±0.21^{b}	4.37±0.35^{c}	3.42±0.46^{b}

Mean followed with the same letter in a column are not significantly different from each other at P < 0.05 (Tukey test).

4.4. Plant damage score

Plant damage score showed different degrees of significance across all growth stages. Here, similar to the percentage of infestation, significant difference was observed in the different treatments that were applied with exception to pretreatment or initial stage. At seedling, T4 (intercropping with awash 2) had the highest mean score of 3.4 while T3 (Avaunt) and T8 (Avaunt + neem + intercropping with awash 2) had the lowest mean score of 1.97. At vegetative, tasseling, grain filling and maturity stage T1 had the highest mean score damage of 4.48, 5.18, 4.08 and 4.05 respectively while the lowest mean score was T3 (Avaunt) with 1.77, T8 (Avaunt

+ neem + intercropping with awash 2) with 1.42, T7 (Avaunt + neem) with 1.28 and T7 (Avaunt + neem) with 1.13 respectively (Table 5).

Table 5: mean (± SE) plant score damage across all growths stages of maize

Treatments	Pre treatment	Seedling	Vegetative	Tasseling	Grain filling	Maturity
Sole maize	2.28±0.22^{a}	3.17±0.23^{ab}	4.48±0.12^{a}	5.18±0.21^{a}	4.08±0.35^{a}	4.05±0.33^{a}
Neem	2.10±0.19^{a}	2.62±0.38^{abc}	3.32±0.39^{b}	3.12±0.22^{b}	2.57±0.22^{b}	2.98±0.19^{a}
Avaunt	1.85±0.22^{a}	1.97±0.18^{c}	1.77±0.08^{c}	1.62±0.06^{c}	1.33±0.02^{c}	1.15±0.02^{b}
Intercropping	2.37±0.21^{a}	3.43±0.28^{a}	3.92±0.25^{ab}	4.53±0.30^{a}	3.67±0.22^{a}	3.23±0.20^{a}
Intercropping + neem	2.55±0.10^{a}	3.02±0.30^{abc}	3.92±0.29^{ab}	3.25±0.20^{b}	2.80±0.07^{b}	3.38±0.72^{a}
Avaunt+intercropping	2.10±0.18^{a}	2.15±0.18^{bc}	1.95±0.13^{c}	1.55±0.08^{c}	1.37±0.03^{c}	1.35±0.05^{b}
Avaunt + neem	2.22±0.24$_{a}$	2.43±0.24^{abc}	1.90±0.24^{c}	1.51±0.06^{c}	1.28±0.04^{c}	1.13±0.02^{b}
Avaunt+neem+intercropping	2.53±0.30^{a}	1.97±0.12^{c}	1.87±0.13^{c}	1.42±0.05^{c}	1.33±0.04^{c}	1.15±0.02^{b}

Mean followed with the same letter in a column are not significantly different from each other at $P < 0.05$ (Tukey test).

4.5. Natural enemy density and percentage of parasitism

Natural enemies that were discovered in the field survey were lady bird beetles and earwigs. Lady bird beetles existed in all the growth stages of maize while earwigs were detected up to the tasseling stage. The total density obtained per treatment were converted to square root to normalize variation. For both natural enemies, no significant difference was observed for the two maize varieties and different treatments across all growth stages ($P > 0.05$).

Table 6: mean (± SE) density of natural enemies per plant across maize growth stages

	Seedling		Vegetative		Tasseling		Grain fill	Maturity
Treatments	Lady bird	Earwig	Lady bird	Earwig	Lady bird	Earwig	Lady bird	Lady bird
Sole maize	0.15 ± 0.09^a	0.05 ± 0.05^a	0^a	0.12 ± 0.08^a	0.05 ± 0.05^a	0^a	0^a	0.15 ± 0.09^a
Neem	0^a	0.11 ± 0.07^a	0.07 ± 0.07^a	0.11 ± 0.07^a	0^a	0.05 ± 0.05^a	0^a	0.07 ± 0.07^a
Avaunt	0.15 ± 0.09^a	0^a	0.23 ± 0.15^a	0.04 ± 0.04^a	0^a	0.11 ± 0.07^a	0^a	0^a
Intercropping	0.15 ± 0.09^a	0.05 ± 0.05^a	0.07 ± 0.07^a	0^a	0.13 ± 0.08^a	0^a	0.07 ± 0.07^a	0.18 ± 0.12^a
Intercropping + neem	0.07 ± 0.07^a	0^a	0^a	0.04 ± 0.04^a	0.05 ± 0.05^a	0.05 ± 0.05^a	0.11 ± 0.11^a	0.22 ± 0.10^a
Avaunt + intercropping	0.07 ± 0.07^a	0.05 ± 0.05^a	0.22 ± 0.10^a	0.04 ± 0.04^a	0^a	0^a	0.07 ± 0.07^a	0^a
Avaunt + neem	0.11 ± 0.11^a	0.05 ± 0.05^a	0.18 ± 0.12^a	0^a	0^a	0^a	0.15 ± 0.09^a	0^a
Avaunt + neem +intercropping	0.07 ± 0.07^a	0^a	0.18 ± 0.12^a	0.09 ± 0.05^a	0.05 ± 0.05^a	0^a	0.07 ± 0.07^a	0.15 ± 0.09^a

Mean followed with the same letter in a column are not significantly different from each other at $P < 0.05$ (Tukey test).

Parasite activity was only observed up to vegetative stages. One egg parasitoid, *Telenomus remus (Platygastridae)* was observed at seedling stage. Larval parasitoid *cotesia icipe (Braconidae)* was observed in both stages while *chapros ater (Ichneumonidae)*, larval parasitoid, was only observed at vegetative stage. At both growth stages, no significant difference was observed for both varieties and the different treatments applied.

Table 7: Mean (± SE) percent of parasitism across two growth stages of maize

Growth stage	Seedling		Vegetative	
Treatment	*Telenomus remus* (Egg parasitoid)	*Cotesia icipe* (Larval parasitoid)	*Chapros ater* (Larval parasitoid)	*Cotesia icipe* (larval parasitoid)
Sole maize	0^a	0^a	$0.78{\pm}0.78^a$	0^a
Neem	0^a	0^a	$0.63{\pm}0.63^a$	0^a
Avaunt	$0.75{\pm}0.75^a$	0^a	0^a	0^a
Intercropping	0^a	0^a	0^a	0^a
Intercropping + neem	0^a	0^a	0^a	$0.97{\pm}0.97^a$
Avaunt+intercropping	0^a	$0.45{\pm}0.45^a$	0^a	0^a
Avaunt + neem	$0.68{\pm}0.68^a$	0^a	0^a	0^a
Avaunt+neem+intercropping	0^a	$0.96{\pm}0.96^a$	0^a	0^a

Mean followed with the same letter in a column are not significantly different from each other at $P < 0.05$ (Tukey test).

4.6. Cob damage

Based on the cob damage scale (1-9) analysis, no significant difference between the two maize varieties ($P > 0.05$) but the treatments were significantly different can be observed from the ANOVA table (Appendix table 8). Treatment control measures like T3 (Avaunt), T6 (Avaunt + intercropping with awash 2), T7 (Avaunt + neem), and T8 (Avaunt + neem + intercropping with awash 2) showed no cob damage with a score of 1, while T1 (sole maize) showed the most damage with a score of 2.29 at maturity growth stage ($F = 3.39$; $df = 7$; $P = 0.01$). At harvest stage ($F = 3.59$; $df = 7$; $P = 0.007$), no cob damage was observed in T6 (Avaunt + intercropping with awash 2), T7 (Avaunt + neem) and T8 (Avaunt + neem + intercropping with awash 2) while the highest damage was observed in T1 (sole maize) with a score of 2.08.

Table 8: Mean (±SE) cob damage score at maturity and harvest stage.

Treatment	Maturity	Harvest
Sole maize	2.29 ± 0.48^{b}	2.08 ± 0.42^{b}
Neem	1.29 ± 0.25^{ab}	1.38 ± 0.18^{ab}
Avaunt	1 ± 0^{a}	1.167 ± 0.11^{ab}
Intercropping	1.96 ± 0.42^{ab}	1.63 ± 0.15^{ab}
Neem+intercropping	1.25 ± 0.17^{ab}	1.5 ± 0.18^{ab}
Avaunt+intercropping	1 ± 0^{a}	1 ± 0^{a}
Avaunt+neem	1 ± 0^{a}	1 ± 0^{a}
Avaunt+neem+intercropping	1 ± 0^{a}	1 ± 0^{a}

Mean followed with the same letter in a column are not significantly different from each other at $P < 0.05$ (Tukey test).

4.7. Yield

The two maize varieties were not significantly different ($P> 0.05$) but the treatments were significantly different in the yield they produced. Treatment methods which involved the use of Avaunt showed a positive effect on maize yield ($F = 27.5$; $df = 7$; $P < 0.01$) with the highest yield obtained from the treatment T7 (Avaunt + neem) with a yield of 7555.08 Kg/ha, followed by T3 (Avaunt) 7208.4Kg/ha, T8 (Avaunt + neem + intercropping with awash 2) 7118.8 Kg/ha and T6 (Avaunt + intercropping with awash 2) 7002.6 Kg/ha. The lowest yield was obtained from the treatment T1 (sole maize) with a yield of 4400.2 Kg/ha.

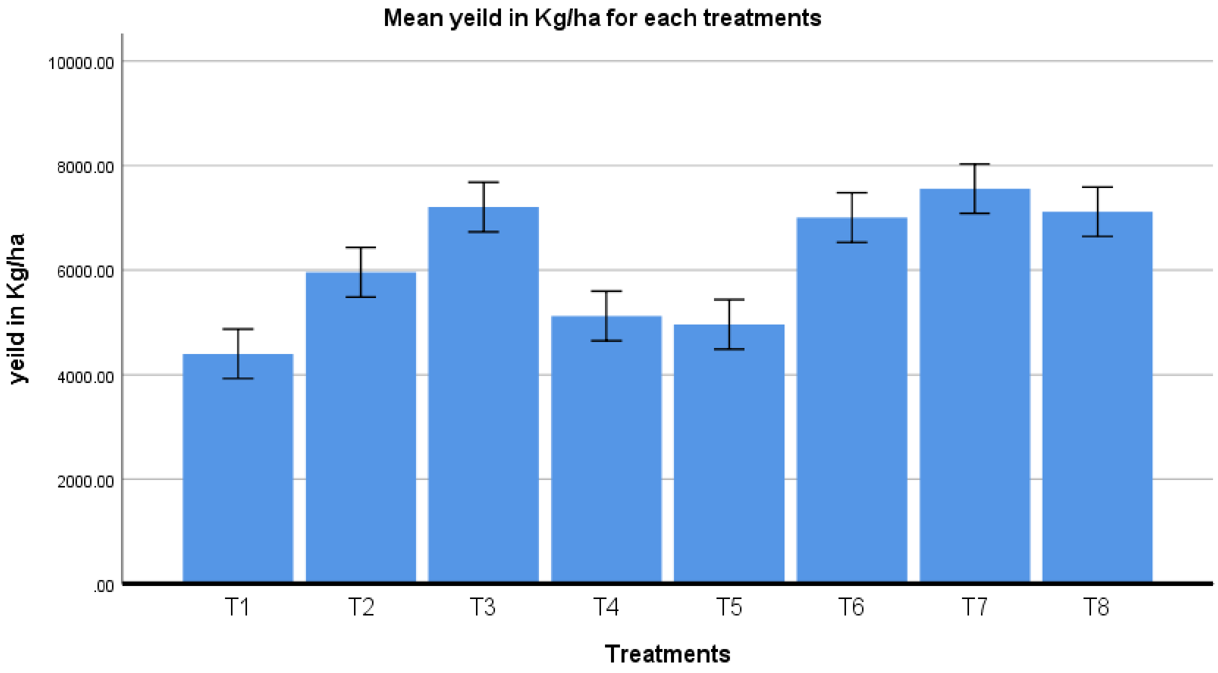

Figure 1: Mean yield of maize for the different treatment applied to control FAW. . T1 (Sole maize), T2 (neem) T3 (Avaunt), T4 (intercropping), T5 (Neem +intercropping), T6 (Avaunt + intercropping), T7 (Avaunt +Neem) and T8 (Avaunt +Neem + intercropping).

5. Discussion

Maize production is recently been under threat from a devastating pest, fall army worm (*Spodoptera fugiperda*). Recent reports on this pest indicate its fast spread across most of Africa and Asia. FAW attacks maize from seedling to maturity stages. After its first detection in 2017 in Ethiopia, it is now confirmed to exist in most parts of the country. Various findings indicate that FAW is a destructive pest and it can affect the food security of underdeveloped nations. Therefore, various potential integrated management options were tested in this experiment to develop a comprehensive way of controlling fall armyworm in Ethiopia.

In this study, egg infestation was detected from seedling to tasseling stage. As each growth stage passes, the number of eggs per plant decreases with time. During the pre-application period, egg infestation was uniform across all the plots. Only when treatment methods were used does a difference in density appear. The highest egg density was observed in the sole or control group. Intercropping with haricot bean (Awash 2) performed poorly while neem powder performed moderately in reducing egg density. All treatments that contain Avaunt performed well in controlling egg infestation where no egg mass was detected at tasseling stage. Hence, it can be said that chemical control measures are good ways of reducing egg mass. This result agrees with the finding of (Tadeos Shiferaw & Fano Dargo, 20l9) that lower egg density was detected in treatment measures that contain chemical control.

Larval density was also similar to egg data where larvae were detected up to tasseling stage and decreased across the growth stage. A uniform larval density was seen from pre-application to vegetative stage. Only at the tasseling stage, variation was seen in the treatments, the two maize varieties (Melkassa 2 and Melkassa 4) showed no significant difference (table 2). Larval density data was derived from a count of both dead and alive larvae, which explains the lack of a significant difference between seedling and vegetative stages. These variations can be clearly seen in the percentage of larval mortality. These data showed a clear image of the effect of each treatment measure applied. Based on this data, the lowest percentage of mortality was recorded in sole maize or control group across each growth stage. Intercropping also showed a lower percentage of larval mortality. Those treatments containing Avaunt had the highest percentage of larval mortality across each growth stage. Here, chemical control measures were successful in reducing larval activity. These findings are similar to that of Babendreier *et al*., (2020), in which pesticides were successful in reducing the number of larvae.

Plant damage score showed various degree of damage across each growth stage. Scores typically rose until vegetative stage, then fall. This is because the larvae are usually active up to the tasseling stage. A uniform damage score was observed in the pre-treatment phase, while the rest differ from treatment to treatment. Across most of the growth stages, the highest plant score damage was recorded in the sole maize or control group where the highest was recorded at the tasseling stage. Intercropping also performed poorly where it has the second highest plant damage. These finding also aggress with that of Menale Kassie, (2020) were maize legume intercropping is not effective in controlling fall army worm. Control measure that contains Avaunt had the lowest plant damage where the lowest one was recorded in T3 (Avaunt only).

Percentage of infestation is different across all growth stages. Because larval activities can only be recorded up to the tasseling stage, the percentage of infestation was highest during the vegetative stage and decreased after that. Uniform infestation was recorded during the pretreatment phase and variation appear when the treatments were applied while the two maize varities (Melkassa 2 and Melkassa 4) showed no significant difference from one another. Here, similar to plant score damage, sole maize had the highest number of plants with FAW damage. Intercropping also performed poorly where most plants are also affected. Neem control measure didn’t perform well when it was compared to the control measure which contains Avaunt. These control measures showed the least number of plants with FAW activities, especially T7 (Avaunt + neem) showed the least number of infested plants compared to the rest in most of the growth stages, which makes them a successful control measure compared to the others. Here, chemical control measures were successful in reducing the number of infected plants. However, this finding contradicts the finding of Tanyi, *et al.*, (2020) where botanical (West African black pepper) and pesticide control measures were used separately to successful in reducing FAW infestation.

In the field survey for natural enemies, lady bird beetle and earwig were discovered. These two predators are common FAW predators across Africa and the rest of the world. The Lady bird beetle was discovered in at all growth stages, but the Earwig was found up to tasseling stage. The explanation for the existence of ear wig up to the tasseling stage can be the presence of FAW larvae up to that stage. In the survey, very few natural enemies were detected across all treatments where it was difficult to find their correlation to the treatments applied or the main plot maize varieties (Melkassa 2 and Melkassa 4). The laboratory on parasitism resulted 3 different species of parasitoid. Here, parasitoids activities were only detected at seedling and vegetative stages. At seedling stages, *Telenomus remus* (Platygastridae), which is an egg parasitoid, and *Cotesia icipe* (Braconidae), which is a larval parasitoid, were detected. At vegetative stage, however, only larval parasitoids were detected, which include *Cotesia icipe* (Braconidae) and *Chapros ater* (Ichneumonidae). Similar to natural enemies, these parasitoids were few in number to establish a correlation between their presence and the treatments applied. From the parasitoid that were discovered, *Telenomus remus* (Platygastridae) was the first time it was detected on FAW in Ethiopia. Similarly, a survey conducted in a selected region of Ethiopia by Birhanu Sisay *et al.,* (2018) were able to find a few larvae parasitoids which include *Cotesia icipe*, *Palexorista zonata* and *Charops ater.* Recent survey by Tesfaye Hailu *et al.,* (*2021*) were able to discover several natural enemies (Lady bird beetles and earwigs) and parasitoids (Trichogramma spp, egg parasitoid)

Cob damage score was assessed at maturity and harvest stage. Both stages showed more or less the same result. In both growth stages, treatments method with Avaunt contains mostly clean cob with a score of 1. The highest cob damage was detected in sole maize or control group in both stages. Intercropping performed poorly here as well, as the cob was damaged badly. Neem on the other hand, showed moderate cob damage compared to the rest of the treatments.

The yield from this experiment differs from treatment to treatment. Here, sole maize or control group has the lowest yield of from all the treatments followed by intercropping, while neem control measures produce moderate yield. The highest yield was obtained from all the treatments that contain Avaunt where the highest yield was obtained from T7 (Avaunt +neem). Hence, a positive correlation can be established between high yield and chemical control measures. This finding also comparable with that of Babendreier *et al.,* (2020) where an increase in yield was achieved by applying insecticides.

6. Conclusion and Recommendation

6.1. Conclusion

From this experiment conducted on *S. frugiperda* reaction to different control measures and maize varieties, the following conclusions were made.

- The result obtained from all parameters across all growth stages suggests that, the main plots or the two maize varieties (Melkassa 2 and Melkassa 4) showed no significance where it is safe to say both are similar to one another and have no difference when both are infested by *S. frugiperda*. However, the subplot or the different treatments applied have shown various degrees of differences across each growth stage.
- It was generally observed that *S. frugiperda*is was usually active up to tasseling stage where most of its active damage was seen at seedling and vegetative stages. This was seen in data on egg and larval density, percentage of infestation, plant score damage, and natural enemy density, where FAW activity is high from seedling to tasseling. Because larvae are usually absent, the plants appear to recover a little after those stages. These can be observed in plant score damage and percentage of infestation.
- Among all the subplot control measures, sole maize has been the most damaged. This indicates that leaving a field infested with FAW with no treatments can be very damaging in terms of plant health and yield.
- Intercropping with haricot bean (Awash 2) has failed to control FAW infestation which can be observed from the various parameters.
- The application of neem has shown moderate to poor results throughout the growth stages.
- Control measures which contain Avaunt showed the most promising results where they produced positive results in reducing egg and larval density, less infected plant, cob and producing high yield of maize compared to the rest of the treatments.
- Several natural enemies and parasitoids were discovered in this experiment. But their existence doesn't have any relation to the treatments applied where it can be safe to say that there is no significant relationship between them and the treatments

6.2. Recommendation

- From the above conclusion, the use of Avaunt 150 SC can be recommended, but it must be used based on proper procedure.
- Different plant species which have strong push pull potential against *S. frugiperda* must be explored as Awash 2 has failed to do so.
- Different formulations of neem (*Azadirachta indica*) like aqueous solution or increased dose of neem powder from 5 kg/ha must also be explored as they can produce a more positive result compared to these.
- Maize varieties that are believed to have FAW resistance capability must be explored as these way it is easy to save money and energy spent on control measures.
- IPM strategies that are safe, inexpensive, and simple to implement must be investigated and proposed for farmers in order to reduce their reliance on chemical control.

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8. Appendices

Part 1, Figure used as reference to asses fall army worm damages

Fig 1. Plant damage score scale used to asses fall army worm damage

Fig 1: Plant score damage scale used for analysis of the fall army worm damage (Davis and Williams 1992).

Fig 2. Cob damage scale used to asses fall army damage

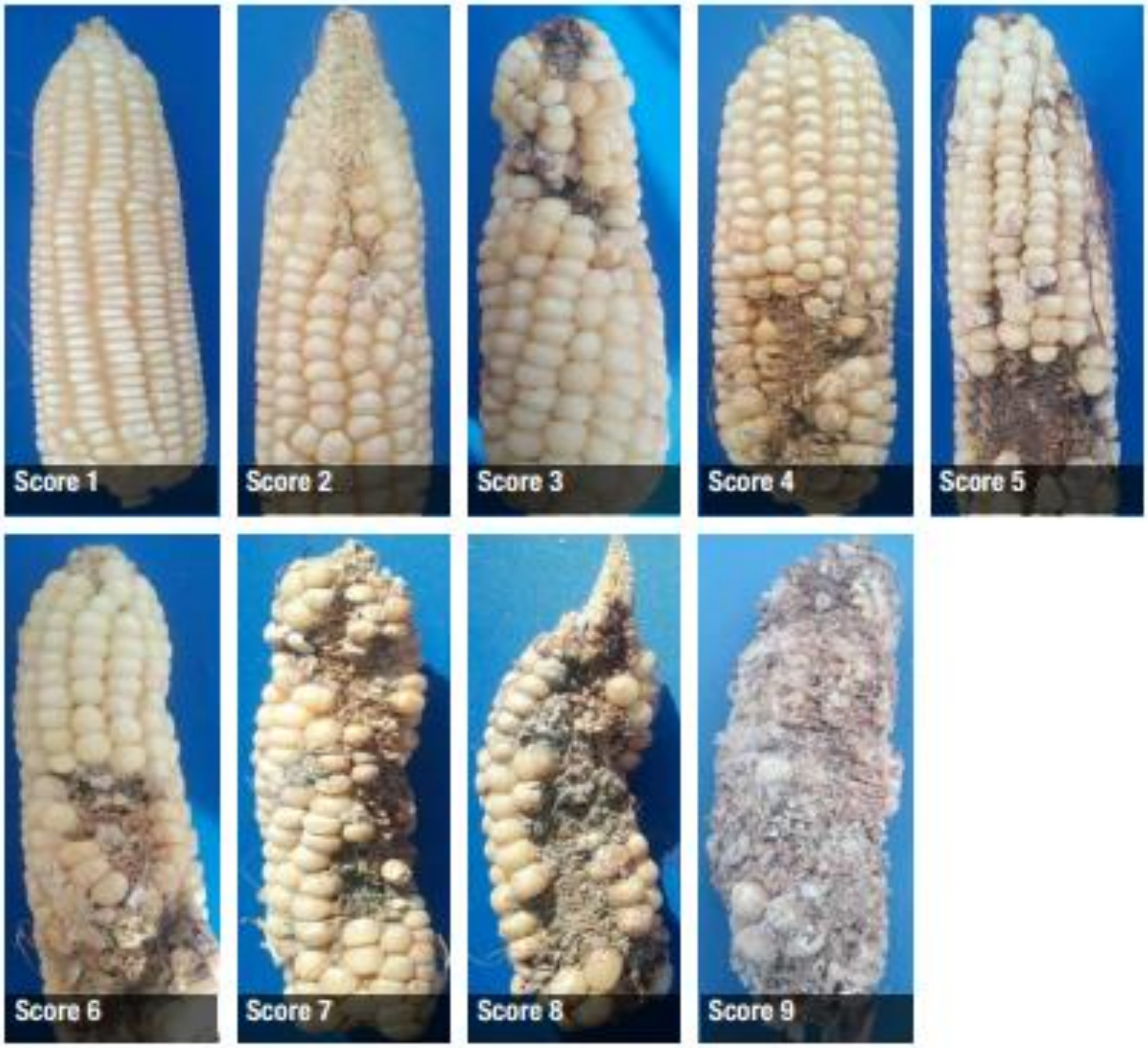

Fig 2: Cob damage score scale used for analysis of cobdamge caused fall army worm (Prasanna *et al.*, 2018).

Appendex (Part) 2

Appendex table 1. Analysis of variance showing egg density in three grwoth stages of maize

Pretreatment

SV	SS	DF	MS	F-value	P- value
Rep	0.033	2	0.016	0.013	0.987
main	5.515	1	5.515	4.525	0.042
Rep * main	0.422	2	0.211	0.173	0.842
sub	11.373	7	1.625	1.333	0.272
main * sub	6.393	7	0.913	0.749	0.633

Seedling stage

SV	SS	DF	MS	F-value	P- value
Rep	7.435	2	3.717	1.064	0.359
main	1.563	1	1.563	0.447	0.509
Rep * main	13.530	2	6.765	1.936	0.163
sub	105.204	7	15.029	4.301	0.002
main * sub	25.818	7	3.688	1.055	0.417

Vegetative stage

SV	SS	DF	MS	F-value	P-value
Rep	3.598	2	1.799	0.758	0.478
main	2.627	1	2.627	1.106	0.302
Rep * main	3.203	2	1.602	0.674	0.518
sub	171.524	7	24.503	10.319	0.000
main * sub	9.962	7	1.423	0.599	0.751

Tasseling stage

SV	SS	DF	MS	F-value	P-value.
Rep	3.457	2	1.728	0.568	0.573
main	7.906	1	7.906	2.597	0.118
Rep * main	1.671	2	0.836	0.275	0.762
sub	111.231	7	15.890	5.220	0.001
main * sub	19.749	7	2.821	0.927	0.501

Appendex table 2. Analysis of variance showing larval density across three growth stage of maize

Pretreament

SV	SS	DF	MS	F- value	P-value
Rep	1.123	2	0.561	0.950	0.399
main	0.418	1	0.418	0.707	0.408
Rep * main	1.058	2	0.529	0.896	0.420
sub	1.007	7	0.144	0.243	0.970
main * sub	3.488	7	0.498	0.843	0.561

Seedling stage

SV	SS	DF	MS	F-value	P-value.
Rep	2.091	2	1.045	4.513	0.20
main	1.263	1	1.263	5.452	0.27
Rep * main	0.395	2	0.198	0.853	0.437
sub	2.726	7	0.389	1.681	0.154
main * sub	2.541	7	0.363	1.567	0.186

Vegetative stage

SV	SS	DF	MS	F-value	P-value
Rep	0.548	2	0.274	6.303	0.795
main	0.001	1	0.001	0.018	0.895
Rep * main	0.243	2	0.122	2.800	0.718
sub	0.403	7	0.058	1.324	0.276
main * sub	0.412	7	0.059	1.356	0.262

Tasseling stage

SV	SS	DF	MS	F-value	P-value
Rep	0.104	2	0.052	0.455	0.639
main	0.068	1	0.068	0.600	0.445
Rep * main	0.115	2	0.057	0.503	0.610
sub	7.207	7	1.030	9.048	0.00
main * sub	0.542	7	0.077	0.680	0.687

Appendex table 3. Analysis of variance showing percentage of larval mortality across three growth stages

Seedling stage

SV	SS	DF	MS	F-value	P-value
Rep	33.943	2	16.971	3.864	0.33
main	1.474	1	1.474	0.336	0.567
Rep * main	27.756	2	13.878	3.160	0.085
sub	495.168	7	70.738	16.105	0.000
main * sub	24.724	7	3.532	0.804	0.591

Vegetative stage

SV	SS	DF	MS	F-value	P-value
Rep	111.603	2	55.801	0.241	0.787
main	0.041	1	0.041	0.000	0.989
Rep * main	410.630	2	205.315	0.887	0.423
sub	15290.809	7	2184.401	9.442	0.000
main * sub	1751.427	7	250.204	1.081	0.401

Tasseling stage

SV	SS	DF	MS	F-value	P-value
Rep	24.577	2	12.288	0.902	0.417
main	0.052	1	0.052	0.004	0.951
Rep * main	8.938	2	4.469	0.328	0.723
sub	218.813	7	31.259	2.293	0.046
main * sub	91.917	7	13.131	0.963	0.476

Appendex table 4. Analysis of variance showing percentage of infestation across all growth stage of maize

Pretreament

SV	SS	DF	MS	F-value	p-value
Rep	0.209	2	0.105	1.737	0.194
main	0.021	1	0.021	0.348	0.560
Rep * main	0.032	2	0.016	0.267	0.768
sub	0.593	7	0.085	1.407	0.242
main * sub	0.220	7	0.031	0.521	0.811

Seedling stage

SV	SS	DF	MS	F-value	P-value
Rep	0.612	2	0.306	1.775	0.188
main	0.376	1	0.376	2.179	0.151
Rep * main	0.081	2	0.040	0.235	0.792
sub	23.928	7	3.418	19.818	0.000
main * sub	1.328	7	0.190	1.100	0.390

Vegetative stage

SV	SS	DF	MS	F-value	P-value
Rep	0.129	2	0.064	0.422	0.660
main	0.001	1	0.001	0.005	0.942
Rep * main	0.766	2	0.383	2.508	0.100
sub	93.461	7	13.352	87.481	0.000
main * sub	0.530	7	0.076	0.496	0.829

Tasseling stage

SV	SS	DF	MS	F-value	P-value
Rep	0.272	2	0.136	0.704	0.503
main	0.003	1	0.003	0.017	0.897
Rep * main	0.713	2	0.357	1.843	0.177
sub	160.675	7	22.954	118.646	0.000
main * sub	1.051	7	0.150	0.776	0.612

Grain filling stage

SV	SS	DF	MS	F-value	P-value
Rep	2.991	2	1.496	4.509	0.250
main	8.57	1	8.57	0.000	0.987
Rep * main	0.757	2	.379	1.141	0.334
sub	214.278	7	30.611	92.286	0.000
main * sub	3.668	7	.524	1.580	0.182

Maturity stage

SV	SS	DF	MS	F-value	P-value
Rep	1.450	2	0.725	1.710	0.199
main	0.051	1	0.051	0.121	0.730
Rep * main	0.090	2	0.045	0.106	0.900
sub	255.594	7	36.513	86.122	0.000
main * sub	1.306	7	0.187	0.440	0.868

Appendex table 5. Analysis of variance showing plant score damage across all growth of maize

Pretreaments

SV	SS	DF	MS	F-value	P-value
Rep	0.566	2	0.283	1.076	0.355
main	0.013	1	0.013	0.051	0.824
Rep * main	0.720	2	0.360	1.369	0.271
sub	2.347	7	0.335	1.274	0.299
main * sub	2.407	7	0.344	1.307	0.284

Seedling stage

SV	SS	DF	MS	F-value	P-value
Rep	1.531	2	0.766	2.393	0.110
main	2.210	1	2.210	6.909	0.194
Rep * main	1.078	2	0.539	1.685	0.204
sub	13.330	7	1.904	5.952	0.000
main * sub	1.421	7	0.203	0.635	0.723

Vegetative stage

SV	SS	DF	MS	F-value	P-value
Rep	1.018	2	0.509	1.616	0.217
main	0.092	1	0.092	0.292	0.593
Rep * main	0.609	2	0.304	0.966	0.393
sub	54.010	7	7.716	24.494	0.000
main * sub	1.756	7	0.251	0.797	0.597

Tasseling stage

SV	SS	DF	MS	F-value	P-value
Rep	0.096	2	0.048	0.332	0.720
main	0.907	1	0.907	6.302	0.918
Rep * main	0.160	2	0.080	0.557	0.579
sub	92.980	7	13.283	92.235	0.000
main * sub	1.793	7	0.256	1.779	0.131

Grain filling stage

SV	SS	DF	MS	F-value	P-value
Rep	0.000	2	0.000	0.001	0.999
main	0.403	1	0.403	1.973	0.171
Rep * main	0.008	2	0.004	0.019	0.981
sub	54.856	7	7.837	38.327	0.000
main * sub	0.687	7	0.098	0.480	0.841

Maturiry stage

SV	SS	DF	MS	F-value	P-value
Rep	0.650	2	0.325	0.804	0.458
main	0.301	1	0.301	0.743	0.396
Rep * main	1.125	2	0.563	1.391	0.266
sub	62.896	7	8.985	22.203	0.000
main * sub	7.516	7	1.074	2.653	0.031

Appendex table 6. Analysis of variance showing natural enemy density across maize growth stages

Lady bird beetle density at Seedling stage

SV	SS	DF	MS	F-value	P-value
Rep	0.077	2	0.039	0.966	0.393
main	0.010	1	0.010	0.263	0.612
Rep * main	0.006	2	0.003	0.079	0.924
sub	0.115	7	0.016	0.411	0.887
main * sub	0.423	7	0.060	1.515	0.203

Lady bird beetle density at Vegeative stage

SV	SS	DF	MS	F-value	P-value
Rep	0.031	2	0.015	0.271	0.764
main	0.007	1	0.007	0.128	0.724
Rep * main	0.004	2	0.002	0.033	0.968
sub	0.384	7	0.055	0.966	0.474
main * sub	0.485	7	0.069	1.221	0.325

Lady bird beetle density at Tasseling stage

SV	SS	DF	MS	F-value	P-value
Rep	0.122	2	0.061	6.344	0.785
main	0.004	1	0.004	0.433	0.516
Rep * main	0.008	2	0.004	0.433	0.653
sub	0.086	7	0.012	1.277	0.297
main * sub	0.049	7	0.007	0.723	0.654

Lady bird beetle density at Grain filling stage

SV	SS	DF	MS	F-value	P-value
Rep	0.097	2	0.049	1.632	0.214
main	0.024	1	0.024	0.816	0.374
Rep * main	0.003	2	0.001	0.048	0.953
sub	0.129	7	0.018	0.617	0.737
main * sub	0.142	7	0.020	0.683	0.685

Lady bird beetle density at Maturity stage

SV	SS	DF	MS	F-value	P-value
Rep	0.162	2	0.081	2.417	0.108
main	0.081	1	0.081	2.417	0.131
Rep * main	0.042	2	0.021	0.620	0.545
sub	0.342	7	0.049	1.456	0.223
main * sub	0.180	7	0.026	0.764	0.621

Ear wick denstiy seedling stage

SV	SS	DF	MS	F-value	P-value
Rep	0.001	2	0.001	0.600	0.556
main	0.003	1	0.003	3.200	0.084
Rep * main	0.003	2	0.001	1.400	0.263
sub	0.006	7	0.001	0.800	0.594
main * sub	0.010	7	0.001	1.371	0.256

Ear wick density Vegetative stage

SV	SS	DF	MS	F-value	P-value
Rep	0.002	2	0.001	0.827	0.448
main	0.000	1	0.000	0.255	0.618
Rep * main	0.001	2	0.001	0.445	0.645
sub	0.010	7	0.001	0.982	0.464
main * sub	0.007	7	0.001	0.691	0.679

Ear wick density Tasseling stage

SV	SS	DF	MS	F-value	P-value
Rep	0.000	2	0.000	0.233	0.793
main	0.000	1	0.000	0.000	0.486
Rep * main	0.001	2	0.001	0.700	0.505
sub	0.007	7	0.001	1.067	0.410
main * sub	0.003	7	0.000	0.533	0.802

Appendex table 7. Analysis of variance showing percentage of parasitism across two grwoth stages

***Telenomus remus* at seedling stage**

SV	SS	DF	MS	F-value	P-value
Rep	3.060	2	1.530	1.996	0.155
main	0.003	1	0.003	0.004	0.952
Rep * main	0.006	2	0.003	0.004	0.996
sub	4.602	7	0.657	0.858	0.551
main * sub	6.129	7	0.876	1.142	0.366

***Cotosia icipe* at seedling stage**

SV	SS	DF	MS	F-value	P-value
Rep	2.989	2	1.495	1.760	0.191
main	0.204	1	0.204	0.240	0.628
Rep * main	0.408	2	0.204	0.240	0.788
sub	5.300	7	0.757	0.891	0.526
main * sub	6.591	7	0.942	1.109	0.385

***Chapros ater* at vegetative stage**

SV	SS	DF	MS	F-value	P-value
Rep	2.996	2	1.498	2.297	0.119
main	1.498	1	1.498	2.297	0.141
Rep * main	2.996	2	1.498	2.297	0.119
Sub	4.565	7	0.652	1.000	0.452
main * sub	4.565	7	0.652	1.000	0.452

***Cotesia icipe* at vegetative stage**

SV	SS	DF	MS	F-value	P-value
Rep	1.402	2	0.701	1.000	0.381
main	0.701	1	0.701	1.000	0.326
Rep * main	1.402	2	0.701	1.000	0.381
sub	4.906	7	0.701	1.000	0.452
main * sub	4.906	7	0.701	1.000	0.452

Appendex table 8. Analysis of variance showing cob damage score across two grwoth stages of maize

Maturiy stage

SV	SS	DF	MS	F-value	P-value
Rep	1.065	2	0.533	1.196	0.317
main	0.064	1	0.064	0.143	0.708
Rep * main	0.674	2	0.337	0.757	0.478
sub	10.561	7	1.509	3.388	0.010
main * sub	0.509	7	0.073	0.163	0.991

Harvest stage

SV	SS	DF	MS	F-value	P-value
Rep	0.375	2	.187	0.758	0.478
main	0.255	1	.255	1.032	0.318
Rep * main	0.198	2	.099	0.400	0.674
sub	6.224	7	.889	3.594	0.007
main * sub	0.599	7	.086	0.346	0.925

Appendex table 9. Analysis of variance showing yeild

Yeild

SV	SS	DF	MS	F-value	P-value
Rep	634263.884	2	317131.942	0.986	0.386
main	1464020.078	1	1464020.078	4.551	0.342
Rep * main	1337563.417	2	668781.708	2.079	0.144
sub	61958685.987	7	8851240.855	27.514	0.000
main * sub	2835222.026	7	405031.718	1.259	0.306