Efficacy of Selected Insecticides against Fall Armyworm, *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera: Noctuidae), in Maize and their Impacts on Associated Parasitoids

Mihiret Kifle Haile

A Thesis Submitted to the Department of Applied Biology

School of Applied Natural Science

Presented in Partial Fulfillment of the Degree of Masters in Applied Biology (Specialization in Applied Entomology)

Office of Graduate Studies

Adama Science and Technology University

July 2023

Adama, Ethiopia

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Declaration

I hereby declare that this Master Thesis is entitled **" Efficacy of Selected Insecticides against Fall Armyworm, *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera: Noctuidae), on Maize and their Impacts on Associated Parasitoids".** It is my original work and it has not been submitted for the award of any academic degree, diploma, or certificate at any other university. All sources of materials that were used for this thesis have been duly acknowledged through citation.

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Recommendation of Advisors

I, the major advisor/supervisor of this thesis, hereby certify that I have closely advised or supervised the student while developing this research and read the draft thesis entitled **"Efficacy of Selected Insecticides against Fall Armyworm, *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera: Noctuidae), on Maize and their Impacts on Associated Parasitoids"** prepared under my guidance by Mihiret Kifle. Submitted in partial fulfillment of the requirements for the degree of Master's of Science, in Applied Biology (Applied Entomology). Therefore, I recommend the submission of revised version of the thesis to the department following the applicable procedures.

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Approval sheet

We, the advisor and co-advisor of the thesis entitled "**Efficacy of Selected Insecticides against Fall Armyworm, *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera: Noctuidae), on Maize and their Impacts on Associated Parasitoids**" and developed by Mihiret Kifle, hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

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Approval of Board of Examiners

We, the undersigned, members of the Board of Examiners of the thesis by Mihiret Kifle have read and evaluated the thesis entitled "**Efficacy of Selected Insecticides against Fall Armyworm, *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera: Noctuidae), on Maize and their Impacts on Associated Parasitoids**" and examined the candidate during open defense. This is, therefore, to certify that the thesis is accepted for partial fulfillment of the requirement of the degree of Master of Science in Applied Biology (Specialization in Applied Entomology).

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Abstract

The fall armyworm, Spodoptera frugiperda (J. E. Smith) (Lepidoptera: Noctuidae), causes high damage on many crops, but maize is the most preferable crop. Maize is one of the most economically important crops in Ethiopia. These invasive pests affect crop production and cause high-yield losses. Due to insecticides effect on non-target organisms (natural enemies), a selection of insecticides with less effect on natural enemies (non-target organisms) is needed. We evaluated three insecticides: Bravo-5000, Aim 10%, and Rambo, which were sprayed in the maze field of MARC based on the recommended dosage of each insecticide. The experiment was arranged in a randomized complete block design (RCBD) with three replications, each insecticide sprays at recommended dosage every seven-day interval. Rambo and Aim 10% high efficacy than Bravo-5000 but all insecticides reduced FAW damage to the maze compared to control or untreated plants. Insecticides caused maize height difference between treated and untreated plants. There is no significance difference between leaf number of treated and untreated plants so chemical treatment did not affect the leaf number of maize plant. There were six parasitoid species from total number of 18 parasitoids which are (Cotesia icipe, Coccygidium luteum, Netelia species, Chelonus inanitus, an unidentified sp., and Charops ater) that have emerged from FAW larvae. Based on the result, Rambo shows a high efficacy next to Aim 10%, but Rambo (0.6% parasitism rate) caused a lower parasitism rate than Aim10% (2% parasitism rate). Non-parasitoid (0.0% parasitoids rate) result was obtained from the larvae that was collected from Bravo-5000 treated plants. Based on the results from three insecticides, Aim 10% is the most advisable insecticide by considering the toxicity of chemicals on FAW larval parasitoids.

Key words: Efficacy; Fall Armyworm; Insecticides; Maize damage; Parasitoids;

Parasitism rate; Parasitoids species

1. INTRODUCTION

1.1 Background of the Study

The Fall Armyworm (FAW), *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae), a polyphagous pest native to the Americas, is found in a few countries, including Mexico, Brazil, and Argentina (Roubos *et al*., 2014). Numerous crops, including maize, soybeans, cotton, rice, and other grasses, suffer severe damage and it also encourages the growth of several weeds FAW had a tendency to attack a variety of crops, which contributed to its rapid spread across the continent its propensity for maize (Name & Name, 2017). Maize is the main cereal crop in Africa, and its capacity to lay a large number of eggs its preference for maize, the continent's primary cereal and its ability to migrate over long distances (FAOb, 2017).

Early in 2016, when it was first discovered in central and western Africa, the pest suddenly appeared on the continent. From there, it spread quickly. It had been discovered in the majority of sub-Saharan Africa by 2017. According to Noctuidae *et al*. (2021), There are two main effects of the FAW's wide distribution in Africa. Firstly, the pest is discovered in a new area where its natural enemies are absent, favoring a startlingly rapid period of population growth and dispersal with detrimental effects on agriculture. Secondly, the crops are at risk because pests may have developed new resistance traits in their new environment (Paudel *et al*., 2022). FAW captured some hectares of flooded maize areas in southern Ethiopia in February 2017 and secured approximately 52,962 hectares in 144 areas in six of the major maize-growing regional states namely Gambella, SNNPR, Benishangul Gumuz, Oromia, Amhara and Tigeray (Assefa & Ayalew, 2019).

FAW larvae eat foliage and causing harm to a variety of plants. Young larvae typically cause leaf damage by poking holes in them and feeding primarily on the epidermis of the leaf's epidermis. Feeding on young plants through the whorl results I dead hearts. Larger larvae in the whorls of older plants may consume maize cobs or kernels, reducing yield and quality (Abrahams *et al*., 2017).

FAW can be extremely destructive from June through August when the minimum average temperature exceeds 10°C. It may be a tropical species adapted to hotter climates in Ethiopia, where temperatures range from 10.9 and 30 degrees Celsius. At lower temperatures (<10 Degree Celsius), all stages of FAW are killed, and at higher temperatures (> 30 degrees Celsius), the adult FAW's wings twist (Assefa, 2018).

FAW infests maize at all stages of plant development, with early invasions causing serious leaf-feeding damage and late invasions causing ear damage and higher yield losses (Kareem *et al.*, 2022). The invasion causes both quantitative and qualitative losses in maize. Additionally, very early infestations, particularly those that occur in the seedling stages, have been linked to crop loss and defoliation (Makgoba *et al.,* 2021). During the vegetative growth stages, larval damage occurs, resulting in extensive foliar damage (Soujanya *et al.*, 2019).

In America, synthetic insecticides and genetically modified crops (*Bt* maize) are the main management strategies for FAW (Horikoshi *et al.*, 2021). In South America, insecticide applications have been the most popular method of controlling FAW (Entomologist, 2011). Since the FAW invasion, insecticides have also been used in Africa regularly and in detail but with lacking in persuasion due to improper application methods of insecticide applications against FAW in maize (Hardke *et al.*, 2011). However, high-rate insecticide applications against FAW have been shown to be more effective than other control methods in terms of speed and efficiency, provided that applications are made on time and accurately (Van *et al.*, 2021). There is conflicting evidence in the scientific literature regarding the effectiveness of chemical control of FAW in reducing yield loss (Sisay *et al.*, 2019; Van *et al.*, 2021). Since the emergence of FAW in African nations, synthetic insecticides have been extensively used as an emergency response to slow the pest's spread and reduce damage to maize fields (Tepa-Yotto *et al.*, 2022).

In addition to other negative effects brought on by relying solely on synthetic insecticides, using insecticides also has an unintended negative impact on the health of people. Insecticides also have impact on natural enemies such as predators, parasitoids and Entomopathogen. Farmers have complained that because the synthetic insecticides available currently decrease effectiveness against FAW through time , they must use high doses and frequent applications, which cause pesticides to build up in the environment and hasten the emergence of resistance (Sisay *et al.*, 2019).

1.2 Statement of the Problem

The Ethiopian economy is thought to be based largely on agriculture. In 2019, agriculture contributed about 34% of Ethiopia's GDP (Ibrahim 2019) and 85% of the population depends on it either directly or indirectly (Mekonnen & Gokcekus, 2020). The top three countries for maize production worldwide are the United States, China, and Brazil (Ranum *et al.*, 2014). Maize has been grown all over the world. In addition, maize serves as the main component of the diet for 85% of Kenyans (Perez *et al.*, 2013). In recent years, maize has become Ethiopia's most important cereal crop. Next to Nigeria, Ethiopia produces the second-most maize in Sub-Saharan Africa from 939 thousand metric tons in 1970 to 8500 thousand metric tons in 2019, maize production in Ethiopia increased at an average annual rate of 7.64%.

Maize can be affected by many pests such as ear borers, army worms, cutworms, beetles, weevils, grain borers, root worms and white grubs can also be found on maize in Sub-Saharan. According to Paudel *et al*. (2022) FAW impact on many crops which includes, maize, soybeans, cotton, rice, other grasses, and vegetables but maize is most preferred crops for FAW.

According to Kumela *et al.* (2019), FAW could reduce maize yield in Africa by 8.3 to 20.6 million tons annually, or 21-53% of production. Only two districts were used in Zimbabwe's single direct measurement of FAW loss in Africa, which put the losses in 2018 at 11.6% (Baudron *et al.,* 2019), as well as according to Kumela *et al.* (2019), FAW infestation rates were 47% (1381 kg/ha) in Kenya and 32% in Ethiopia (with yield reductions of 934 kg/ha). Because of the new invasive of the species and high potential losses, management of FAW is mandatory. Control method includes, biological control method, chemical control method, cultural control method, botanical control method and integrated pest management (IPM). Among those chemical (insecticide) control method is one and the successful method.

There are different types of insecticidal option which are produced in different company with different composition to manage FAW, also in different agro-ecosystems which can cause variations to efficacy. There are different tested insecticides in different areas like lambda-cyhalothrin; indoxacarb; spinetora; chlorantraniliprole; emamectin benzoate; flubendiamide in India (Deshmukh *et al*., 2020). According to Sisay *et al* 2019 different insecticides were tested in Ethiopia which includes: chlorantraniliprole (Coragen 200 SC), spinetoram (Radiant 120 SC), agro-Thoate 40% EC (Dimethoate 40%), spinosad (Tracer 480 SC), lambda-cyhalothrin (Karate 5 EC), Malathion 50% EC, chlorantrniliprole + lambda-cyhalothrin (Ampligo 150 SC), and Imidacloprid (Sisay *et al.*, 2019). More importantly, evaluating their efficacy is not enough but evaluating insecticidal effect on natural enemies (parasitoids) has a great roll to use effective specific chemicals from many options. Because insecticides have a great effect on non-targeted organism includes FAW parasitoids. Therefore, this research is conducted to select the insecticides which have high efficacy and low factors to natural enemies of FAW and using the best insecticides to reduce damage of maize by FAW.

1.3 Objectives of the Study

General Objective

- To evaluate the efficacy of some insecticides against the FAW and their effects on its parasitoids in the field.

Specific Objectives

- To identify effective insecticides against FAW on maize.
- To identify larval parasitoids of FAW in the study area.
- To evaluate the effect of insecticides on FAW larval parasitoids.

1.4 Significance of the Study

The findings of this study can provide baseline information about FAW damage to maize, the efficacy of some selected insecticides against FAW and their effects on the natural enemies of the pest. The results of this study can also be used as references by researchers/students from higher educational institutions conducting their studies on the FAW as well as farmers using the recommended insecticide.

1.5 Scope of the Study

The study was conducted at Melkassa Agricultural Research Center (MARC) due to its accessibility, persistence of the pest/FAW throughout the year in the research station (field) of the Research Center and MARC doesn’t have insecticides specific for FAW instead uses insecticides of army worm as emergency response (Mulatuwa Wondimu, personal communication). Insecticides and facilities required for the study are not available at the Center. Due to a lack of extra land in the Center for growing maize and financial constraints, the number of insecticides used in this study was limited. All three insecticides were selected by considering availability and their low cost. Only five parameters were selected which indicates damage of maize plant.

2. LITERATURE REVIEW

2.1 The Fall Armyworm and its Distribution

Several countries, including Mexico, Brazil, Argentina, and the USA, are home to the Lepidoptera (moth) polyphagous pest known as the Fall armyworm (FAW), *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera: Noctuidae) (Roubos *et al.,* 2014). Early in 2016, FAW was discovered for the first time in Central and Western Africa. As of 2018, it has spread to almost all of Sub-Saharan Africa, with the exception of Djibouti, Eritrea, and Lesotho (FAO, 2018a). Ethiopia acquired roughly 52,962 hectares in 144 locations across six of the main maize-growing regional states, including Benishangul-Gumuz, Amhara, Tigray, Gambella, Oromia, and the South Nation Nationalities, and Peoples' Region (SNNPR), in 2017 (Figure 1) (Assefa, 2018).

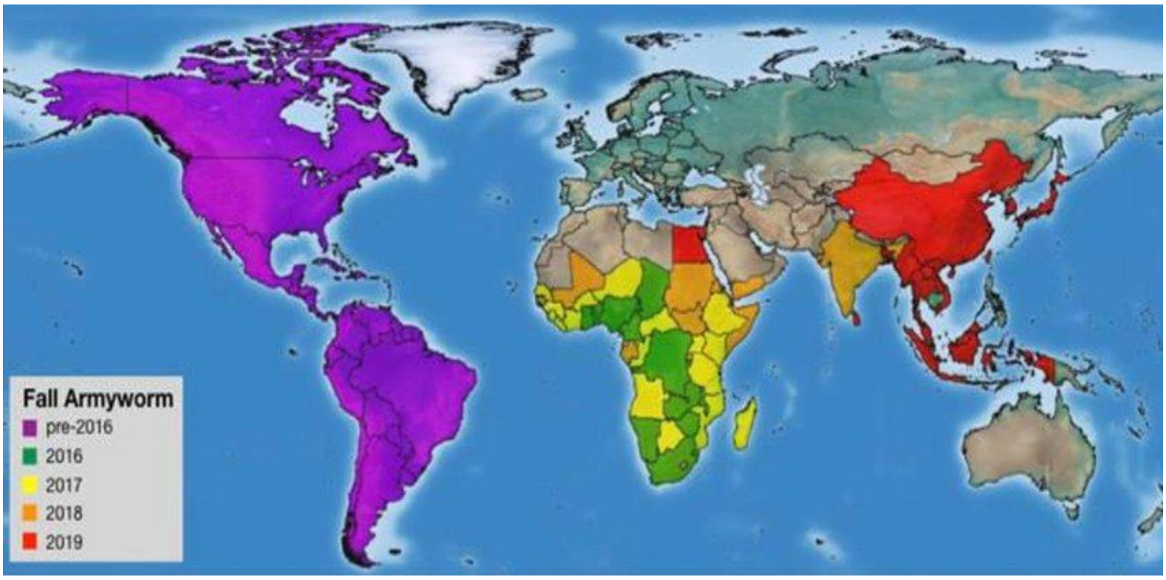

Figure 1**:** Geographic distribution of FAW with recorded year (Naganna *et al*., 2020).

In June, 2017 the FAW infestation in Ethiopia significantly worsened, affecting 145,000 hectares of land as opposed to 53,000 at the end of May (Note *et al*., 2017). At least six of Ethiopia's states have been affected by the infestation, which has spread to at least 16 other African nations and millions of people since late 2016 and is likely to continue. The SNNPS, which has about 100,000 people (or 20,000 households), is most affected by the loss of livelihoods (Note *et al.,* 2017*)*.

2.1.1 Life cycle of FAW

Throughout the entire year, the moths persistently continue to migrate and lay eggs. Over the course of her lifetime, the female FAW moth can lay up to 1,000 eggs, which she deposits in clusters of up to 150-200 eggs. The eggs are sometimes deposited in layers, but most eggs are spread over a single layer attached to foliage.

Fall armyworm typically has six instars. For instars 1 to 6, head capsule diameters are around 0.35, 0.45, 0.75, 1.3, 2.0, and 2.6 mm. During these instars, larvae grow to be about 1.7, 3.5, 6.4, 10.0, 17.2, and 34.2 mm long. Young larvae have a greenish body and a black head, which turns orangish in the second instar. The dorsal surface of the body becomes brownish in the second and third instars, and lateral white lines emerge. The head is reddish brown and mottled with white in the fourth to sixth instars, and the brownish body has white subdorsal and lateral lines. Elevated patches appear dorsally on the body and are usually dark in color with spines. When studied closely, the mature larva's face is also marked with a white inverted "Y," and its epidermis is rough or granular in texture (Hardke *et al.*, 2015). It has six larval instars, the last of which lasts 14 to 22 days (FAO, 2017a). Because of their ability to manufacture silken thread, larvae can be dropped or blown to other areas (a process known as ballooning). FAW generations might occur every 23 to 30 days (Figure 2) (Barlow & Kuhar, 2009)**.**

Pupation occurs in the soil at a depth of 2 to 8 cm. By connecting soil particles together with silk, the larva creates a loose cocoon that is oval in shape and 20 to 30 mm long. Larvae may web together leaf detritus and other material to form a cocoon on the soil surface if the soil is too hard. The pupa is reddish brown in color and measures 14 to 18 mm long by 4.5 mm wide (The *et al.*, 2014).

Adult moths have wingspans ranging from 32 to 40 mm. The forewing of the male moth is normally gray and brown, with triangular white patches at the tip and in the center of the wing. Females' forewings are less distinct, ranging from a uniform grayish brown to a faint mottling of gray and brown. In both sexes, the hind wing is iridescent silver-white with a short dark border. Adults are nocturnal and most active in the evenings when it is warm and humid. The female generally deposits the majority of her eggs within the first four to five days of life after a three to four day pre-oviposition period, however some oviposition occurs for up to three weeks (The *et al.*, 2014).

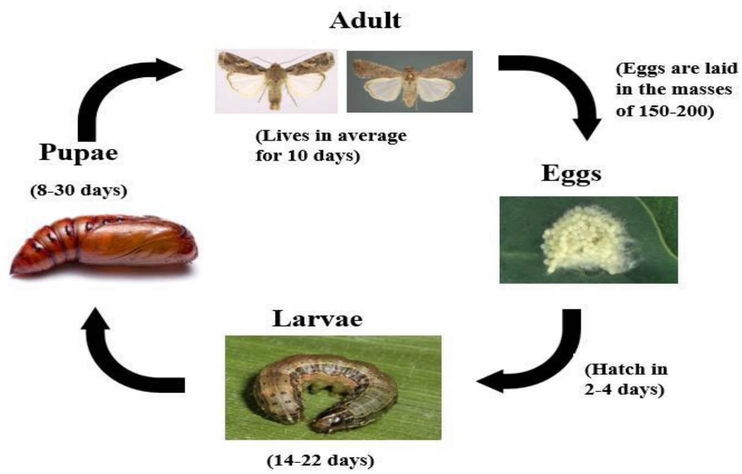

Figure 2: FAW life cycle (Naharki *et al*., 2020)

2.1.2 Economic important of FAW

I. Research Use

In biomedical research, *S. frugiperda* cells (Sf9 and Sf21 cell lines) are frequently used for the production of recombinant proteins using baculoviruses that are insect-specific viruses (Sanchez, 2011).

II. Pest of Crop plants

FAW larvae are a problem on a variety of crops because of their food preferences. Georgia published the first account of the FAW's destruction in 1797. Due to the difference in food requirements between the early and later stages of a caterpillar's life, destruction can occur almost instantly. The presence of larvae won't be discovered until they've completely destroyed everything in as little as a night due to this abrupt change in food consumption (Van *et al*., 2017).

2.2 Host Plants of FAW

With over 350 different host plants, including both crop and non-crop species, the FAW is an alien polyphagous insect pest that is native to the Americas. With over 80 plants recorded, this species appears to have a wide host range, but it clearly prefers grasses. Field and sweet corn, sorghum, Bermudagrass, and grass weeds like crabgrass, *Digitaria spp*., are the most commonly consumed plants. FAW is known to have a strong preference for host plants, despite the fact that it can survive in a variety of host plants (Canico *et al*., 2021). Apple, grape, orange, papaya, peach, strawberry, and a number of flowers are other crops that can occasionally suffer damage. *Agrostis species,* crabgrass, Johnson grass, Sorghum halepense, morning glory, *Ipomoea species, nutsedge, Cyperus species, pigged*, *Amaranthus species*, and sandspur, *Cenchrus tribuloides* are among the weeds known to act as hosts (Barlow & Kuhar, 2009).

2.2.1 Maize plant

In terms of global grain production, maize (*Zea mays L.),* a cereal grass related to wheat, rice, oats, and barley, comes in second place behind wheat and is followed by rice, which comes in third. Because of its greater adaptability than wheat, rice, or any other crop, this plant is regarded as being versatile with a wide range of uses and is grown in a wider range of environments. Maize yields more than other cereals, is simple to process, is easily absorbed, and is less expensive (Getahun & Wondimu, 2020).

In Africa, where it is widely grown and consumed, maize is a very significant cereal grain. It provides humans with a source of dietary carbohydrates. About 17% of Ethiopia's total cultivated land is dedicated to it, and 24% of the grain produced there is grown there under a variety of ecological conditions. One of the most important cereal crops grown in Ethiopia for food and feed is maize. It is one of the most significant cash crops and staple foods, giving consumers calories and giving traders money (Getahun & Wondimu, 2020). Due to its high nutritional value as a stable food source as well as its consistent demand for animal feed, fuel, and even construction purposes, maize (*Zea mays L.)* is one of the most important and widely used cereal crops (Abebe & Feyisa, 2017).

On maize in the field, more than 40 different species of insects have been identified. A more recent invasive species, the maize stalk borer *(Busseola fusca*), spotted stalk borer (*Chilo partellus),* and various termite species (Macrotermes and *Microtermes spp*.) have also been identified as major pests. 16 February 2018, Rome - Faced with the infestation of millions of hectares of maize, most in the hands of smallholder farmers, and the relentless spread of FAW across most of Africa, the UN Food and Agriculture Organization (FAO) launched today a comprehensive guide on the integrated pest management of the FAW on maize (FAO, 2018b).

The FAW causes crop growth distortion, reduced crop yield and total crop failure in the absence of effective management intervention. In the absence of effective control measures, FAW has the potential to cause an estimated yield loss of about 8.3 to 20.6 million tonnes of maize per annum (valued at US$ 2,481–6,187 million) in 12 maize producing countries in Sub-Saharan Africa, which accounts for approximately 20% of the total production in the region (Abrahams *et al.* 2017). According to Kareem *et al*. (2022) FAW on maize shows an estimated production loss of between 4.1 and 17.7 million tones (1,088 USD and 4,661 million USD) due to FAW compared with the total expected production of 39.3 million tonnes (US$ 10,343 million) across Africa. In Ghana, the recent average maize loss was reported to be 26.6% extrapolated to an annual value of 177 million USD, which was much lower than the loss in 2017 (Koffi *et al.*, 2020). FAW is major insect pests causing substantial yield losses of maize in Ethiopia (Mitku, 2022).

2.3 FAW Control Options

The key to managing FAW infestations is spotting them before they cause harm to the economy. Applying an efficient control measure to maize is advised if 5% of seedlings are cut or 20% of small plant whorls are infested with FAW (during the first 30 days) in order to prevent further damage (Fernández, 2002). Different control FAW and these are described below.

2.3.1 Cultural control of FAW

A one of component of FAW pest management strategy is cultural control. According to Murray *et al.* (2019) in Malawi, farmers control FAW by using Cultural control methods which includes apply sand, ash or soap directly into the whorl, physically remove and kill the insects they can find, use crop residue (often from maize but also from other crops) to mulch fields for moisture retention and rain protection. Farmers feel this might also provide some benefit in management of FAW, Fish soup: farmers apply small amounts of fish soup, which attracts ants that feed on the FAW larvae. Farmers used seasonal rotation mostly late planting are less advantage than early planting because maize ears severely attacked by a greater FAW infestation than early plantings is one method of cultural control. In addition, rotating maize with non-host crops like beans and sunflower may be helpful to reduce the invasion of FAW (FAO, 2018). The majority of subsistence farmers in Africa culturally do not spray pesticides on maize to ward off pests either; instead, they employ cultural pest control techniques that either deter or eliminate pests, such as inter-cropping maize, handpicking and killing caterpillars, and applying soil and wood ashes to leaf whorls (Assefa & Ayalew, 2019).

2.3.2 Botanical control of FAW

In 2018 there are insecticidal plant to control FAW those are spinetoram, Solaris 6 SC® (75 ml/ha) and Capsoil 9,82 EC® (Capsicumm annum + mustard (Sinapis alba) + garlic (Allium sativum) (2L/ha) were evaluated by comparing them with two homemade extracts: garlic extract + neem (Azadirachtaindica) + detergent (20 ml/1L water) and garlic extract + oregano (Origanumvulgare) + juanilama (Lippia alba) + rosemary (Rosmarinusofficinalis) (20 ml/1L water); and a control with the objective to evaluate the effectiveness of non-chemical alternatives to treat the Spodopterafrugiperda (Ballal *et al.*, 2021). Sisay *et al.,* (2019) showed that 11 insecticidal plants/botanicals that includes *Azadirachta indica* (Neem), *Militia ferruginea* (Birbira), *Phytolacca dodecandra* (Endod), *Jatropha curcas* (Jatropha), *Schinnus molle, Croton macrostachyu*s (Bisana), *Chenopodium ambrosoid*s leaf extract, *Melia abyssinica* (Melia), *Eucalyptus globulus, Nicotina tabacum* (Tobacco), and *Lantana camara* used to control FAW (Sisay *et al.,* 2019).

2.3.3 Biological control of FAW

One of the most significant alternative control methods for providing environmentally secure and long-term plant protection is biological control, which is a potent tool. The biological control method involves controlling the pest within biological agents, which are parasitoids, predators, pathogens, and parasites. Globally, 53 species of parasites, belonging to 43 genera and 10 families, that attack on FAW (Ashley, 1979; Sparks, 1986). Entomogenous pathogens have the ability to control FAW populations through at least three different mechanisms: enhancement of naturally occurring diseases; introduction and colonization of pathogens into insect populations as natural regulatory agents; and repeated applications of pathogens as microbial (Assefa, 2018). In order to control fall armyworm populations, a number of microbial pathogens have been studied. Viruses show limited efficacy against fall armyworm but are not temporally effective, allowing for significant damage prior to insect mortality (Sparks, 1986).

Biological agents become established in agricultural ecosystems is essential to the success of biological control. Microbial pathogens and arthropod bio-control agents have been used successfully in agricultural systems (Pilkington *et al*., 2010). According to Assefa & Ayalew (2019) states that their production costs have recently significantly decreased because they are mass produced in liquid media (such as bacteria, fungi, and nematodes). A variety of parasitoids, predators, and pathogens attack the larval and adult stages of the FAW.

Parasitoids are closely associated with one of the pest stages and have a higher level of specificity. Predators are rarely linked with a specific insect pest. They feed on the prey with a lower trophic level of specificity than other animals, e.g., the earwigs, ladybird beetles, podisus, and orius prey on different life stages of FAW. Entomopathogens include bacteria, fungi, viruses, protozoans, and nematodes that are the main cause of disease in insects. FAW was infected by several entomopathogens, including *Bacillus thuringiensis* (*Bt*), *Metarhizium anisopliae*, *Beauveria bassiana*, and *Spodoptera frugiperda* multiple nucleopolyhedroviruses (Abbas *et al*., 2022).

2.4 Natural Enemies of FAW

Organisms that manage the population of hosts or prey are considered natural enemies. In areas where FAW overwinter, cool, wet springs followed by warm, muggy weather help the species survive and reproduce while protecting it from natural predators. Once northward dispersal starts, natural enemies are left behind. Because of this, even though FAW has numerous natural enemies, very few of them are powerful enough to prevent crop damage (Malik *et al*., 2014).

2.4.1 Parasitoids of FAW

Many parasitoids, some of which are listed in Table 1 affect FAW. The most prevalent wasp parasitoids raised from larvae in the United States are *Cotesia marginiventris* and *Chelonus texanu*s (both Hymenoptera: Braconidae, as shows in Table 1), which are also connected to other *noctuid species* (FAO & ASARECA, 2018). *Archytas marmoratus* (Townsend) is usually the most abundant fly parasitoid (Diptera: *Tachinidae*). However, the dominant parasitoid frequently varies from location to location and year to year. Many of the FAW parasitoids can be described and illustrated (Meagher et al., 2016).

Table1: Major known Parasitoids of FAW (FAO & ASARECA, 2018)

Parasitoids	Stages of FAW parasitized
Archytas incertus	Larva
Archyta marmoratus	Larva/pupa
Campoletis flavicinatus	Larva
Chelomus curvimaculatu	Eggs/larva
Chelomus insularis	Egg/larva
Cotesia marginventris	Larva
Cotesia rinficrus	Larva
Euplectrus platyhypenae	Larva
Glyptapanteles creatonoti	Larva
Lespesia archippivora	Larva
Microchelonus ovata	Eggs/larva
Brachymeria ovataa	Pupa
Telenomus remus	Eggs
Trichogramma achaeae	Eggs
Trichogamma chilotraeae	Eggs
Trichogamma pretiosum	Eggs
Trichogammarojasi	Eggs

2.4.1.1 FAW parasitoid species distribution in Africa

FAW larvae are susceptible to various parasitoids, corroborating earlier field reports in West Africa: Senegal (18) species, Benin, and Ghana (17, 21) species respectivelly. Many Chelonus species are generally solitary egg-larvae koinobiont endoparasitoids that attack Lepidoptera, including *S. littoralis*, *S. exigua, S. frugiperda,* and *Heliothis virescens Fabricius* (42) species. *Chelonus* spp. have been reported in the FAW in several countries (Ahissou *et al.,* 2021)**.**

2.4.2 Predators of FAW

FAW predators are polyphagous generalists that feed on a range of caterpillars. The predators of FAW like, *Calasoma sayi, Carabidae* and some other listed in the Table 2. The larvae and pupae of FAW are readily consumed by vertebrates like birds, skunks, and rodents. Predation could have a big impact, as Pair and Gross (1984) demonstrated that predators kill 60 to 90 percent of pupae in Georgia. Beetles, earwigs, and other insects are common predators. Direct predation has been shown to cause significant losses in caterpillar populations.

Table 2: Major known Predators of FAW (FAO & ASARECA 2018)

Predators	**Stages of FAW**
Colosma altermans	Larva
Calasoma sayi	Larva
Carabidae	Larva
Doru luteipes	Larva/pupa
Doru laeniatum	Larva
Ectomma ruidum	Larva
Geocoris punctipes	Larva
Stelopolybia pallipes	Larva
Podisus maculiventris	Larva

2.4.3 Pathogens of FAW

Few pathogens actually cause epizootics, despite the fact that many of them have been linked to FAW, including viruses, fungi, protozoa, nematodes, and a bacterium. Microorganisms and other pathogens can affect FAW hatchlings and cause color changes. According listed in a Table 3 there are few major pathogens (Fall Armyworm , 2018).

Table 3: Some Known pathogens of FAW (CABI and FAO 2019)

Pathogen	Stages of FAW
Bacillus cereus	Larvae
Bacillus therigienesis	Larvae
Bacillus therigienesis alesti	Larvae
Bacillus therigienesisdarmsadiensis	Larvae
Bacillus therigienesis	Larvae
Bacillus therigienesis kustaki	Larvae
Beauveria baassiiana	Larvae/egg
Granolusis virus	Larvae
Metarhizim amisophae	Larvae/egg
Nucleopolyhedrosis virus	Larvae

2.4.4 Sex pheromone control of FAW

Sex pheromones are chemical signals generated by an organism that induce a sexual response in an organism of the opposite sex. More than 600 varieties of lepidopteran pheromones have been identified since the structural characterization of the first sex pheromone of the silkworm moth Bombyx mori in 1959. Their main characteristics, such as species-specificity, non-toxicity to mammals and other beneficial organisms, minute activity, and rapid degradation in the environment, were quickly envisioned as promising tools for controlling insect pests, estimating pest populations, detecting the entry and progression of invasive pests, and preserving endangered species (Rizvi *et al*., 2021)

Pheromone traps have the capacity to forecast where and when FAW infestations may occur. A variety of FAW pheromones are commercially available, and some of these have been shown to be effective in traps such as the universal moth trap (Issct *et al*., 2005). FAW females from the Americas generate a male attractive pheromone that contains at least two components: the major component (Z)-9-tetradecenyl acetate (Z9-14: Ac) and the minor component (Z)-7-dodecenyl acetate (Z7-12: Ac). (Z)-9-dodecenyl acetate (Z9-12: Ac) and (Z)-11-hexadecenyl acetate (Z11-16: Ac) are two other minor chemicals discovered in the pheromone gland. (E)-7-dodecenyl acetate (E7-12: Ac) is a minor components (Jiang 2020).

2.5 The Concept of Insecticides (Chemical Control of Insect Pests)

Insecticides are chemicals that are used to kill insects (Ishizuka *et al*., 2022). Ovicides and larvicides are types of insecticides that are used to kill insect eggs and larvae. Insecticides are used in agriculture, healthcare, industry, and by consumers. It is believed that insecticides significantly increased agricultural productivity in the 20th century (Van *et al*., 2021). Insecticides can be either repellent or not (Important Terms for Structural and Public Health Pest Control Definitions for Pest Control Categories 7 and 8, 2016).

The use of baits, conventional and very low volume airborne formulations, and granular insecticide formulations applied to plant whorls or tips have all been considered as alternatives to using large amounts of water in insecticides. Aerial applications of 19 to 47 liters per hectare typically result in inadequate coverage and, consequently, less control than ground tools that use more water. In some crops, aerial application methods can effectively control FAW, but only when combined with repeated insecticide applications (Assefa, 2018).

Insecticides have been used successfully to control the larvae of FAW, in many fields (Ishizuka *et al*., 2022). FAW described factors (such as plant height and canopy density) restricting effective insecticide control due to insufficient spray coverage, seedling protection with systemic insecticides applied at planting and soil applicators including tractor mounted spreaders, high clearing sprayers, granule applicators, and application in irrigation systems (Sparks, 2014).

All insecticides have the potential to drastically alter ecosystems in the beginning; many of them are toxic to people and/or animals, and some concentrate as they move up the food chain. Systemic insecticides, which have long-term or residual activity, and contact insecticides, which have no such activity, are the two main categories of insecticides (Roubos *et al*., 2014).

2.5.1 Chemical control of FAW

Synthetic insecticides are typically used to control FAW, but doing so comes at a high cost, poses a risk to the environment, encourages the development of chemical resistance, and frequently results in pest resurgence (Abbas *et al*., 2022). Ethiopia uses a variety of general insecticides (including pyrethroids, carbamates, and organophosphates) to combat FAW.

Effective pest control depends on the precise timing of chemical applications; both the life cycle and the time of day are important; for example, spraying when larvae are deeply embedded inside the whorls and ears of maize is ineffective (Assefa & Ayalew, 2019).

2.6 The Effective Insecticide on FAW

Sulprofos, thiodicarb, and methomyl are known to be effective against this pest in areas of the United States, Central and South America, and the Caribbean, whereas carbaryl, trichlorfon, and methyl and ethyl parathion provide either poor or no control of the FAW. In tests conducted over the past ten years at recommended doses for the control of other insect pests, synthetic pyrethroids have produced erratic results (FAO & ASARECA, 2018) discovered that pyrethroids were ineffective against FAW. In Mississippi laboratory tests with FAW, permethrin was discovered to be more effective than methyl parathion and carbaryl. Methylparathion, trichlorfon, and carbaryl were found to be less effective than permethrin at controlling FAW (Type, 2022).

Chlorpyrifos, methomyl, fonofos, and deltamethrin were all effective against FAW larvae in field tests conducted in Brazil; while carbaryl and heptachlor were less effective. Eight of the nine pyrethroids tested in laboratory bioassay tests were more toxic (3–120X) than diazinon. The various reactions to fenvalerate and cypermethrin, two synthetic pyrethroids, suggest that some of the insect population may be tolerant (Sparks, 2014).

A treatment including emamectin benzoate, deltamethrin, and chlorantraniliprole significantly decreased the number of FAW pests (Roubos *et al*., 2014). Mian (2022) reported that spinosad, methoxyfenozide, carbaryl, and methomyl are effective. Insecticide use can increase crop production by reducing pest populations. Emamectin benzoate are the most toxic chemical and deltamethrin insecticide, followed by chlorantraniliprole (Roubos *et al*., 2014; Type, 2022). Chlorpyrifos, methomyl, fonofos, and deltamethrin are all effective against FAW larvae in field tests conducted in Brazil; carbaryl, and heptachlor were less so. The various reactions to fenvalerate and cypermethrin, two synthetic pyrethroids, suggest that some of the insect population may be tolerant (Sparks, 2014).

In 2014 a study discovered that, all treatments including emamectin benzoate, deltamethrin, and chlorantraniliprole significantly decreased the number of FAW pests (Roubos *et al.,* 2014). Mian (2022) reported that, after 13 days post-treatment, it was discovered that the insecticides spinosad, methoxyfenozide, carbaryl, and methomyl were effective. They concluded that pyrethroids were the least toxic chemical, while emamectin benzoate was next (Roubos *et al.*, 2014). According to Maruthi *et al*. (2020), Intrepid 2F (methoxyfenozide, 70.02 gm per ha), Lannate 2.4LV (methomyl, 252.16 gm per ha), Sevin XLR Plus 4F (carbaryl, 560.39 gm per ha), and Tracer 4SC (spinosad, 35.06 gm per ha) were all tested and found to be effective reducers (Deshmukh *et al*., 2020). The Van *et al.* (2014) reported that chlorantraniliprole provided better control (14 days, 85.9% mortality) when foliage was collected from treated fields and used in the lab. However, at 7 days after treatment, lambda-cyhalothrin caused 28.1% mortality while flubendiamide caused only 53.1% (Van *et al*., 2021).

Idrees *et al.* (2022) reported that among seven synthetic insecticides, which including novel and conventional ones, from four chemical groups, spinetoram and spinosad (spinosyns), lambda-cyhalothrin, cypermethrin and bifenthrin (pyrethroids),abamectin (avermectins), and broflinilide (diamides), were tested for their efficiency in causing mortality to second instar FAW (10 to 0.625 mg liter-1). According to Idrees *et al*. (2022) Broflanilide and abamectin had LC50 values of 0.606 and 0.774 mg liter-1, respectively, at 72 hours after treatment, while cypermethrin and bifenthrin had LC50 values of 0.803 and 0.906 mg liter-1, respectively. The remaining synthetic insecticides ranged in moderate toxicity index from 42.11 to 62.09%, with LC50 values at 72 hours post-treatment ranging from 1.439 to 0.976 mg/liter. The effectiveness of synthetic insecticides increased with increased concentration and exposure time.

2.7 Indirect Effects of Insecticides on Non-target Organisms

The majority of legislation aimed at regulating or outlawing the use of particular pesticides is based on the effects of insecticides on non-target organisms, which have been a source of debate and concern around the world for more than ten years (Aktar *et al.*, 2009). Although pesticide toxicity to non-target organisms is more likely to occur, it gained popularity after Rachel Carson's "Silent Spring" was published in 1962 and sparked a general awareness of environmental issues. Since then, pesticide toxicity has been linked to a large number of unintended fatalities and massive destruction incidents (Culver *et al.*, 2012). Animal food or water contamination is the primary method of animal poisoning. Because of tainted food and water sources, as well as the use of pesticides on livestock areas, pigsties, and sheepfolds, persistent organic pollutants, such as OC (organo-carbon) pesticides, can build up in livestock and domestic animals (Friend, 1999; Hashimi *et al.*, 2020). Examples include the > 5000 Swainson's hawk mass extinctions caused by monocrotophos poisoning in the Argentine pampas, the Prince Edward Island fish deaths caused by nabam and endrin, and the Florida fish deaths caused by fenamiphos, among many other cases (VanEngelsdorp *et al.*, 2009).

Sometimes non-target organisms are more exposed to pesticides than target organisms. Target weeds may be less exposed to herbicides used for aquatic weed control than (non-target) fish, which live interred in the water in addition to the accumulation of fat Many DDT-derived pesticides are withdrawn from the market or banned due to their off-target toxicity. Wang *et al*. (2007) reported as Carbamate insecticides were responsible for 50.3% of the poisoning in domestic animals and livestock, followed by rodenticides-anticoagulants (18.9%), OP insecticides (5.1%), rodenticides-non-anticoagulant (3.4%), and others (22.3%). However, the toxic effects of pesticides are very obvious and otherwise can be confirmed (Damalas & Eleftherohorinos, 2011).

An insecticide that reduces the non-target population by 50% may be much safer than one that prevents it from reproducing and carrying out its activities. However, when viewed as a whole, reproduction and predatory potential can be more relevant in pest management and thus proposed. Risk assessment of pesticide application on non-targets is typically used for assessing and comparing toxic effects and exposure levels (Sparks, 2014).

2.7.1 Negative impacts of insecticides on human health

Synthetic insecticides, a diverse class of biologically active substances first developed in the 1940s, are now essential, frequently employed tools for the prevention and treatment of infectious diseases (Summary & Exposure, 2011). Pesticide residues in food supplies and the food chain that have caused growing concern in recent years that they pose a risk to the general public (Important Terms for Structural and Public Health Pest Control Definitions for Pest Control Categories 7 and 8, 2016) have an impact on human health, wildlife, and sensitive ecosystems (Figure 2) (Damalas & Eleftherohorinos, 2011).

Overuse of synthetic insecticides led to a number of unanticipated issues, such as the acute and chronic poisoning of handlers, farm workers, and even consumers as pesticides entered the food chain; the extinction of aquatic life, birds, and other wildlife; the disruption of natural biological control agents and pollinators; extensive groundwater contamination (Figure 2), which may endanger human health by posing direct risks to users; and the emergence of resistant pests (Bolzonella *et al*., 2019). In addition to exposure to pesticides at work and harmful effects on human health, such as leukemia, lymphoma, liver, kidney, pancreas, breast, prostate, kidney, skin, and other chronic diseases, as well as potential harm to mental health and reproduction (Gupta, 2004).

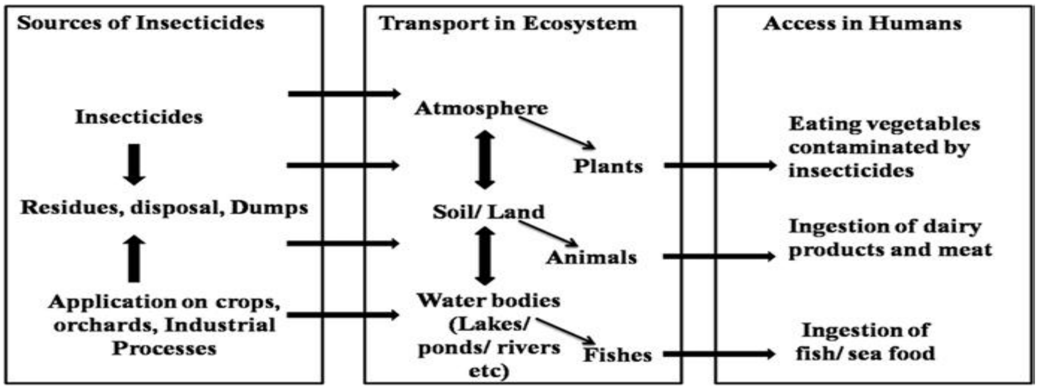

Figure 3: Entry of Insecticides into the human body (Malik *et al.,* 2014).

2.7.2 Negative Impacts of Insecticides on Useful Insects

Insecticides, both accidental and intentional, can kill honeybees and other insect pollinators. Pesticide residues have been found in hive products, specifically beeswax (Johnson *et al.* 2010). One-fifth of honeybee colonies have been destroyed by pesticide use in the fields, and 15% of them are endangered in the USA. A variety of pesticides have an effect on honeybee colonies and production, and more than 150 different chemicals have been found in colony samples approximately. The majorities of these chemicals were insecticides and were more concentrated in pollen than in adult bees. Different pesticides are used by farmers in the study area to manage weeds, insects, and fungus. As a result, pesticides have significantly contributed to the decline in honey bee populations and the loss of their products (Bekele *et al*., 2021).

Several studies on the effect of insecticides on beneficial insects have been conducted. In hotspots, there has been a significant decline in the population of natural predators such as *Coccinellids, Chrysoperia carnea, Trichogramma spp., Apanteles spp., spiders, black burni, Cheloanus,* etc. Insecticides have exhibited various degrees of toxicity to *Tricho-gramma spp*. Predator of brown *planthopper, Nilaparvata lugens Cotesia plutellae, endoparasitoid of P. xylostella* natural enemies of citrus scale pests *Aphytis melinus DeBach, Coccophagus lycimnia Walker, Leptomastix dactylopii Howar* (Suma *et al.*, 2009). *Aphytis melinus Debach, Eretmocerus eremicus Rose* and Zolnerowich, and *Encarsia formosa (Ga-han)* and *Mymaridae, G onatocerus ashmeadi Girault that attack Californiaredzscale, Aonidiellaaurantii (Maskell);* sweet potato whitefly*, Bemisiatabaci (Gennadius)(both E. eremicus* and *E. formosa*); and glassy-winged sharpshooter*, Homalodisca vitripen-nis(Germar)*,*Coccinellids spp* and the *chrysopid, Chrysoperla externa* an important predator respectively (Preetha *et al.*, 2010).

Insecticides, Ops (oregano-phosphates), carbamates, pyrethroids, insect growth regulators (IGRs), neonicotine, phenylpyrazole, and antibiotics were all found to be toxic to adult parasitoids (Golsteyn *et al.*, 2021). *Anagrus nilaparvatae* is an egg parasitoid of the rice planthopper. OPs (chlorpyrifos, fenitrothion, phoxim, profenofos and triazophos) and carbamates (carbaryl, carbsulfan, isoprocarb, metolcarb and promecarb) exhibited the highest intrinsic toxicity to Trichogramma japonicum, an egg parasitoid of rice and occasionally honey, than in wax in the USA (Bommarco *et al*., 2011).

2.7.3 Effect of insecticides on natural enemies of FAW

Insecticides change the population dynamics or life history characteristics of natural enemies either directly or indirectly. Indirect effects on natural enemies may have occurred through a variety of mechanisms, including prey killing, consumption of contaminated floral parts, plant fluids, and prey parts that contained lethal or sub-lethal concentrations of the active ingredient, ingesting contaminated honey dew excreted by phloem-feeding insect prey, as well as changes in prey quality or induced changes in host plants that may lessen the attractiveness of the prey (Friend 1999).

By preventing adult emergence; post-application residues may indirectly affect parasitoids. Consumption of tainted honeydew excreted by phloem-feeding insect prey indirectly harms natural enemies. Some pesticides may also be repulsive or change the physiology of the host plant, which may negatively impact natural enemies' capacity to indirectly control arthropod pest populations that are already present (Aslam *et al*., 2004). Fore examples the systemic insecticide's active ingredient is released into flower parts, where it indirectly affects natural predators that consume plant pollen or nectar, like the tiny pirate bug *Orius spp.,* which consumes plants throughout its life cycle. After consuming the nectar of buckwheat (*Fagopyrum esculentum)* plant, adults of Anagyrus pseudococc are indirectly impacted. After consuming cotton plants' extrafloral nectaries, *Microplitis croceipes'* foraging capacity and longevity were reduced (Cloyd, 2012).

Since natural enemies are non-target organisms that are susceptible to insecticide applications, the fact that natural enemy density was generally lower in fields treated with insecticides. Several studies also demonstrate that natural enemies typically exhibit greater insecticide sensitivity and develop insecticide resistance more slowly than their prey (El-Wakeil *et al*., 2013).

2.7.3.1 Insecticides toxicity to predators

Arthropod predators like insects, mites, and spiders use natural predation to control pests. Another crucial component of pest management is the introduction of predators for biological control. However, whether they are native or introduced, these predators are exposed to pesticides either directly or indirectly through contact with sprayed parts or by ingesting poisoned prey. Natural enemies may become extinct locally or in large populations, which could affect the ecosystem and tip the scales in favor of pest infestation and resurgence. The toxicity of pesticides to predators off-target were examined (Waage *et al*., 1988).

2.7.3.2 Insecticide toxicity to parasitoids

The most effective insect pests' natural enemies are parasitoids, which include eggs, larvae, and pupae. The parasitoid bites the host at various stages, including the egg-pupal, larval-pupal, pupal, and adult stages. When used against specific pests, certain parasitoids are incredibly effective. Because they are simple to use and inexpensive, it is crucial to encourage the natural occurrence of insect parasitoids in all production systems in order to control the target pests. However, the indiscriminate use of insecticides to eliminate pests has resulted in the eradication of beneficial natural parasitoids and an imbalance in agro-ecosystems (Malik *et al*., 2014).

Through direct contact with spray droplets, residue uptake through contact with contaminated surfaces, and uptake from contaminated food sources, chemical pesticides can affect insect parasitoids. To address the issue of insecticides' detrimental effects on parasitoid organisms if we can figure out a way to use them selectively (Santos & Medina, 2020) and selective insecticides should be screened and identified for use in agro-ecosystems, resulting in parasitoids being conserved for natural parasitization. It is possible to evaluate the toxicity of insecticides on various insect parasitoids stages. To find a potent insecticide that is selective to parasitoids, studies on acute, chronic, persistent, sub-lethal, and field toxicity are conducted. By utilizing methods to evaluate pesticide toxicity to parasitoids, pesticide effects can be precisely determined and risks to parasitoids avoided (El-Wakeil *et al.,* 2013).

3. MATERIALS AND METHODS

3.1 Description of the Study Area

This research had laboratory and field experiments, both of which were carried out at the Melkassa Agricultural Research Center (MARC). The Center is located in Ethiopia's Central Rift Valley at 8^{o}24' N latitude and 39^{o}21' E longitude, at an elevation of 1550 m above sea level, with a mean relative humidity of 80% and an annual rainfall of 763 mm. The annual mean maximum and minimum temperatures are 28.4^{o}C and 14^{o}C, respectively. According to Ethiopia's most recent agro-ecological zone classification, the Melkassa Hypo Calcic Regosol ecotope is located in the hot to warm semi-arid lowlands zone. The dominant textural classes of soil are loam and clay loam (Getahun & Wondimu, 2020).

3.2 Maize Planting and Study Design

Maize grain variety 'Melkassa 2' was used for the study based on the recommendation of MARC and the surrounding farmers and it is specifically applicable for semi-arid environment including Adama area. The maize grains were planted in three blocks each containing four plots. The size of each plot was 4 m × 3 m (12 m^2), with a spacing of 75 cm between rows and 25 cm between plants. With blocking system of four rows by three columns with a two-meter gap between rows and 1.5-meter gap between columns. There were three treatments and one untreated control plots with three replications. Three seeds were planted per hill in each experimental and control plot and thinned to one seedling per hill after two weeks of emergence. Hand weeding was performed to control weeds (Sisay *et al.*, 2019).

3.3 Preparation of Synthetic Insecticides

Three insecticides were acquired from various sources (Table 4). Due to the lack of proper screened recommended insecticides of FAW on MARC, insecticides were purchasing randomly from available insecticides in Adama city pesticide shop because the farmers mostly purchase insecticide from pesticide shop. But there were different trade names with similar active ingredients or common names. Each synthetic insecticide was thoroughly mixed with tap water for 5–10 minutes, based on instructions of the manufacturers.

Table 4: List of treatments used in the experiment against FAW

Treatments (Trade Name)	**ml/ha (Insecticide)**	**Technical name**	**Mode of action**
Bravo-5000®	350	Lambda cyhalothrin 5% E.C.	Paralyses nervous system
Aim 10%®	350	Alpha cypermetrin 100g/l	Affects the normal function of nervous system
Rambo®	200	Chlorpyrifos 50% E.C.	Hyper-central nervous system

ml = milliliter; ha = hectare

3.3.1 Field insecticide application on maize

Four weeks after planting (at the three-week vegetative stage and one week after leaf damage by FAW larva was observed naturally), insecticides were applied within every seven-day gap, at the recommended field application rate. As indicated in Table 4, the recommended dosage amount of synthetic insecticides required to spray 12 m^2 was calculated. Rotational spray system was used to equalize the distribution of insecticides on the treatment plots. Then each insecticide was added to a sprayer and sprayed on maize plants located on one plot of each block until the backpack sprayer became empty. The maize plants in the control plots (3 plots) were sprayed with water. The experiment was arranged in randomized complete block design (RCBD) with three replications.

3.4 Collection of FAW Larvae from the Field for Investigation of Parasitoids

Indications like feeding injuries in the leaf whorl caused by larvae and the presence of frass were used locate larvae. Based on morphological differences, FAW larvae (second and higher larval instar, due to the limitation of time) were collected from the treated and untreated field. The larvae were collected one day before the next spray and gathered in plastic jars with a mesh cover at the top to allow ventilation while preventing larval escape. FAW larvae were collected separately in the field based on the type of insecticide applied on treated plots. Each twelve larvae were collected from each plot of each treatment including control plots (48 larvae per round). Larvae were collected from all the treated plots in four rounds, at one-week intervals, for a total of 192 larvae.

After returning from the field, larvae were identified and categorized based on size (second-instar and above-instar larvae) and placed individually in conical transparent rearing containers with volume of 514.25 cm^3 (8.5×5.5×11cm). The collected FAW larvae were fed with maize leaf in the laboratory for the investigation of the possible emergence of parasitoids. The leaves were cleaned by treating them with tap water to decrease impurities and placed in a plastic jar with a perforated lid. The collected leaves were divided and weighed to 60 g (from FAW rearing experience of MARC entomology laboratories) of maize leaf fed approximately 10 to 15 larvae for 3 days separately). Each container contained 5–7 pieces of leaf measuring 5–6 cm in length. The maize leaves were changed every 24 hours to 72 hours. The bioassay was repeated for each sample of larvae that was collected from each maize plot. Larval mortality and parasitoid emergence were checked at every 24 hours.

3.5 Parasitoid Identification and Determination of Parasitism Rate (Relative Abundance) from the Field Collected FAW Larvae

The numbers of dead larvae and live larvae of FAW were counted from the total number of each sample. Then parasitoids that emerged from collected FAW larvae were recorded every 24 hours and parasitoid rates calculated, and the emerged adult parasitoids were placed in 70% ethanol. The emerging adult parasitoids species were identified using the morphology of parasitoids (Tendeng *et al*., 2019). The identification of parasitoids was done by using online identification key websites those are https://bugguide.net/, https://earthlife.net/ and https://insectidentification.org/ and using different published journals (Ba, 2018; Sisay *et al*. 2019; Caniço *et al.,* 2020 and Entomologist *et al.,* 2023).

3.6 Data Collection

3.6.1 Insecticides efficacy on maize plants

One day before the next application of insecticides, the plants data were collected. The collected data includes; numbers of live larvae, damaged leaf; total leaf numbers and level of leaf damage were counted in the treated plots and untreated control plots.

The FAW level of leaf damage was recorded on an individual plant basis at seven-day intervals based on the rating scale described above.

0 = no visible leaf damage
1 = only pin-hole damage to the leaf
2 = pin-hole and shot-hole damage to leaf
3 = small elongated lesions (5–10 mm) on 1–3 leaf
4 = mid-sized lesions (10–30 mm) on 4–7 leaf
5 = large elongated lesions (>30 mm) or small portions eaten on 3–5 leaf
6 = elongated lesions (>30 mm) and large portions eaten on 3–5 leaf
7 = elongated lesions (>30 cm) and 50% of leaf eat
8 = elongate lesions (30 cm) and large portions eat 70% of leaf
9 = Most leaf have long lesions, and complete defoliation was observed

3.6.3 Insecticide effect on parasitoids (parasitoid rate) of FAW

To investigate the effect of insecticides on parasitoids of FAW, the emergence of parasitoids was observed every day from the larvae which were collected from each treatment, and when emerged, the parasitoids were identified, counted and the rate of parasitism was calculated. The percentages of the different species of emerged parasitoids from the total emerged parasitoids were also calculated.

3.7 Data Analysis

3.7.1 Statistical analysis

The mean and standard error of the mean (± SEM) and percentage of total sum of three replicates were used to express the experimental results. One-way analysis of variance (ANOVA) multivariate test was performed on the data for multivariable. The larval number from field both synthetic insecticides and from control group was transformed using an arcsine transformation to normalize the variances. The Tukey's honest significant difference (HSD) test was used to separate the means, and the significance level was set at $p = 0.05$. The Kruskal-Wallis test was used to determine the statistical significance of each variable, and the results were displayed in tables and graphs. SPSS 21 statistical software was used to conduct all statistical analyses.

3.7.2 Parasitism rates and relative abundance of parasitoids of FAW

Before calculating the percent parasitism, the number of FAW collected was adjusted to account for those who died from injury or unknown causes during the first few days after collection. After field collection, additional FAW larvae were gathered while considering larval mortality from insecticide toxicity.

Total parasitism rates

The total parasitism rate per round (TPr) of each parasitoid species was calculated by dividing the number of larvae parasitized (Ni) by the total number of FAW larvae collected per round (Nt) and expressing this value as a percentage (Ahissou *et al*., 2021).

$$\mathbf{TPr = Ni/Nt\ (live\ larvea - death\ larvae\ of\ FAW)*100} \qquad \text{(Equation 1)}$$

Relative abundance of parasitoids

The relative abundance of each parasitoid species (RA) was determined by dividing the number of individuals of a given parasitoid species (ni) by the total number of individuals of all parasitoid species (N) and converted to percent values (Caniço *et al*., 2020).

$$\mathbf{RA = ni/N * 100\%} \qquad \text{(Equation 2)}$$

Total larval population were calculated by $\mathbf{N = n/1+n\ (e)^{2}}$ (Neilson, 2011) (Equation 3)

Where; N = Sample size for parasitoid

n = Estimated population number of FAW larvae

e = p-value

4. RESULTS

4.1. Field Evaluation of Selected Synthetic Insecticide against FAW

4.1.1 Numbers of damaged leaf caused by FAW

Number of damaged leaf by FAW larvae was significantly different ($p < 0.05$) among treatments and between spraying round numbers. The non-treated plants had highest numbers of leaf injury by FAW compared to the plants that are treated with insecticides. Pre-spray showed vary in numbers of damage leaf due to different damaging level of FAW on maize. In the first-round spraying, the lowest numbers of damaged leaf was recorded from the plants treated with Rambo followed by Aim 10% but Bravo-5000 showed highest numbers of damaged leaf whereas in the second-round spraying, Bravo-5000 showed the lowest numbers of damaged leaf. In third round spraying Aim 10% showed lowest numbers of damaged leaf followed by Rambo but Bravo showed low leaf damage than other (Table 5). When compares to untreated plants, treated plants showed high progress in decreasing number of damaged plants by FAW as spraying round numbers increases. In contrary to Aim 10% and Bravo-5000, Rambo showed progress in decreasing of leaf damage by FAW (Table 5).

Table 5: Mean (± SEM) numbers of damaged leaf of maize pre- and post-treatment with selected treatments against FAW

Mean (± SEM) numbers of damaged leaf				
Treatments	**Pre-spray**	**1st spray**	**2nd spray**	**3rd spray**
Aim 10%	2.28 ± 0.162a	2.53 ± 0.164ab	2.10 ± 0.098b	1.34 ± 0.080a
Bravo-5000	3.05 ± 0.166c	3.19 ± 0.182b	2.62 ± 0.110b	2.30 ± 0.118b
Rambo	2.70 ± 0.154b	1.82 ± 0.153a	1.38 ± 0.057a	1.48 ± 0.090a
Control	3.99 ± 0.168d	6.60 ± 0.163c	6.02 ± 0.0126c	6.08 ± 0.146c

Means within a column not sharing a common letter are significantly different at $p < 0.05$ using Tukey's test

Pre-spray = 4 weeks after plant emergence

1st round spray = 5 weeks after plant emergence

2nd round spray = 6 weeks after plant emergence

3rd round spray = 7 weeks after plant emergence

4.1.2 Level of leaf damage caused by FAW

After first-round spraying, the lowest level of leaf damage was recorded in plants treated with Aim 10% and followed by Rambo. Whereas in the second-round spraying, Rambo showed the lowest level of leaf damage followed by Aim 10% but Bravo-5000 showed highest level of leaf damage. In third spraying there was low level of leaf damage by Rambo followed by Aim 10% but Bravo-5000 showed highest level of leaf damage. So, Rambo showed highest efficacy than other treatment but Bravo-5000 showed low efficacy.

When compares to untreated plants, treated plants showed high progress in decreasing level of plant damage by FAW as spraying round numbers increases. Plants that are treated with Rambo and Aim 10% showed more progress on reducing the level of leaf damage than Bravo-5000 (Table 6).

Table 6: Mean (± SEM) level of maize leaf damage pre- and post-treatment with selected treatments against FAW

	Mean (± SEM) numbers of damaged leaf			
Treatments	**Pre-spray**	**1st spray**	**2nd spray**	**3rd spray**
Aim 10%	1.95 ± 0.160a	1.95 ± 0.160a	2.53 ± 0.164b	3.16 ± 0.235b
Bravo-5000	2.92 ± 0.154b	2.69 ± 0.154b	3.19 ± 0.182c	5.25 ± 0.288c
Rambo	2.42 ± 0.145ab	2.42 ± 0.145ab	1.82 ± 0.153a	2.64 ± 0.167a
Control	2.74 ± 0.163b	2.92 ± 0.152c	6.60 ± 0.163d	9.32 ± 0.173d

Means followed by different letter within a column are significant to each other at, $p < 0.05$ using Tukey's test

Pre-spray = 4 weeks after plant emergence

1st round spray = 5 weeks after plant emergence

2nd round spray = 6 weeks after plant emergence

3rd round spray = 7 weeks after plant emergence

4.1.3 Numbers of FAW larvae per plant

Mean mortality of FAW larvae was significantly different among treatments ($p < 0.05$) during the first, second and third-round spraying. Plants that are treated with Bravo-5000 have the highest larval numbers. Aim 10% and Rambo scored a smaller number of FAW larvae during the first spray. After the second round of insecticide spraying, Rambo showed lower number of larvae than Aim 10% and Bravo-500. Similarly, after third round of insecticide spraying Aim 10% showed low number of larvae next to Rambo. When compared to untreated plants, treated plants showed low number of FAW larvae (Table 7).

Based on the results of Table 7 determined that Rambo and, Aim 10% lowest larvae number but Bravo-5000 treatments has the lowest efficacy. Rambo and Aim 10% showed high toxicity to FAW larvae than Bravo-5000.

When compares to untreated plants, treated plants showed high progress in decreasing number of FAW larvae as spraying round number increases. In contrary to Aim 10% and Bravo-5000, Rambo showed decreasing FAW larvae numbers through increasing of spray round (Table 7).

Table 7: Mean (± SEM) numbers of larvae on maize plants pre- and post-treatment with selected treatments against FAW

	Mean (± SEM) numbers of larvae			
Treatments	**Pre-spray**	**1st spray**	**2nd spray**	**3rd spray**
Aim 10%	0.48 ± 0.056a	0.21 ± 0.038a	0.29 ± 0.039a	0.18 ± 0.029a
Bravo-5000	0.67 ± 0.065ab	0.26 ± 0.055bc	0.62 ± 0.051b	0.55 ± 0.053b
Rambo	0.68 ± 0.072ab	0.31 ± 0.025a	0.12 ± 0.035b	0.14 ± 0.024a
Control	0.72 ± 0.078b	1.15 ± 0.072d	1.34 ± 0.078c	1.02 ± 0.114c

Means within a column not sharing a common letter are significantly different at $p < 0.05$ using Tukey's test

Pre-spray = 4 weeks after plant emergence
1st round spray = 5 weeks after plant emergence
2nd round spray = 6 weeks after plant emergence
3rd round spray = 7 weeks after plant emergence

4.1.4 Total leaf number per plant

As showed in Table 8 among all treatments and control plots (Aim 10% , Bravo-5000 and Rambo), the plants that are treated with insecticide Bravo-5000 showed higher leaf number than other treatment. Plants that are treated with Rambo and Aim 10% showed no significant difference ($p < 0.05$) between mean of total leaf numbers but Bravo-500 showed significant difference between mean leaf numbers.

Table 8: Mean (± SEM) leaf number of maize plant treatment application with selected treatments against FAW

Treatments	**Mean (± SEM)**
Aim 10%	8.75 ± 0.111a
Bravo-5000	9.03 ± 0.122b
Rambo	8.89 ± 0.106a
Control	8.82 ± 0.108a

Means within a column not sharing a common letter are significantly different at $p < 0.05$ using Tukey's test

In Figure 4 it showed that the increase in the total number of plant leaf corresponds to an increase in the age or spray round numbers of the maize plant. However, there is slightly significant difference ($p < 0.05$) in the number of leaves between the treated and untreated plants. These results showed that treatments have less or no impact on the leaf number of the plants.

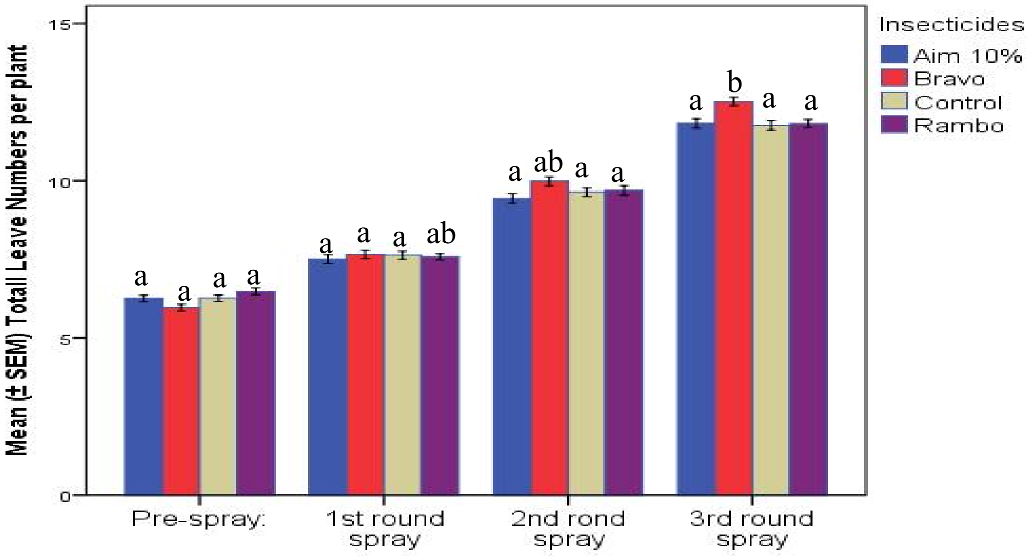

Figure 4: Mean (± SEM) numbers of leaf on maize plants pre- and post-treatment with selected treatments against FAW

Pre-spray = 4 weeks after plant emergence

1st round spray = 5 weeks after plant emergence

2nd round spray = 6 weeks after plant emergence

3rd round spray = 7 weeks after plant emergence

4.1.5 Height of maize plants

The maize plants treated with Bravo-5000 were significantly ($p < 0.5$) taller than those plants treated with Aim 10% and Rambo. There was no significant difference in the height of plants treated with Rambo and Aim 10% (Table 9).

Table 9: Mean Height (cm) (± SEM) of maize leaf after application of selected insecticides against FAW

Treatments	**Mean ± SEM (cm)**
Aim 10%	226.4 ± 3.83b
Bravo-5000	243.6 ± 3.49c
Rambo	219.5 ± 2.73b
Control	197.6 ± 2.89a

Means within a column not sharing a common letter are significantly different at $p < 0.05$ using Tukey's test.

4.2 Effect of Insecticide on Parasitoids FAW

According to the current findings, a total of six species of natural enemies emerged with the FAW. Out of 192 total larvae, 150 (78.1%) pupated and 42 (21.9%) larval mortality and from all FAW larvae collected 18 total emerged parasitoids.

All treatments have effect on parasitoids when compared to untreated plants (Table 10).The experiment result showed that Aim 10% recorded the highest parasitism rate (2%) and Bravo-5000 showed the least parasitism rate (0%). As shown in Table 10 Aim 10% have less effect on parasitoids of FAW larvae but Bravo-5000 shows high effect on parasitoids. The toxicity of insecticides on the number of parasitoids was different among treatments.

Table 10: Mean (± SEM) number of parasitoids emerged from FAW larvae which is collected from maize treated with different treatments against FAW

Treatments	**Mean (± SEM)**	**TPr (%)**
Aim 10%	6.3 ± 0.04c	2.0
Rambo	2.1 ± 0.02b	0.6
Bravo-5000	0.0 ± 0.00a	0.0
Control	39 ± 0.07d	8.6

TPr (%) = Percentages of total parasitism rate

4.3 Parasitoid Species of FAW

Six species of parasitoids belonging to Hymenoptera were identified from FAW larvae in this study. The parasitoids were *Coccygidium luteum, Cotesia icipe*, *Charops ater, Netelia Species*, *Chelonus inanitus* and unidentified sp. (Table 11). From a total of 18 parasitoids emerged from 150 live FAW larvae, 11parsitoids were *Cotesia icipe,* 3 parsitoids were *Charops ater and* single parasitoid were emerged from the rest of the identified species listed in Table 11. Three larval parasitoids emerged from plants that are treated with Aim 10% and only one larval parasitoid emerged from Rambo. There was no, emerged larval parasitoids from Bravo-5000 and the rest (14 parasitoids) were collected only from untreated plants. Only single species (*Cotesia icipe*) emerged from FAW larvae that collected from plants which are treated with treatments and six different species emerged from untreated plants. The larvae that collected from insecticidal treated plants showed less larval relative abundance and less parasitism rate number than larvae collected from untreated plants.

The experiment shows that *Costesia icipe* species showed high relative abundance, followed by *Charops ater* species but *Coccygidium luteum, Chelonus inanitu,* unidentified sp., and *Netelia Species* showed equal relative abundance (Table 11).

Table 11: Percentage of relative abundance of parasitoids species and parasitism rate of FAW larvae on different treatments of maize plant

Parasitoid species	**RA (%)**	**TPr (%)**
Cotesia icipe	61.1	7.3
Coccygidium luteum	5.6	0.7
Chelonus inanitus	5.6	0.7
Netelia Species	5.6	0.7
Charops ater	16.7	2.0
Unidentified sp.	5.6	0.7

RA (%) = Percentage of relative abundance of parasitoids of each species

TPr (%) = Percentages of total parasitism rate

5. DISCUSSION

5.1 **Field efficacy of insecticides on FAW**

Three different insecticides were tested on maize plant against FAW larvae in field conditions. The current study showed that the level of damage caused by FAW on treated plots was significantly lower ($p < 0.05$) when compared to the untreated plots. The results revealed that different chemicals have varying degrees of efficacy, with Rambo had a higher efficacy than the rest of the insecticides and Bravo-5000 being less effective in controlling FAW damage on maize. On this study, level of efficacy variation was caused due to the difference in insecticidal toxicity on FAW and the percentage of leaf damage decreased as the repetition of spraying rounds increase.

As common with this study, synthetic insecticides are important management options in FAW control in Ethiopia (Sisay *et al.,* 2019; Sileshi *et al.,* 2022). Due to the new invasive species of FAW in Ethiopia, several insecticide efficacy evaluation needs in different agro-ecosystem. Studies conducted within different years shows efficacy variations on insecticides that indicates insecticidal résistance of FAW (Roy *et al.,* 2023).

Additional to this study, there are different insecticides which are used to control FAW in different agro-ecosystem that reports in other studies like Deshmukh *et al.* (2020) which reports that Emamectin benzoate (5 SG), chlorantraniliprole (18.5 SC), and spinetoram (11.7 SC) were the two highest toxic insecticides against FAW in India. In Florida, according to Beuzelin *et al*. (2022) Indoxacarb treated plots shows intermediate injury level reduction while methoxyfenozide and spinetoram treated plots shows injury levels comparable to those seen in plots treated with chlorantraniliprole (Beuzelin *et al*., 2022). In India among the insecticides spraying with mean cumulative affectivity of three sprayed rounds, emamectin benzoate 5 SG (1.79 larval number per plant) was most effective for management of FAW and indoxacarb 14.5 SC (2.56 larval number per plant) shows next effective (Sangle *et al*., 2020). Insecticides efficacy can be affected by different types of agro-ecosystems and by formations of resistance. Generally, based on above studies this efficacy level variations shows difference toxicity among different insecticides.

Chemical protection is the most commonly used method (Kumar *et al.*, 2018). Insecticides are employed as a last resort during IPM when the pest has caused significant harm or has invaded a large population. For chemical control of the pest, alternate applications of contact or systemic insecticides based on pyrethroids, carbamates, or organophosphates are recommended. American FAW management in the Nepalese maize field proposed direct control tactics for the FAW (Naharki *et al.*, 2020). Insecticides are becoming more commonly utilized, with 13% and 15% of agricultural households in Tanzania and Uganda, respectively, using pesticides in one form or another. Pesticide use is substantially greater in Nigeria and Ethiopia, with 31% and 34%, respectively (Sheahan *et al*., 2017).

5.2 FAW Parasitoid Species and Parasitism Rate

The different insecticides effects on parasitoids were tested on larvae of FAW in field conditions. The current study showed, parasitism rate was significantly lower ($p < 0.05$) when compared to the untreated plots these decreasing of parasitism rate which may indicate residual toxicity of the synthetic insecticides to FAW parasitoids. In the current study six parasitoid species were collected from FAW larvae and all belongs to, *Cotesia icipe* (7.3% parasitism rate), *Charops ater* (2% parasitism rate), *Netelia Species*, *Chelonus inanitus*, *Coccygidium luteum* and unidentified wasp sp. So the study showed that *Cotesia icipe* scored the highest parasitism rate of larval parasitoids species followed by *Charops ater* it means that *Cotesia icipe* are the most dominant parasitoids in Awash Melkassa Agricultural Research Center.

When comperes to other studies reports shows different rate on parasitoids abundance and vary in parasitism rate likes Sisay *et al.* (2019) reported that there were two species (*Cotesia icipe* and *Palexorista zonata*) of FAW in the Awash Melkassa Agricultural Research Center. However, in the current study, four additional parasitoid species of FAW, including *Charops ater, Netelia Species, Coccygidium luteum* and an unidentified sp., were identified. The results indicated that the number of parasitoids in FAW had been increasing, which is important and promising for the management of the pest.

Results of this study are in consistent with recent findings of Sisay *et al*. (2019) on the occurrence or abundance rate of *Coccygidium luteum*, Kenya and Ethiopia in 2018 as well as in Mozambique (Caniço *et al.*, 2020). Similarly reports indicates that *Palexorista zonata* is the dominant parasitoid, followed by *Charops ater* and *Coccygidium luteum* (Agboyi *et al*., 2020). But the current study showed that *Cotesia icipe* was dominant species similar reports with Entomologist *et al.,* (2023) next to *Coccygidium luteum* this indicates that variability of parasitoid species dominancy or abundance so based on the above studies variation of parasitoids abundance due to different agro-ecosystem and periods. This study showed that, *Cotesia icipe* was the dominant larval parasitoid, with parasitism rate 7.3% similar to report by Sisay *et al.* (2019) that *Cotesia icipe* was the dominant larval parasitoid, with parasitism rate ranging from 33.8% to 45.3% in Ethiopia. *Charops ater* (2%) was the most common parasitoids in Kenya and Tanzania, with parasitism rate of 6% to 12% similar to this study result *Charops ater* is common next to *Cotesia icipe* (Sisay *et al.,* 2019) but *Coccygidium luteum* was the most common parasitoids in Kenya and Tanzania, ranging from 4% to 8.3%, respectively. According to Ahissou *et al*. (2021) *Coccygidium luteum* shows parasitism rates of 0.5% in Burkina Faso. Maximum parasitism rate of 23.68% was recorded for *Coccygidium luteum* in Mozambique (Caniço *et al*., 2020) but this study result indicated that *Coccygidium luteum* showed lowest parasitism rate of 0.7% .

This study showed smaller parasitism rate of *Coccygidium luteum* than the study by Caniço *et al.* (2020) with parasitism rate of 0.7%. Current study showed similar parasitoids species of *Charops ater* (7.3%) and *Coccygidium luteum* (0.7%) but with reports by Sisay *et al.* (2019) showed variations between level of parasitism rate. As reported by Volter *et al.* (2022), parasitism rate differences are caused by geographical locations, agronomic practices and crop type and stage of a crop.

Several species of natural enemies that attack FAW have been documented in various studies. In Tanzania, for example, five different parasitoids from the Hymenoptera and Diptera orders have been extracted from FAW eggs and larvae (Ballal *et al*., 2021). In 2001 in Mexico reports the recovery of 11 parasitoid species during collections carried out in four Mexican states with which was *Campoletis sonorensis*, *Cotesia marginiventris*, *Meteorus laphygmae*, *P. spinator* and *Chelonus insularis*, *E. plathypenae*, and *Aleiodes laphygmae* (Hoballah *et al*., 2004). Based on the above studies, there are differences in parasitoid species number when compared to the current result. This may be resulted by nativity of FAW in Mexico but it is new invasive pest in both Tanzania and Ethiopia (Sisay *et al*., 2019). This may indicate that while emphasis should be given to local surveys of native natural enemies, introduction of effective natural enemies from the native countries through classical bio-control can be an option to increase FAW parasitoids species and abundance (Fiabo *et al*., 2017; Prasanna *et al.,* 2018).

Unlike insecticides, biological control method is the effective and caused positive effect on natural enemies which eliminate pest without affecting non targeted organism *(Kumar et al*., 2018) and without harming an ecosystem (Stoner, 2004). Parasitoids are utilized for biological pest management. The information in the study on the relative quantity and rate of parasitism of indigenous parasitoids is essential in limiting pests with mass rearing of natural enemies as a control strategy for FAW without affecting other organisms, as well as how insecticide affects FAW parasitoids.

5.3 Effect of Insecticides on Parasitism Rate of FAW

Different insecticides were tested against FAW larvae in field conditions. The FAW larvae that are collected from insecticide-treated plants showed low number of parasitoid emergence, this indicates that insecticides have high effect on parasitoids number when compared to the untreated plots, so insecticides are toxic to FAW parasitoids. Based on number of FAW parasitoids emerged from FAW larvae, the findings of this study suggested that Aim 10% (2% parasitism rate) showed low toxicity to parasitoids, but Bravo 5000 had high effect on parasitoids when compared to Aim 10% and Rambo. Therefore, this indicates that different insecticides have different toxicity level.

This study showed that insecticides are one way of controlling FAW damage, but they have side effects on beneficial insects specifically on larval parasitoids of FAW. For examples Meagher *et al.* (2016b) reported that parasitism of FAW was comparable between the fall and spring seasons but was much higher in unsprayed fields than in sprayed fields. To minimize the toxicity of insecticides on non-targeted organism using effective insecticides and considering non-targeted parasitoids is necessary. This study showed the minimization of parasitoids by the course of insecticidal toxicity. One of the biggest problems with insecticides is their toxicity to other non-targeted organisms and natural enemies in particular. FAW organisms, considering the negative effect on natural enemies, use more effective insecticides with a low effect on natural enemies. From natural enemies, parasitoids are one of the most beneficial insects, which include FAW. To summarize, to minimize the non-target effect of parasitoids, use an insecticide with less effect on non-target organisms.

The minimization of parasitoids can be caused by toxicity of insecticide on fresh stages, dried residues on leaf, toxicity of residues on leaf over time, or direct spray on an adult or pupated parasitoid, as reported by Hall & Nguyen (2010) on a parasitoid of the *Asian citrus psyllid.* On the other hand, repelling insecticide volatile chemicals or a parasitism chance due to a decrease in FAW larvae populations on the treated area may decrease parasitism rates.

6. CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

The study reports that it is better to use only the effective insecticides against FAW damage on maize that has low effect on FAW parasitoids. As the result Aim 10% is the best recommended insecticides from the insecticides used in the study, it is less toxic to parasitoids of FAW. From the six species of FAW parasitoids *Cotesia icipe* is the most common parasitoid. The Result shows that currently there is increasing in number of parasitoid species in MARC.

6.2 Recommendations

Based on current experimental result the following recommendations were forwarded.

- Using synthetic insecticide has a great effect on parasitoids of FAW therefore using insecticide which have less effect on non-target organisms is recommended.
- Further continuous studies should be conducted controlling of FAW damage in maize by mass rearing of parasitoids and predators.
- Further studies should be conducted to search for insecticides which have less effect on predator and pathogens of FAW.
- More studies needed to be done on why efficacy difference occurs among different insecticides.

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