EVALUATION OF DIFFERENT MANAGEMENT OPTIONS OF FALL ARMYWORM, *Spodoptera frugiperda* (J.E. Smith) (LEPIDOPTERA: NOCTUIDAE) AND ASSESSMENT OF ITS PARASITOIDS IN SOME PARTS OF ETHIOPIA

MSc THESIS

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Evaluation of Different Management Options of Fall Armyworm, *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae) and Assessment of its Parasitoids in Some Parts of Ethiopia

A Thesis Submitted to the Department of Plant Science, School of Graduate Studies
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As research Advisors, we hereby certify that we have read and evaluated the Thesis prepared by Birhanu Sisay Amare under our guidance, which is titled "**Evaluation of Different Management Options of Fall Armyworm,** *Spodoptera frugiperda* **(J.E. Smith) (Lepidoptera: Noctuidae) and Assessment of Their Parasitoids in Some Parts of Ethiopia"**. We recommended that the Thesis be submitted as it fulfills the requirements.

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DEDICATION

This piece of work is dedicated to the memory of my late Grandmother Eseye Teshome who, deceased without seeing my success.

STATEMENT OF THE AUTHOR

By my signature below, I declare and affirm that this Thesis is my own original work. I have folowed all ethical and technical principles of scholarship in the preparation , data collection, data analysis and compilation of this Thesis. Any scholarly matter that is included in the Thesis has been given recognition through citation.

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BIOGRAPHICAL SKETCH

The author, Birhanu Sisay Amare, was born in october 06, 1990 from his father Ato Sisay Amare and his mother W/r Beyenech Belay in Amhara regional state, at North Wollo zone, Woldia, Gubalafto Woreda, in area called Wudmen. He attended elementary school at Wudmen primary school from 1998-2006, and high school education at Dessie Kidamie Gebeya and Woldia secondary school from 2007 to 2010. After completion of his secondary school, he joined Ambo University, College of Agriculture and Veternary Sciences in 2011. He obtained his BSc degree in Horticulture in 2013.

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ACRONYMS AND ABBREVIATIONS

ANOVA	Analysis of Variance
CABI	Centre for Agriculture and Biosciences International
CRD	Complete Randomized Design
CSA	Central Statistical Agency
CV	Coefficient of Variation
DAP	Diamonium Phosphate
EIAR	Ethiopian Institution Agricultural Research
FAO	Food and Agricultural Organization
FAW	Fall Armyworm
ICIPE	International Center of Insect Physiology and Ecology
IPM	Integrated Pest Management
LSD	Least Significant Differences
MARC	Melkasa Agricultural Research Center
SD	Standard Deviation
SV	Source of variation

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ABSTRACT

The fall armyworm (FAW) is a major pest of maize in America and its outbreaks in 2017 in Africa threatened maize, a staple food crop in the region. The effect of parasitoids, nine synthetic insecticides, eleven botanicals, five entomopathogens and pheromone lures have been studied against FAW in 2017 and 2018. Survey conducted in Jimma, Awash Melkasa, Hawasa, East and West Gojam identified three different species of parasitoids from FAW larvae belonging to Hymenoptera and Diptera. Cotesia icipe (Braconidae) was the dominant larval parasitoid in Hawassa, Jimma and Awash Melkassa with parasitism ranging from 33.8 to 45.3%. Tachinid fly, Palexorista zonata (Tachnidae), was the main parasitoid with 6.4% parasitism in Hawassa whilst, Charops ater (Ichneumonidae) commonly occurred in Jimma with 4.6% parasitism. In laboratory, Karate 5% EC, Radiant 120 SC and Tracer 480SC caused 100% larval mortality 48 and 72hrs after treatment application. In greenhouse experiment, all insecticides significantly reduced foliar damage to maize compared to the untreated check. Among the botanicals tested, Azadirachta indica, Schinnus molle and Phytolacca dodecandra resulted in the highest percentage larval mortality (96-100%) 72 hrs after treatment application. The result of entomopathogenic fungi study also showed Beauveria spp. (APPRC-44BC and B4 strains) and Metarrhizium spp. (APPRC-34 GM strain) highly pathogenic inducing 100% and 80% mortality five days and six days after treatment application, respectively. The trapping experiment showed higher number of male moths in the lure E,7-12 OAC, Z-9-12OAc and Z-11-16OAc. The effective parasitiods, synthetic insecticides, botanicals, entomopathogenic fungi and pheromone lures can be used as a component in an integrated management of FAW under smallholder farmers' condition in Ethiopia and elsewhere in Africa with further field studies.

Keywords: botanical, entomopathogen, insecticide, insect parasitism, maize, pheromone trap

1. INTRODUCTION

Maize (*Zea mays*) is the most important staple food crop grown predominantly by smallholder farmers in Africa. In East African countries combined production of maize was 3, 0679,856 m tones produced on 17,266,889 hectares of land (FAOSTAT, 2017). In Ethiopia out of the total grain crop area, maize covered 16.98% (about 2,135,571.85 hectares) and 27.02% (7,847,175 tonnes), in production (CSA, 2017).

The low yield is attributed to a combination of several constraints among maize production mainly to lack of improved production technologies such as varieties and pest management practices, moisture stress, low fertility and poor cultural practices (Tufa and Ketema, 2016). Arthropod pests are among the key factors contributing to low yield of maize and they are central to many, if not most, of the serious problems facing maize production today. Despite use of pesticides, there are still great crop losses at present due to arthropod pests, particularly in developing countries (Ferdu *et al*., 2001). More than 40 species of insects have been recorded on maize in the field. Out of these pests, the maize stalk borer (*Busseola fusca*), spotted stalk borer (*Chilo partellus*), and various termite species (*Macrotermes* and *Microtermes spp*.) are recognized to be the key pests. Similarly, *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera: Noctuidae), is one of the major insect pests causing substantial yield losses of maize. FAW which is indigenous in the America is a polyphagous pest causing economic damage of various crops such as maize, sorghum, beans and cotton (Roger *et al*., 2017). Fall armyworm was first reported in West Africa in late 2016, and early 2017, the pest invaded Eastern and Southern Africa. Recent report confirmed the occurrence of FAW in 28 countries in Africa (Abrahams *et al*., 2017b; Roger *et al*., 2017) indicating the rapid spread of the pest in the African continent threatening food security of millions of people.

There are two morphologically identical but genetically different strains of FAW. The rice strain is associated with rice and bermudagrass, while the corn strain predominates on corn, sorghum, and cotton (McMichael & Prowell, 1999; Goergen *et al*., 2016; Abrahams *et al*., 2017b; Cock *et al*., 2017). Additional behavioural and physiological distinctions between these strains have been reported, including differences in pesticide resistance, susceptibility to transgenic plants, and nutritional adaptation (Pashley *et al*., 1995; Adamczyk *et al*., 1999).

In maize, fall armyworm attack all stages of the plant from seedling until tasseling and earing causing defoliation, killing young plant, tunnel into the stem and attack ears resulting in grain damage and subsequently reduce quantity and quality of yield (Peairs and Sanders, 1979). Recent studies conducted by Center for Agriculture and Bioscience International (CABI) in 12 maize-producing African countries showed that without proper management, FAW can cause maize yield losses of between 8 – 21 million tonnes, leading to monetary losses of up to US$ 6.1 billion, while affecting over 300 million people in Africa, who, directly or indirectly, depend on the crop for food and well-being (Abrahams *et al*., 2017b; Midega *et al.*, 2017).

Larvae of FAW cause damage to the plant by consuming the foliage. Neonate larvae mainly feed on leaf tissue whereas the second and third instars feed on the leaf making holes in leaves, typical damage symptom of FAW (Belay *et al*., 2012).

Given FAW is a new invasive pest in Africa, apart from report on its occurrence, there is no information on distribution and level of damage. Furthermore, natural enemies associated with FAW are not documented.

As common with other major agricultural pest, the common management strategy for the FAW in its native ranges of Americas has been the use of insecticide spray and genetically modified crop (Bt maize). Nevertheless, the FAW has developed resistance for several insecticides (Abraham *et al.,* 2017a; Yu *et al*., 2003), which suggests the use of integrated management strategy for sustainable management of this invasive pest.

Since the occurrence of FAW in African countries, insecticides have been widely used as emergency response to halt distribution of the pest and minimize damage in maize fields. Although insecticides play important role in FAW management, given confirmed reports of insecticide resistance development in FAW population (Yu, 1991) as well as due to other adverse effect, sole dependence on insecticides is not feasible. It is imperative to use integrated pest management strategy for FAW. There are no registered insecticides for

FAW control in Africa countries, suggesting urgent need for insecticide screening. Farmers complained that the currently used insecticides are not effective against the FAW; hence, they were forced to use high dose and with high frequency of applications. This will lead to accumulation of pesticides in the environment and speeds up resistance development. Botanical insecticides have long been considered as attractive alternatives to synthetic chemical insecticides for pest management. Botanical insecticides are eco-friendly, economic, target specific and biodegradable. The botanical insecticides are characterized in their specificity, as most are essentially nontoxic to animals and humans. Botanicals are readily available and affordable which are an important means of pest control for farmers in Africa.

Parasitoids and predators readily attack larval and adult stages of fall armyworm. In native regions of FAW different species of hymenopteran parasitoids from the families Ichneumonidae, Braconidae and Eulophidae were recorded. Dipteran parasitoids in the family Tachinidae are also reported to be important natural enemies of FAW in the region (Ruiz-Najera *et al*., 2007). Several predator prying on *S. frugiperda* in the field. The most common predator were the true bugs, *Castolus sp*., *Podisus sagittal* and *Zelus longipes* which attacked larger *Spodoptera frugiperda* larvae and *Coccillenillid coleomegilla sp*., Chrysopidae, *Doru spp* (Dermaptera) and the bug *Orius sp*. that attacked newly emerged larvae (Fritzsche Hoballah, 2001).

FAW is also attacked by a number of entomopathogens including viruses, fungi, protozoa, nematodes, and bacteria. These cause significant level of mortality in FAW population and help to reduce leaf defoliation in maize (All *et al*., 1996). However, empirical information on this approach is still scanty in Africa.

Lepidopteran pheromones have been successfully used for insect monitoring, mass trapping, and mating disruption for diverse of insect pests (Wyatt, 1998). Although different pheromone lures are available for monitoring and mass trapping FAW elsewhere, no information is available in their efficacy under Ethiopian condition.

The objectives of the study were, therefore;

- To assess occurrence of natural enemies (parasitoids) associated with FAW
- To screen some synthetic insecticides against FAW under laboratory and greenhouse conditions
- To test the efficacy of locally available insecticidal plants for management of FAW larvae under laboratory condition
- To evaluate some isolates of entomopathogenic fungi against FAW larvae
- To evaluate trapping efficiency of some different pheromone lures against FAW male moth

2. LITERATURE REVIEW

2.1. Taxonomy of Fall Armyworm, *Spodoptera frugiperda* (Lepidoptera: Noctuidae)

The order Lepidoptera, one of the largest insect orders in the world and contains butterflies and moths. Butterflies and moths are characterized by scales on their wings that come off when they are handled. Many species in the order Lepidoptera are economically important pests feeding on plants, stored grains or fabrics. Insects that belong to the order Lepidoptera undergo complete metamorphosis passing through egg, larva, pupa and adult stages (Ferreira, 2015). The genus *Spodoptera* belongs to the family Noctuidae where the moths are nocturnal. Noctuidae larvae are smooth and dull colored having 5 pairs of prolegs; most of them feed on foliage of plant and few on fruits (Borror *et al*., 1989).

The genus *Spodoptera* consists of a number of species that are important crop pests including *S. littoralis* (Boisduval) (the Egyptian cotton leaf worm), *S. exempta* (Walker) (the African armyworm), *S. litura* (Fabricius) (the tobacco caterpillar), *S. exigua* (Hübner) (the beet armyworm), *S. ornithogalli* (Guenée) (Yellow striped armyworm), and *S. frugiperda* (J.E. Smith) (the fall armyworm). The larvae of the African armyworm are major pests of cereals and rangeland in many sub- Saharan African countries; during outbreaks, the species' population size and invasion areas can be vast (CABI, 2017; Erik, 2017).

2.2. Origin, Distribution and Biology of Fall Armyworm

2.2.1. Origin and Distribution of Fall Armyworm

The fall armyworm (FAW), *S. frugiperda*, is native to the tropical regions of the western hemisphere from the United States to Argentina. *Spodoptera frugiperda* is an important pest of maize and many other crops throughout the Americas, remaining one of the most common lepidopteran pests in the United States (Ferreira, 2015). It causes significant damages to the cultivated grasses of economic importance such as maize, sorghum, sugarcane but also other legumes and cotton. It is a quarantine pest with a large dispersal potential which has been intercepted several times in Europe (Erik, 2017). *Spodoptera frugiperda* has been reported for the first time in 2016 in Africa, in Nigeria, Sao Tomé, in Benin and Togo (Erik, 2017) causing significant damages to maize. It has been confirmed in Ghana (CABI, 2017; Erik, 2017) and in Zimbabwe (Erik, 2017; FAO, 2018) and some cases have been recorded in Malawi, in Mozambique, in Namibia, in South Africa and in Zambia (Erik, 2017). In Ethiopia FAW was reported for the first time in Bench Maji zones of Southern Nations, Nationalities and Peoples State in January 2017 (Teshome *et al*., 2018).

2.2.2. Biology of Fall Armyworm

The life cycle is completed in about 30 days during the summer, but 60 days in the spring and autumn, and 80 to 90 days during the winter (Capinera, 2014). Like all insects, fall armyworm development rate is greatly affected by temperature. In laboratory study, conducted with caterpillars feeding on maize leaves at constant temperatures, the larval stage lasted about 22 days at 70 °F, 14 days at 80 °F, and 10 days at 90 °F. Development rate is faster at higher temperatures, although it does begin to decline at temperatures above 93 °F. Fall armyworms cannot survive freezing temperatures. Populations usually begin to decline a little before first frost because fall armyworms cannot develop at temperatures below about 50 °F (Silva *et al*., 2016). The number of generations occurring in an area varies with the appearance of the dispersing adults. The ability to diapause is not present in this species. In Minnesota and New York, where fall armyworm moths do not appear until August, there may be but a single generation. The number of generations is reported to be one to two in Kansas, three in South Carolina, and four in Louisiana. In coastal areas of north Florida, moths are abundant from April to December, but some are found even during the winter months (Capinera, 2014).

Eggs are usually laid on the upper surface of the leaves but occasionally they may lay on other parts of the host plants. The egg of FAW is dome shaped with flattened base that measures about 0.4 mm in diameter and 0.3 mm in height. Eggs are laid in mass and number of eggs per mass can vary from 100 to 200. A single adult female can lay on average 1500 to 2000 during its life time (CABI, 2017).

There are six instars in fall armyworm. Head capsule widths are about 0.35, 0.45, 0.75, 1.3, 2.0, and 2.6 mm, respectively, for instars 1-6. Larvae attain lengths of about 1.7, 3.5, 6.4, 10.0, 17.2, and 34.2 mm, respectively, during these instars (Capinera, 2014). Young larvae are greenish with a black head, the head turning orangish in the second instar. But particularly the third instar, the dorsal surface of the body becomes brownish, and lateral white lines begin to form. In the fourth to the sixth instars the head is reddish brown, mottled with white, and the brownish body bears white sub dorsal and lateral lines. Elevated spots occur dorsally on the body; they are usually dark in color, and bear spines (Capinera, 2014; CABI, 2017). Newly hatched larvae are gregarious and feed on the leaves of the host plant on which the eggs were deposited, but when they grow larger they will disperse to other plants (CABI, 2017). The first and second instars feed on one side of the leaf and skeletonizing it, but as they grow they eat and making a hole through the leaf. The face of the mature larva is also marked with a white inverted “Y” and the epidermis of the larva is rough or granular in texture when examined closely (Capinera, 2014). The four black dots at the last abdominal segment are also distinctive to FAW larvae (CABI, 2017). Duration of the larval stage tends to be about 14 days during the summer and 30 days during cool weather (Capinera, 2014).

Pupation normally takes place in the soil, at a depth 2 to 8 cm (Capinera, 2014; CABI, 2017). The larva constructs a loose cocoon, oval in shape and 20 to 30 mm in length, by tying together particles of soil with silk. If the soil is too hard, larvae may web together leaf debris and other material to form a cocoon on the soil surface. The pupal stage of fall armyworm cannot withstand protracted periods of cold weather. Duration of the pupal stage is about eight to nine days during the summer, but reaches 20 to 30 days during the winter in Florida (Capinera, 2014).

Adult moths of FAW are variable in color and their wing span can reach 32 to 40 mm. Male moths have a shaded gray and brown forewing with triangular white spots at the tip and near the center of the wing. Forewings of females are less distinctly marked, ranging from a uniform grayish brown to a fine mottling of gray and brown. The hind wing of both sexes is shining silver-white with a narrow dark border. Adults of FAW are nocturnal and are most active during nights (CABI, 2017). After a preoviposition period of three to four days, the female normally deposits most of her eggs during the first four to five days of life, but some oviposition occurs for up to three weeks. Duration of adult life is estimated to average about 10 days, with a range of about 7 to 21 days (Capinera, 2014).

2.3. Nature of Damage

The FAW is a polyphagous pest that attacks over 80 plant species (Capinera, 2005). It commonly feeds on field corn, sweet corn, sorghum, Bermuda grass, rice and grass weeds such as crabgrass and *Digitaria* spp. Other field crops that are frequently injured by FAW include alfalfa, barley, buckwheat, cotton, clover, oat, millet, peanut, ryegrass, sugar beet, Sudan grass, soybean, sugarcane, timothy, tobacco, and wheat (Pashley, 1986; CABI, 2017).

Young larvae initially consume leaf tissue from one side, leaving the opposite epidermal layer intact. By the second or third instar, larvae begin to make holes in leaves, and eat from the edge of the leaves inward. Feeding in the whorl of corn often produces a characteristic row of perforations in the leaves. Older larvae cause extensive defoliation, often leaving only the ribs and stalks of maize plants, or a ragged, torn appearance (Capinera, 2014).

Marenco *et al*. (1992) indicated that infestation by FAW on sweet corn causes more injury at late whorl stage compared to early and mid-whorl stages. Larvae of FAW burrow into the growing point of plants (buds, whorls, etc.) and destroy the growth potential of plants, or clip the leaves. In corn, they also burrow into the ear and feed on kernels like that of corn earworm, *Helicoverpa zea* (Boddie). But, unlike corn earworm, fall armyworm will feed by burrowing through the husk on the side of the ear. Leaf damage by FAW and stem borer is also confusing. However, it is possible to determine which species is responsible for the damage through close examination as the holes formed by FAW have smooth edges whereas holes cut by maize stem borer larvae have raged edges (Goergen *et al.*, 2016).

2.4. Management Methods of Fall Armyworm

Detecting fall armyworm infestations before they cause economic damage is the key to their management (Ferreira, 2015). FAW monitoring can be done by capturing the flying moths with black light and pheromone traps. Pheromone traps are more efficient compared to backlight traps; they should be suspended at canopy height at the whorl stage in crops like corn. Trap catches can determine the presence or absence of the pest; however they are not necessarily good indicators of density. Other strategies have been used to manage fall armyworm including cultural practices, Biological (Parasitoids, Predators and Pathogens), botanicals and synthetic insecticides (Viana and Prates, 2003).

2.4.1. Cultural

Cultural control is an important component of pest management strategies including FAW. Sole maize cropping systems offer favourable environment to FAW to spread fast. FAW adult female moths find the preferred conditions to lay egg masses and increase the number of generations within a season, favouring increased levels of infestation. Plant diversity, including intercropping systems and the use of multiple varieties, can reduce the rate of oviposition by confusing the FAW female moth, therefore helping reduce the level of infestation (FAO, 2018). A recent study has established that a climate-adapted version of Push-Pull, an already widely used technology developed by *icipe* and partners is effective in controlling the fall armyworm, providing a suitable, accessible, environmentally friendly and cost-effective strategy for management of the pest. These findings represent the first documented report of a readily available technology that can be immediately deployed in different parts of Africa to efficiently manage the fall armyworm. The study revealed fall armyworm infestation to be more than 80% lower in plots where the climate-adapted Push-Pull is being used, with associated increases in grain yields, in comparison to monocrop plots. The findings were supported by farmers' perceptions through their own observations regarding significantly reduced presence of fall armyworm in Push-Pull plots (Midega, 2018).

Similarly, most of subsistence farmers in Africa do not apply pesticides to maize to control pests; nevertheless, they do practice cultural control methods which deter or kill pests, such as maize intercropping, handpicking and killing of caterpillars, application of wood ashes and soils to leaf whorls (Tsedeke *et al.,* 2000). Survey conducted in Ethiopia and Kenya showed that 14% and 39% of the farmers practiced cultural methods (such as handpicking) for FAW managements (Teshome *et al.*, 2018).

2.4.2. Biological

Biological control can be considered as a powerful tool and one of the most important alternative control measures providing environmentally safe and sustainable plant protection. The success of biological control will depend on understanding the adaptation and establishment of applied biological control agents in agricultural ecosystems. Microbial pathogens and arthropod biocontrol agents have been successfully used in agricultural systems. They are safe for non-target vertebrates and for the environment, and production costs have been significantly reduced in recent times as they are mass produced in liquid media (Mahmoud, 2017). Even though biological control may not replace conventional insecticides a number of parasitoids, predators and pathogens readily attack larval and adult stages of FAW.

2.4.2.1. Parasitoids and Predators

The migratory behaviour of the FAW away from over-seasoning and reproduction sites makes the natural enemies less efficient. Various insects have been reported parasitizing *S. frugiperda* larvae and eggs. Ashley (1979) listed 53 species of parasitoids reared from *S. frugiperda* eggs and larvae. Only 18 of these are common to the continental United States, while 21 are present in South America and Central America, including Mexico. Ashley (1986) studied the impact on *S. frugiperda* population of eight native and one imported parasite in south Florida. These included: *Apanteles marginiventris, Campoletis grioti, Chelonus insularis, Meteorus autographae, Ophion spp., Rogus laphygmae, Ternelucha spp.* and *Eiphosoma vitticole* (imported). Although 63% of the first four larval instars were destroyed by parasitoid, they concluded that *S. frugiperda* has the reproductive potential to increase its population beyond regulation by native parasites.

In Mexico nine species of hymnopteran parasitoids and five species of dipteran parasitoids were recovered from FAW larvae. In hymnopteran parasitoids, five species belonged to the family Braconidae, three species belonged to the family Ichneumonidae, and only one species belonged to the family Eulophidae were recovered. In dipteran parasitoids four species of belonged to the families Tachinidae and one species belong to Phoridae were recovered (Rui'Za'Jera *et al*., 2007).

Molina-Ochoa *et al*. (2003) recorded eleven species from three families of Hymenoptera: seven Braconidae, three Ichneumonidae and one Eulophidae from FAW larvae. According to Capinera (2005), *Cotesia marginiventris* and *Chelonus texanus* (both Hymenoptera: Braconidae), are the most commonly reared wasp parasitoids from larvae of FAW in the United States. Among fly parasitoids, *Archytas marmoratus* (Diptera: Tachinidae) is the most abundant larval parasitoids in United State. In Kenya Tachinid fly, *Archytas marmoratus* was the main parasitoid with 12.5% parasitism. *Charops ater* and *Coccygidium luteum* were commonly occurred parasitoids in Kenya and Tanzania with parasitism ranged from 6 – 12% and 4 – 8.3%, respectively (Birhanu *et al*., 2018).

The predators of FAW are general predators that attack larvae of other lepidopterans. The most important predators of FAW include various ground beetles (Coleoptera: Carabidae); the striped earwig, *Labidura riparia* (Pallas) (Dermaptera: Labiduridae); the spined soldier bug, *Podisus maculiventris* (Hemiptera: Pentatomidae); and the insidious flower bug, *Orius insidiosus* (Hemiptera: Anthocoridae) (Capinera, 2001). Among the vertebrate predators, birds, skunks, and rodents are important ones that feed on larvae and pupae of FAW (Capinera, 2005

2.4.2.2. Entomopathogens

The development of resistance to synthetic insecticides is one of the driving forces for changes in insect pest management (Mahmoud, 2017). The use of microbial control is a potentially valuable alternative to chemical pesticides with their high cost, possible pest resurgence, development of resistance, and environmental contamination (Lezama-Gutiérrez *et al*., 2001).

Entomopathogens may be used to supress insect population in at least three ways: (1) optimization of naturally occurring diseases, (2) introduction and colonization of pathogens into insect population as natural regulatory and (3) repeated application of pathogens as microbial insecticides (Wayne *et al*., 1980).

Fall army worm is susceptible to at least 16 species of entomopathogens including viruses, fungi, protozoa, nematodes and bacteria (All et al., 1996; Wayne *et al.,* 1980). Among the pathogens, *Bacillus thuringiensis, Metarhizium anisopliae and Beauveria bassiana* are cause significant level of mortality in FAW population and help to reduce leaf defoliation in crops (Molina-Ochoa *et al*., 2003).

Fungal pathogen such as *M. anisopliae and B. bassiana* can cause a common disease in FAW larvae (Molina-Ochoa *et al*., 2003). Many of them occur naturally in fall armyworm population. Some cause natural epizootics (Wayne *et al*., 1980). Molina-Ochoa *et al*. (2003) recorded 3.5 % FAW larval mortality in Mexico due to naturally occurring entomopathogens and parasitic nematodes. The authors recovered three species of entomopathogenic fungi representing two different classes, Hyphomycetes (*Nomuraea rileyi,* and *Hirsutella sp.)* and Zygomycetes (*Entomophthora sp*.) from FAW larvae, and additional two species of Hyphomycetes (*Metarhizium anisopliae* and *Beauveria bassiana*) from soil samples.

2.4.3. Pheromone Lure

Insect traps are important tools for monitoring pest populations in surveys and integrated pest management (IPM) programs. Traps can help detect invasions by novel pest species, the onset of seasonal pest activity, determine the range and intensity of pest infestations, and track changes in pest populations, all of which help informed decision making for pest management (Wyatt, 1998). Traps typically use olfactory (chemical) and/or visual cues or stimuli to attract pest insects. Phermone lures are a critical tool for detecting and managing insect pest populations (Spears, 2016). Lepidopteran pheromones have been successfully used for insect monitoring, mass trapping, and mating disruption for diverse of insect pests (Wyatt, 1998).

The use of pheromone traps as a strategy for monitoring adult *S. frugiperda* will be useful to indicate the real demand for control of the fall armyworm in maize, especially when the trap is placed in field soon after planting (Cruz *et al.*, 2010). Commercially available FAW sex pheromones have been used in the USA, and have been shown to be a useful tool for monitoring FAW males (Adams *et al*., 1989; Gross and Carpenter, 1991; Mitchell *et al*., 1989). Populations of adult male FAW are monitored in agricultural systems with a multicomponent sex pheromone as a lure in traps (Mitchell *et al*., 1989).

2.4.4. Botanicals

The use of botanical pesticides is considered as a substitute to hazardous synthetic pesticides such as pyrethroid and organophosphorus pesticides due to the disturbance in the environment, increasing user cost, pest resurgence and pest resistance to pesticide (Arya and Tiwari, 2013). As a result of serious impacts of the use of persistent and deleterious insecticides, research on the identification of eco-friendly and locally available alternative tools for pest control has been agenda of entomologist. Because of affordability and availabilities, farmers of developing countries used botanical insecticides for centuries to control insect pests of both field crops and stored produce (Schmutterer, 2009).

Botanical insecticides are not only effective against crop pests but remain safer to natural enemies. Among many botanicals, plants such as *Azadirachta indica*, *Milletia ferruginea, Croton macrostachyus, Phytolacea docendra*, *Jatropha curcas*, *Nicotina tabacum* and *Chrysanthemum cinerariifollium* were successfully used to control insect pests (Schmutterer, 2009; Addisu *et al*., 2014). Some of these plant species possess one or more useful properties such as repellency, anti-feeding, antijuvenile hormone activity, oviposition/ hatching deterrence, antifertility or growth disrupters, biodegradability and ability to reduce insect resistance (Metcalf, 1992; Mochiah *et al*., 2011).

Melia azadirachata belongs to the family Meliaceae are one of the potential bioactive plants extensively studied in laboratory and also in field against several insect pests and vectors (Charleston, 2004). The compound cisdehydrocrotonin isolated from *Croton macrostachyus* bark inhibits the growth of lepidopteran pests (Viegas, 2003). In rural areas of Ethiopia, *Schinus molle* is commonly used to drape branches over their head believing to repel housefly, *Musca domestica*. The traditional belief on repellent activities and also feeding deterrent was confirmed by two choice laboratory bioassay methods against houseflies (Wimalaratne *et al*., 1996).

Hellpap (1995) tested three synthetic insecticides, and insecticidal plants (extracts of *J. curcas* and *A. indica*) against stem borer. Neem products were effective for control of stem borers, including the spotted stalk borer. A Preliminary field studies also showed that, application of extracts of chinaberry (*M. azedarach*), endod (*P. dodecandra*) and pepper tree (*S. molle*) significantly reduced the levels of leaf infestation and dead heart injury due to larvae of maize stalk borer, *Busseola fusca* (Asefa and Firdu, 1999).

According to Asmare *et al*. (2006), botanicals like *N. tabacum* and *J. Curcas* were found superior and better than untreated controls in reducing insect damage and increasing yield of maize similarly, extracts of many plants show insecticidal activity against FAW, but relatively few have been successfully commercialised.

The aqueous extract of neem seed cake is more toxic than the leaf extract which is usually used by farmers to control *S. frugiperda* (Silva *et al*., 2015). According to Afonso and Teixeira (2003) the mortality level of *S. frugiperda* caterpillars was low during the first three days, after initial feeding, and high by 10 days using an aqueous extract of neem leaves. Globally, there are registered products on rotenone, garlic, nicotine, ryanodine and quassia extracts (Guerrero *et al*., 2014). The products may be formulated with water and sprayed in the same way as chemical pesticides. In Brazil neem aqueous extract was prepared, and used as a control agent for the FAW. Extract of chinaberry is used by Paraguayan farmers for FAW control. In Costa Rica a preparation of garlic extract, neem and detergent also reported to be effective for FAW control (Abrahams *et al*., 2017b).

2.4.5. Synthetic Insecticides

As it is true in many other insect pest species, insecticides are important management options in FAW control (Capinera, 2001). In Florida, fall armyworm is the most important pest of corn and insecticides are applied against FAW to protect both the early vegetative stages and reproductive stage of corn (Capinera, 2001). High volume of liquid insecticide is required to obtain adequate penetration and kill larvae feeding deep in the whorl of the plants. In situations where overhead sprinklers are used for irrigation, insecticides can also be applied in the irrigation water. Keeping plants free of larvae during the vegetative period can help to reduce the number of sprays needed at the silking stage (Foster, 1989). Hence, sprays should be spaced evenly during the growing period instead of concentrating at silking period.

Yu (1991) reported that a strain of the fall armyworm collected from corn in North Florida showed resistance to commonly used insecticides. Resistance to pyrethroids ranged from 2- to 216-fold; the highest resistance level observed was to fluvalinate. Resistance to organophosphorus insecticides ranged from 12- to 271-fold; the highest resistance level observed was to methyl parathion. Resistance to carbamates ranged from 14- to >192-fold with the highest resistance level being observed with carbaryl. Yu (1991) further indicated that the broad spectrum of insecticide resistance observed in the field strain was due to multiple resistance mechanisms, including increased detoxication of these insecticides by microsomal oxidases and target site insensitivity such as insensitive acetylcholinesterase. Resistance management is a vital component of IPM. Pesticide resistance management will extend the useful life of valuable IPM-compatible pesticides. It is likely to be successful when combined with routine monitoring of pests, use of reasonable treatment thresholds, and make full use of non-pesticidal methods, such as biological and cultural management, field sanitation and host plant resistance. Judicial and appropriate use of insecticides is essential for the successful management of FAW and to sustain increased productivity of maize in Africa.

The recent invasion of FAW alarmed governments of different African countries to deploy a massive pesticide spray program as an emergency response in FAW affected areas mainly in maize fields to protect crop damage and prevent further expansion of the pest. In recent surveys conducted in Ethiopia and Kenya noted that farmers were applying different types un-registered insecticides that might be due to the invasive nature of the pest that need rapid response and lengthy pesticide registration process (Teshome *et al*., 2018).

In Mexico, chemical control of *S. frugiperda* in maize is achieved by application of methyl parathion, chlorpyrifos, methamidophos, and phoxim, among other insecticides (Malo *et al*., 2004). Chlorantraniprole (Coragen), Flubendiamide (Belt SC 480), Spinetoram (Radiant) and Spinosad (Tracer) are effective in the control of *Tuta absoluta* on tomato (Hamdy *et al*., 2013; MoA, 2017). Similarly, high mortality of fall armyworm was recorded sprayed in this insecticide as compared to non-sprayed (Cruz *et al*., 2010; Hardke *et* al., 2011b).

Fall armyworm mortality on treated diets with Chlorantraniprole, lambda-cyhalothrin, spinetoram and flubendiamide were significantly higher (90.6 to 100%) than non-treated control three days after treatment application (Hardke *et* al., 2011b). According to Belay *et al*. (2012) Spinetoram, acephate, and thiodicarb caused significantly higher (≥60%) FAW mortality at 16 h after application, and the effects of spinosad, chlorantraniprole and cyhalothrin were intermediate under laboratory condition. Similar trend in FAW larval mortality was observed at 48 h after insecticide application. Spinosad at 48 h caused a level of mortality that was similar to that of spinetoram, acephate, and thiodicarb. Cyhalothrin also showed an increased larval mortality at 48 h that was equivalent to spinetoram and acephate. At 96 h after application, all insecticides except methoxyfenozide and bifenthrin, resulted in more than 80% FAW larval mortality. Spinosad, spinetoram, acephate and thiodicarb resulted in relatively quick (16 h) mortality of FAW larvae. Indoxacarb, flubendiamide, indoxacarb, and cyhalothrin required longer (≥ 96 h) to achieve higher levels of mortality of FAW (Belay *et al*., 2012).

Dursban 48% EC *(chlorpyrifos-ethyl*) and Malathion 50% EC are registered for the control of armyworm, locusts and grasshoppers on cereals and pastures (MoA, 2017). Agro-Thoate 40% EC (Dimethoate 40%) also registered for the control of beanfly (*Ophiomiya phaseoli*), bean aphid (*Aphis fabae*); thrips (*Taenothrips spp*.) ABW (*Helicoverpa armigera*) on french beans, aphids (*Myzus persicae*) and ABW (*H. armigera*) on tomato, cabbage aphid and various aphids on cabbage and potato, respectively (MoA, 2017). Similarly, these synthetic insecticides have been registered for the control of FAW in the native region of the pest (Cruz *et al*, 2010).

3. MATERIALS AND METHODS

3.1. Assessment Occurrence of Natural enemies (Parasitoids) Associated with FAW

Survey of FAW were conducted in Jimma and Esat shewa zone of Oromia, Sidama Zone of Southern Nations, Nationalities, and Peoples (SNNP), and East and West Gojam zones of Amahara region of Ethiopia (Fig 1).

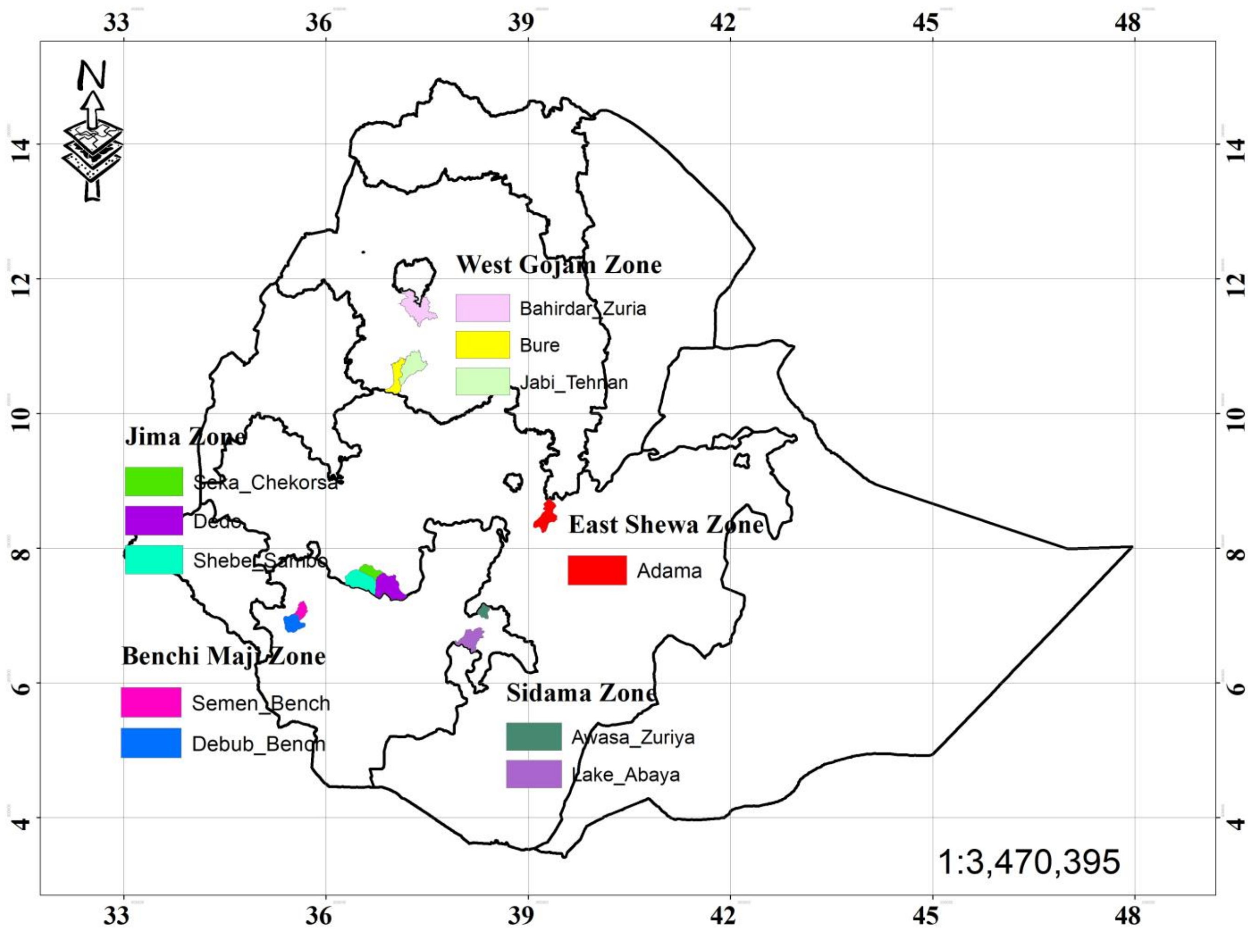

Figure 1: Map of the Surveyed Localities

A total of thirty-one sites were purposively selected based on the report of occurrence of FAW through official report. In all farms, the survey covered full growing period of maize, one month after planting to harvest. Location details such as latitude, altitude and longitude were taken using GPS. In each surveyed farm, three quadrants measuring 3m x 3m were randomly selected. The number of egg masses and larvae were counted on the damaged maize plants. The egg masses were placed in plastic cup with 5 grams of natural diet (fresh maize leaf). The larvae were placed in rectangular plastic cages (4 cm height x 15 cm width x 21 cm length), covered on top with fine screen to prevent the parasitoids escape. The larvae were fed with pieces of fresh maize shoot about 60 gm which were replaced every 48 hours until pupation. The eggs and larvae were kept in the laboratory at room temperature of 24-26 ^oC, 50-70% RH and a photoperiod of 12:12 (L:D) hour until parasitoids emerged. The parasitoids that emerged from the egg or larvae were recorded every 24 h until pupation. For the dead egg or larvae where nothing emerged, no dissections were made to examine for dead parasitoids (Molina-Ochoa *et al*., 2000; Ruiz-Najera et al., 2007). Parasitoids were preserved in 70% ethanol and sent for identification to ICIPE's insect taxonomist, Dr Copeland Robert and in UK natural history museum. Percent parasitism was calculated according to Pair *et al*. (1986).

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

3.2. Laboratory Bioassay of Insecticides against FAW

Laboratory bioassays of insecticides were conducted at Melkassa Agricultural Research Center (MARC) in Entomology laboratory in September 2017.

Maize planting: The maize variety 'Melkassa-2' was planted at MARC field station on a plot size of 5m X 5m, with a spacing of 75 cm between rows and 25 cm between plants within a row. Two seeds were planted per hill and were thinned to one seedling per hill two weeks after emergence. The maize plot was fertilized with DAP at planting, at the rate of 100kg/ha. No pesticide was applied to control pests.

Insect colony*:* FAW starter colony was collected from unsprayed maize farm at MARC. About 100 fourth instar larvae were collected; the larvae were placed in rectangular plastic cages in the lab and fed with maize leaves collected from 15-30 days old maize plant (Melkassa-2). The pre-pupal stage was transferred to a plastic jar one-third filled with soil for pupation. The pupae were collected and placed in a moistened Petri Dish in an oviposition cage. Sterile cotton soaked in a sugar solution was placed in a Petri dish inside the oviposition cage as a food source for the emerging adults. The wall of the oviposition cage was lined with wax paper as an oviposition media (Deryck, 1979; Cruz *et al*., 2010; Hardke *et al*., 2011a).

About 2-3 days old egg batches were collected from the oviposition cages and placed in a sterile plastic container. Eggs were monitored daily for hatching; as soon as the first instars emerged, they were provided with tender and fresh maize leaves (Deryck, 1979). The insects were reared as described above until sufficient population was maintained to run the experiment. The rearing was done at room temperature 24-26 ^{o}C and 40-50 % RH. Second generation (F_2) larvae were used for the study.

Preparation of insecticides: Nine different insecticides were used (Table 1). These were: Chlorantraniprole (Coragen 200 SC), Spinetoram (Radiant 120SC), Dimethoate 40% (Agro-Thoate 40% EC), Spinosad (Tracer 480 SC), Lambda-cyhalothrin (Karate 5% EC), Malathion 50% EC, Chlorantraniprole + lambda-cyhalothrin (Ampligo 150 SC), Carbaryl (sevin) and Bandit (Imidacloprid). Each insecticide was thoroughly mixed with water following the manufacturer's recommendation for 5-10 minute. Twenty millilitre of the solution was added to a hand sprayer.

Treatment application: Maize shoot were obtained from 3-4 weeks old seedlings as described above. The shoot were cut and weighed to 60 g. Each 60 g contains 3-4 pieces of leaves with 5-6 cm length and were placed in rectangular plastic cages and sprayed with 20 ml of each of the above insecticides. Ten 3rd instar larvae were released into the plastic container containing the treated leaves 5 minutes after leaves were treated. Leaves treated with sterile water were included as a control. The treatments were laid out in a Complete Randomized Design (CRD) with nine replications.

Data collection*:* Insect mortality was assessed 24, 48 and 72 hrs after treatment application. A larva was considered dead if it could not move itself when placed on its dorsal surface.

Table 1: Details of insecticides used in the experiment against FAW

Trade name	Active ingredient	Formulation	Manufacturer	Rate of application/ha	
				Insecticide	Water (Liter)
Coragen 200 SC	Chlorantraniliprole	SC	DuPont	250ml	500
Radiant 120SC	Spinetoram	SC	Dow AgroSciences	130ml	500
Dimethoate 40% EC	Dimethoate	EC	Adami Tuluu	1.5L	200
Tracer 480 SC	Spinosad	SC	Dow AgroSciences	150ml	500
Karate 5EC	lambda-cyhalothrin	EC	Syngenta	320 ml	500
Ampligo 150 ZC	Chlorantraniliprole + lambda-cyhalothrin	ZC	Syngenta	300ml	500
Bandit	Imidacloprid	SL	Tagror	112.5ml	600
Sevin 85% WP	Carbaryl	WP	Honobor Weilike	2kg	350
Malathion 50% EC	Malathion: 0,0 dimethyl phosphorodithioate	EC	Honobor Weilike	1.5L	200

3.3. Screening of Synthetic Insecticides against FAW in Greenhouse

Screenings of insecticides were conducted at Melkassa Agricultural Research Center (MARC) in greenhouse.

Maize planting: The maize (variety “Melkassa 2”) was planted in plastic pots (23 cm height x 27 cm width x 50 cm length)) in greenhouse at MARC. The pots were filled with soil up to 15 cm from the top edge with ration of 2:1:1 top soil, compost and sand soil, respectively. The soil was solarized under sun for 10 days covered with black polyethylene sheet. Five seeds were sown per pot. The plants were watered as required. Fifteen days after seedling emergence, five third instar larvae per plant were released (Silva *et al*., 2017). The larvae were obtained from a laboratory colony maintained at MARC Entomology laboratory as described above.

Insecticides application: The nine insecticides screened in the lab were used in greenhouse trial. The treatments were laid out in a Complete Randomized Design (CRD) with three replications. Each insecticide was thoroughly mixed with water following the manufacturer’s recommendations for 5-10 min. Each of 500ml solution was added to a hand sprayer and sprayed to each treatment. Plants treated with sterile water were included as a control. Insecticide spray started seven days after first infestation of each plant with five insects. They were repeatedly sprayed seven days after the first spray a total of two times.

Data collection*:* Seven days after each of the insecticide applications, the number of live larvae and dead larvae and pupae were counted in each treated and untreated control plants.

Similarly, FAW damage severity was recorded at seven days intervals based on the rating scale described by Davis *et al*. (1992) and Williams *et al*. (2007); 0 = no visible leaf damage, 1= only pin-hole damage on leaves, 2=pin-hole and shot hole damaged to leaf, 3= small elongated lesions (5-10mm) on 1-3 leaves, 4 = mid-sized lesions (10-30mm) on 4-7 leaves, 5= large elongated lesions (>30mm) or small portions eaten on 3-5 leaves, 6= elongated lesions (>30mm) and large portions eaten on 3-5 leaves, 7=elongated lesions (>30cm) and 50% of leaf eaten, 8= elongated lesions (30cm) and large portions eaten on 70% of leaves, 9= most leaves with long lesions and complete defoliation was observed.
Plant height, stem thickness, leaf number, fresh weight, and dry weight were recorded 70 days after planting. Dry weight was obtained after keeping the plant stems and leaves in a dryer for oven dry for 48 hrs at 70 ^{o}C.

3.4. Laboratory Bioassay of Botanicals against FAW

Laboratory bioassays of botanicals were conducted at Melkassa Agricultural Research Center (MARC) in Entomology laboratory in October 2017.

Plant extracts: Eleven insecticidal plants/botanicals were collected from different part of Ethiopia in July 2017. Leaf parts of *C. ambrosoids* and *N. tabacum*, and seeds of the remaining plant species were dried separately under shade and then ground to a fine powder using pestle and mortar. The powder of each botanical plant was soaked in100 ml of distilled water for 24 h at the effective rate previously reported by different authors for lepidopteran larvae as described below (Table 2). Then after, the solution/ mixture of the different botanicals were filtered through a cheese cloth and the solution was left overnight.

Table 2. List of insecticidal plants and their rate of application

Name of insecticidal plants	Local Name	Part used	Rate (gram)	Reference
Azadirachta indica	Neem	Seed	5	Feyissa and Tebkew, 2015
Militia ferruginea	Birbira	Seed	50	Ararso, 2010
Phytolacca dodecandra	Endod	Seed	25	Tadele *et al*., 2013
Jatropha curcas	Jatropha	Seed	11.5	Mulatwa, 2013
Schinnus molle	Turmanturi	Seed	25	Tadele *et al*., 2013
Croton macrostachyus	Bisana	Seed	25	Tadele *et al*., 2013
Chenopodium ambrosoids	Amadamddo	Leaf	35	Addisu *et al*., 2014
Melia abyssinica	Melia	Seed	8	Selvaraj and Mosses, 2011
Eucalyptus globulus	Bahar Zaf	Seed	25	Tadele *et al*., 2013
Nicotina tabacum	Tobacco	Leaf	25	Tadele *et al*., 2013
Lantana camara	Yewof Kolo	Seed	40	Raghavendra *et al*., 2016 ; Feyissa and Tebkew, 2015

Insects*:* FAW rearing was done as described above and 3rd instar larvae were used for this bioassay.

Treatments: The eleven botanicals described above were screened against the third instar FAW larvae in a Complete Randomized Design (CRD) with three replications. About 60g of maize shoot was prepared as described above and were placed in rectangular plastic cages and sprayed with 20 ml of each of the botanical extracts. Leaves treated with sterile water were included as a control. Ten third instar larvae were released into each jar containing the treated leaves.

Data collection: Insect mortality was assessed 24, 48 and 72 hrs after treatment application. A larva was considered dead if it could not move itself after being placed on its dorsal surface.

3.5. Evaluation of Entomopathogenic Fungi against FAW

The experiment was conducted in the Entomology laboratory of Ambo Plant Protection Research Center in February 2018. Larvae of FAW were obtained from FAW colony established in the Entomology laboratory of Melkassa Agricultural Research center. Three *Beauveria sp.* (APPRC-44BC, B4, and S #10H) and two *Metarrhizium sp.* (APPRC-34GM and DS-51-2) isolates obtained from Ambo Plant Protection Research Center were evaluated (Table 3).

3.5.1. Germination Test

All isolates were subjected to germination test to assess viability of the conidia according to the standard methods developed by Goettel and Inglis (1997). Three weeks after incubation on SDA, the conidia of each fungal isolates were harvested by scraping with sterile metal spatula and suspended in a test tube containing 10ml sterile water with Tween 80 (0.01%V/V) to make stock suspension. Conidial concentration of the stock suspension was adjusted to $3x10^6$ conidia/ml with heamocytometer using a light microscope (40x magnification power). 100µl of the suspension was spread plated on SDA media in 90mm diameter Petri-dishes and 1ml of 70% alcohol was spread on each Petri-dish after 24hr of incubation to stop over germination. A sterile cover slip was put on each Petri-dish and percentage of germination determined by counting at least 300 conidia under a light microscope (40 x magnifications) and a conidium will be considered to be germinated if it showed a germ tube growth as big as its size. Each isolates were replicated three times. Percent of spore germination were calculated by dividing number of germinated spore with total number of spore examined multiplied by 100 (Chandel and Gaonkar, 2014).

3.5.2. Pathogenicity Test

All the isolates were evaluated for their virulence against the fall armyworm. Stock suspensions were prepared as described above and the concentration was adjusted to $1x10^8$ conidia/ ml.

In each experiment, 3rd instars of FAW were treated by immersing in 10ml fungal suspension for 30 seconds in a sterile beaker and transferred to sterilize plastic Petri-dish. The controls were treated with sterile distilled water containing Tween 80 (0.01%V/V). All treatments and their controls were replicated five times with five larvae per replication. They were arranged in a Completely Randomized Design (CRD). The treated insects and controls were provided with maize leaves (5g) daily after frass and leaf debris removed. Mortality was recorded daily.

The infected insects that showed symptoms of dry body and the presence of white or green fungal conidia on the body of the larvae were isolated or purified and placed in Petri dishes lined with moist filter paper. Mortality due to treatment was obtained by calculating the difference percent of living in the check and percent of living in the treatment.

In the laboratory trial, due to the mortality of larvae in the control, one way- ANOVA was used to analyse percentage mortality instead of corrected mortality (Braham and Hajji, 2010). The data were then arcsine-transformed in order to stabilize the variances (Gomez and Gomez, 1984).

Table 3. Details of entomopathogenic fungi used in experiment against FAW

Fungal spp.	Isolates	Area of collection	Host	Year of collection
	APPRC-44BC	West Wollega	Soil	2016
Beauveria spp.	B4	West Wollega	Soil	2016
	S #10H	West Wollega	Soil	2016
Metarrhizium spp.	APPRC-34GM	West Wollega	Soil	2016
	DS-51-2	West Wollega	Soil	2016

3.6. Evaluation of Pheromone Lures for Monitoring of FAW

Five commercially available sex pheromone lures (Table 4) were evaluated for their efficacy of trapping male FAW moth in maize fields in Ethiopia from August to October 2017. The pheromone lures were obtained from Pest Control India PLC. Funnel traps were obtained from the Deseret Locust Control Organization for East Africa, Addis Ababa. Five sex pheromone lures were evaluated in Hawasssa ($7^0$1.147'N; $38^0$22.579'E) farmers maize field. Since smallholder maize farmers rarely cultivate maize beyond one hectare, it was not possible to replicate each treatment in one farm; hence, each selected farm was used as a replicate. Traps with the lures were hung approximately 1.5 m above the ground on wooden stakes placed at 50 m intervals along planted maize rows. The traps were placed when maize plants were about 4-6 weeks old, and they remained in place until flowering stage, about 10-12 weeks after planting. At maize flowering stage, the male moth catches were low and the trial was terminated. All lures were changed every 15 days. Trap captures were recorded every 5 days. On each date, traps were emptied and the numbers of FAW males recorded (Malo *et al*., 2001; Marr, 2009).

Table 4: Pheromone lures and their specificity to FAW strain

Pheromone Components	FAW strain specificity
Z-9-Tetardecenyl Acetate (Z,9-14 OAC)	Rice
Z-7-Dodecenyl Acetate (Z,7-12 OAC)	Rice
Z-11-Hexadecenyl acetate (Z,11-16OAC)	Corn
Z-9 Dodecadienyl acetate (Z,9-12 OAC)	Corn
E-7-Dodecenyl acetate (E,7-12 OAC)	Brazilian population

3.7. Data Analysis

Percent parasitism of natural enemies was summarized and descriptive statistics (means and percentages) were calculated. Percent larval mortality, plant height, stem thickness, leaf number, fresh and dry weight data were obtained from laboratory and green house trials and number of moths collected with traps baited with different pheromone lures were subjected to one-way analysis of variance. To normalize the variance, percent larval mortality due to Entomopathogenic fungi and number of moths per trap were transformed using arcsine and log10(x+1) transformed, respectively (Gomez and Gomez, 1984).. Significance level was set at 0.05 and means were separated by Tukey's Honestly Significant Difference test. All data analysis was done using MINITAB 16 statistical software.

4. RESULTS

4.1. Parasitoids of Fall Armyworm

Three species of larval parasitoids namely, *Cotesia icipe* (Hymenoptera: Braconidae), *Palexorista zonata* (Diptera: Tachnidae) and *Charops ater* (Hymenoptera: Icheneumonidae) were identified. *Cotesia icipe* was the commonest parasitoids that emerged in Hawassa, Jimma and Awash melkassa surveyed areas. The parasitism ranged from 33.8 to 45.3% in Awash Melkassa and Jimma respectively. On the other hand, parasitism by a Tachinid fly, *Palexorista zonata* and *Charops ater* was relatively lower (6.4%) (Table 5).

Table 5: List of identified FAW parasitoids collected from some parts of Ethiopia and their mean percent parasitism

Country	Location	Natural enemies	Insect stages parasitized	% Parasitism
Ethiopia	Hawassa	*Cotesia icipe*	Larva	33.8
		Palexorista zonata	Larva	6.4
	Jimma	*Charops ater*	Larva	4.6
		Cotesia icipe	Larva	45.3
	Awash-Melkasa	*Cotesia icipe*	Larva	33.8
		Palexorista zonata	Larva	5.7

4.2. Laboratory Bioassay of Insecticides against FAW

There were significant differences between the insecticides in causing mortality to the larvae (Appendix Table 1). Karate 5% EC caused 86.7% mortality followed by Tracer 480 SC (72.2%), Ampligo 150 SC (68.8%), Coragen 200 SC (69%), and Radiant 120SC (62.2%), 24 hr after application. Karate 5% EC and Radiant 120SC caused 100% larval mortality 48 hr after treatment application whilst Tracer 480SC caused 100% mortality 72 hrs after treatment application. Carbaryl was less effective causing 21% mortality while Malathion was moderate causing 60% mortality 72 hr after treatment application (Table 6).

Table 6: Mean percent cumulative mortality of FAW larvae 24, 48 and 72 h after application of insecticides in laboratory test

	Percent mortality of the larva after		
Treatments	24hr	48hr	72 hr
Coragen 200 SC	69 ± 5.78^{ab}	88.8 ± 7.03 ^{b}	90 ± 10 ^{a}
Radiant 120SC	62.2± 5.36 ^{b}	100 ± 0 ^{a}	-
Dimethoate 40%	27.8± 7.44 ^{c}	81.1 ± 5.59 ^{b}	86.7± 5.58 ^{b}
Tracer 480 SC	72.2± 6.87^{ab}	98.3 ± 3.02 ^{a}	100 ± 0 ^{a}
Karate 5% EC	86.7± 4.5 ^{a}	100 ± 0 ^{a}	-
Ampligo 150 SC	68.8± 5.34^{ab}	94.3 ± 4.84 ^{a}	95 ± 5 ^{a}
Imidacloprid	47.8± 5.93^{bc}	65.6 ± 4.93 ^{c}	70 ± 8.16 ^{b}
Carbayl	2.2± 1.6 d^{e}	14.4 ± 3.95 ^{e}	21.1 ± 5.12^{d}
Malathion 50% EC	11.1± 4.07^{d}	41.1 ± 3.19 ^{d}	60 ± 8.16 ^{c}
Control	0± 0 ^{e}	0 ± 0 ^{f}	2.2 ± 1.47 ^{e}

Means within a column followed by different letters are significantly different at $P < 0.05$ (Tukey test)

4.3. Screening of Insecticides against FAW in Greenhouse

The mortality of FAW larvae was significantly different among treatments during the first and second spray (Appendix Table 2). Dimethoate 40% EC caused the highest larval mortality (40%) followed by Coragen 200 SC, Radiant 120 SC, and Karate 5% EC (mortality 33.3%), Tracer 480 SC (mortality 20%) and Carbaryl (mortality 6.7%). Malathion caused no mortality during the first spray. During the second-round insecticide spray, Karate 5% EC caused 60% mortality followed by Dimethoate 40% EC causing 53.3% larval mortality. Radiant 120 SC, Ampligo 150 SC and Imidacloprid caused 40% mortality. On the other hand, Carbaryl and Malathion were the least effective causing 6.7% larval mortality (Table 7).

Table 7: Mean percentage 3rd instar larval mortality of FAW at seven days intervals in two consecutive sprays in greenhouse.

Insecticide	1st spray	2nd spray
	Larval mortality	Larval mortality
Coragen 200 SC	33.3 ± 4.23 a	46.7+ 6.67 b
Radiant 120 SC	33.3 ± 4.23 a	40 ± 0 b
Dimethoate 40% EC	40.0 ± 0 a	53.3± 6.67 a
Tracer 480 SC	20.0 ± 11.5bc	26.7± 6.67 c
Karate 5% EC	33.3 ± 4.23 a	60 ± 11.5 a
Ampligo 150 SC	13.3 ± 8.74 c	40 ± 11.5 b
Imidacloprid	26.7± 13 b	40 ± 23.1 b
Carbayl	6.7± 2.74 cd	6.7± 3.67 d
Malathion 50% EC	0 ± 0 d	6.7± 3.67 d
Control	0 ± 0 d	0 ± 0 de

Means within a column followed by different letters are significantly different at $P < 0.05$ (Tukey test).

Leaf damage inflicted by FAW larvae was also significantly different among treatments in both spray rounds. The non-treated control plants had extensive leaf injury by FAW larvae compared to the insecticide treated plants. In the first-round spray, the lowest leaf damage was recorded in plants treated with Radiant 120 SC and Karate 5EC. Similarly result was obtained in the second-round spray where Radiant 120 SC showed the lowest leaf damage but having no significant differences with Tracer 480 SC, Karate 5EC and Ampligo 150 SC. Treatment with Malathion and Carbaryl gave the least protection to leaf damage (Figure 2).

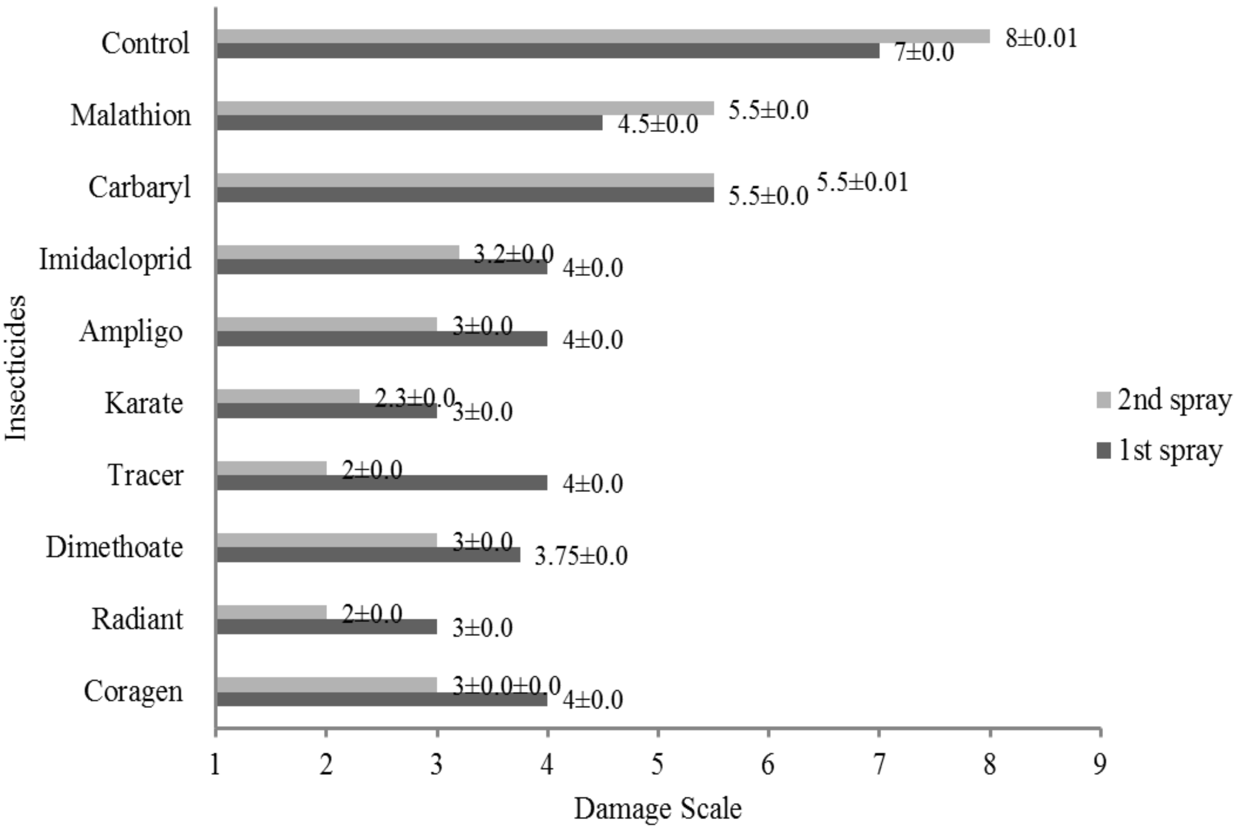

Figure 2. Mean leaf damage of maize by FAW under different treatments in the greenhouse

There were significant difference in plant height, stem thickness, fresh weight and dry matter among treatments. The highest plant height (172cm), stem thickness (22.02mm) and fresh weight (504g) were obtained from maize plants treated with radiant 120 SC. The highest dry mater (75kg) was obtained from maize plants treated with Tracer 480 EC (Table 7). On the other hand leaf number of maize plant showed no significant differences among treatments (Appendix 3).

Table 8: Mean percent plant height, stem thickness, leaf number, fresh and dry weight of maize under different insecticide treatments in greenhouse

Treatments	PH	ST	LN	FW	DW
Coragen 200SC	161.67 ±5.7[ab]	19.017[bc]±1.1[bc]	13.667[a]	356.5±7.43[cde]	58.37±6[c]
Radiant 120SC	172.33±5.7 [a]	22.02[a]±1.6	15.00[a]	504.4±26.8[a]	61.73±3[c]
Dimethoate 40% EC	161.67±5.7[ab]	18.49±0.5[bc]	13.333[a]	303.43±9.82[e]	60.03±0.9[c]
Tracer 480 SC	165.67±5.13[a]	19.5±1.3[abc]	14.33[a]	406.0±9.35[bc]	75.0±1.27[a]
Karate 5% EC	163.33±7.64 [a]	20.4±0.3[ab]	14.667[a]	432.7±9.43[b]	64.06±1.1[bc]
Ampligo 150 SC	166.00±13.86[a]	19.51±0.2 [abc]	13.667[a]	380.77±7.7[bcd]	47.2±2.86[d]
Imidacloprid	151.67±12.58[ab]	18.42±1.2[bc]	13.00[a]	300.9±23.5[e]	58.23±4.9[c]
Carbaryl	126.67±2.89[cd]	17.5±0.5[c]	13.00[a]	329.9±48.6[de]	72.13±2.3[ab]
Malathion 50% EC	140.00±5	17.48±1[c]	13.00[a]	182.5±28.4[f]	36.73±3.99[e]
Control	117.00±2.65[d]	12.147±0.4[d]	12.33[a]	142.93±5.3[f]	21.57±3.44[f]

Means within a column followed by different letters are significantly different at $P < 0.05$ (Tukey test). PH= plant height; ST= stem thickness; LN=leaf number; FW= fresh weight; DW= dry weight.

4.4. Laboratory Bioassay of Botanicals against FAW

There were significant differences between botanicals in causing mortality to the larvae (Appendix Table 4). Extracts of *P. dodecandra*, *S. molle*, *and A. indica* caused the highest percentage mortality (66.7 to 70%) to the larvae 24 hr after treatment application and over 80% mortality 48 hr after treatment application. *P. dodecandra* and *A. indica*, however, caused 100% larval mortality 72 hr after treatment application. *M. abyssinica*, *J. curcas* and *C. macrostachyus* resulted in higher percentage larval mortality (>90%) 72 h after treatment application; however, *E. globulus* and *C. ambrosoids* caused the least mortality, 10-20% (Table 9).

Table 9: Mean percent mortality of FAW larvae 24, 48 and 72 h after application of botanicals in laboratory test

Treatments	Percent mortality of the larva after		
	24 hrs	48 hrs	72 hrs
Azadirachta indica	66.7 ± 2.10[a]	86.7 ± 2.01[a]	100 ± 0 [a]
Schinnus molle	66.7 ± 5.39 [a]	80 ± 5.39 [a]	96.7 ± 6.04 [a]
Melia abyssinica	23.3 ± 6.05 [c]	56.7 ± 6.05[b]	93.3 ± 6.04[ab]
Militia ferruginea	10 ± 0 [d]	33.3 ± 0 [cd]	76.7 ± 2.22 [c]
Phytolacca dodecandra	70 ± 3.66[a]	86.7 ± 3.66[a]	100± 0 [a]
Jatropha curcas	53.3 ± 5.17[b]	76.7 ± 5.17[a]	90 ± 7.75 [b]
Croton macrostachyus	13.3 ± 2.71[cd]	43.3 ± 2.71[c]	86.7± 2.71[bc]
Nicotina tabacum	6.7± 2.04 [de]	26.67 ± 2.04[d]	50 ± 3.33[d]
Lantana camara	6.7± 2.04 [de]	26.67 ± 2.04[d]	46.7± 1.92[d]
Eucalyptus globulus	0 ± 0[ef]	0 ± 0[ef]	10 ± 7.75[ef]
Chenopodium ambrosoids	3.3± 2.04[de]	6.67 ± 2.04[e]	20 ± 4.27[e]
Untreated	0 ± 0[ef]	0 ± 0[ef]	0 ± 0 [f]

Means within a column followed by different letters are significantly different at $P < 0.05$ (Tukey test).

4.5. Evaluation of Entomopathogenic Fungi against FAW

The percentage germination of conidia showed significant differences ($F= 7.98$, $P = 0.004$, $df = 4$) among isolates (Appendix 5). Conidial germination of all isolates ranged from 81.37 to 93.4% (Table 10).

Table 10. Percentage conidial germination of isolates

Treatments	Mean
DS-51-2	93.40[a] ±2.6
APPRC-34GM	89.73[a] ± 0.45
S#10H	92.25[a] ±2.11
B4	91.93[a] ±1.46
APPRC-44BC	81.37[b] ±5.56

Differences between treatments were not significant a day after treatment application. Differences between treatments were significant ($p\leq 001$) starting from two days after treatment application (Appendix Table 6). Larval mortality in the control was lower than the rest of the treatments starting from the fifth day after treatment application. During this period the highest larval mortality (100%) was recorded in APPRC-44BC treatment.

APPRC-34 GM and B4 resulted in higher percentage larval mortality (80%) six days after treatment application. DS-51-2 and S#10H also caused 68-72% of mortality after seven and eight days of treatment application respectively (Table 11).

Table 11 : Mean percent mortality of FAW larvae after treatment in laboratory in nine consecutive days

Treatments	Percent mortality of the larva after								
	1st Day	2nd Day	3rd Day	4th Day	5th Day	6th Day	7th Day	8th Day	9th Day
DS-51-2	0^{a}	$0.0^{a}\pm0^{a}$	0.0 ± 0^{a}	$0.0^{a}\pm0^{a}$	20.0 ± 10.95^{b}	40.0 ± 10.95^{b}	68.0 ± 10.95^{b}	68.0 ± 10.95^{b}	68.0 ± 10.95^{b}
APPRC-34GM	0^{a}	0.0 ± 0^{a}	20.0 ± 0^{b}	40.0 ± 0^{b}	60.0 ± 0^{c}	80.0 ± 0^{c}	80.0 ± 0^{bc}	80.0 ± 0^{bc}	80.0 ± 0^{bc}
S#10H	0^{a}	0 ± 0^{a}	0.0 ± 0^{a}	0.0 ± 0^{a}	20.0 ± 10.95^{b}	40.0 ± 10.95^{b}	72.0 ± 10.95^{bc}	72.0 ± 10.95^{bc}	72.0 ± 10.95^{bc}
B4	0^{a}	0.0 ± 0^{a}	20.0 ± 0^{b}	40.0 ± 8.93^{b}	60.0 ± 8.93^{c}	80.0 ± 8.93^{c}	84.0 ± 8.93^{c}	84.0 ± 8.93^{c}	84.0 ± 8.93^{c}
APPRC-44BC	0^{a}	20.0 ± 0^{b}	40.0 ± 0^{c}	60.0 ± 0^{c}	100.0 ± 0^{d}	-	-	-	-
check	0^{a}	4.0 ± 0.94^{a}	4.0 ± 0.94^{a}	4.0 ± 0.94^{a}	4.0 ± 0.94^{a}	4.0 ± 0.94^{a}	4.0 ± 0.94^{a}	4.0 ± 0.94^{a}	4.0 ± 0.94^{a}

Means within a column followed by different letters are significantly different at $P < 0.05$ (Tukey test)

4.6. Evaluation of Pheromone Lures for Monitoring of FAW

There were significant differences between the pheromone lures in catch size (Appendix Table 7). E,7-12 OAC and Z-9-12OAc followed by Z-11-16OAc caught significantly more FAW than the other lures. On the other hand, Z-7-12OAc and Z-9-14OAc lures captured the least number of moths (Table 12). The result also showed that Z-7-12OAc and Z-9-14OAc pheromone lures captured relatively high mean number of non-target insects.

Table 12: Numbers of FAW males collected with traps baited with different pheromone lures

Lure component	Moths/trap		
	Minimum and Maximum	Mean $\pm$ SE	Total
Z-7-Dodecenyl Acetate (Z-7-12OAc)	0 – 5	2.2 $\pm$ 0.662[cd]	5
Z-9-Tetardecenyl Acetate (Z-9-14OAc)	0 – 10	4.7 $\pm$ 1.34 [c]	10
Z-11-Hexadecenyl acetate (Z-11-16OAc)	0 – 40	14.7 $\pm$ 4.83 [b]	40
Z-9 Dodecadienyl acetate (Z-9-12OAc)	8 – 98	52.1 $\pm$ 10.3 [a]	98
E-7-Dodecenyl acetate (E,7-12 OAC)	3 – 108	56.2 $\pm$ 14.5 [a]	108
Trap without lure (Check)	0 – 6	0.9 $\pm$ 0.655 [d]	6

Means within a column followed by different letters are significantly different at $P < 0.05$ (Tukey test).

5. DISCUSSION

In this study, three species of parasitoids were recovered from FAW larvae collected from eleven districts of Ethiopia. Level of parasitism varied considerably among the surveyed fields. *C. icipe* (Braconidae) was the most prevalent parasitoid that occurred in three localities with percent parasitism ranging from 33.8% to 45.3%. Tachinid fly *P. zonata* (Tachnidae) is the second dominant larval parasitoid of FAW in Hawassa with 6.4 % parasitism, whilst in Jimma *C. ater* (Icheneumonidae) was commonly occurred parasitoid with 4.6% parasitism. Recruitment of native parasitoids by FAW suggests potential for biological control of the pest. Recruitment of native parasitoids to different invasive insect pests has been reported by different workers (e.g. Vercher *et al*., 2005; Matosevic and Melika, 2013).

Surveys conducted in different countries in the native region of FAW documented various species of natural enemies of FAW. For example, in Mexico Hymenopteran and Dipteran parasitoids (Ruı´z-Na´jera, *et al*., 2007); in Honduras the braconid *Aleiodes laphygmae* (Viereck) and the Ichneumonid, *Campoletis sonorensis* (Cameron) as the main parasitoids (Wyckhuys and O’Neil, 2006); in Brazil the Braconidae, *Aleiodes laphygmae, Chelonis insularis and Homolobus truncator* were recorded (Blanco *et al*., 2016; Meagher *et al*., 2016; Hay-Roe *et al*., 2016). Variations in species occurrence and level of parasitism may vary due to differences in geographical locations, agronomic practices, crop type and stage (Ruı´z-Na´jera *et al*., 2007). An inventory of FAW natural enemies in Americas and Caribbean documented a total of 150 species of parasitoids of FAW (Molina-Ochoa *et al.*, 2003) indicating the level of natural enemy complex and prospect of biological control of FAW.

Information on the occurrence and rates of parasitism of indigenous natural enemies has a paramount importance in designing biological control of FAW either through conservation of native natural enemies, introduction from aboriginal or augmentative release. The current blanket recommendation and indiscriminate use of pesticides against the fall armyworms might have negative impact on the natural enemies; hence, it is crucial to conserve natural enemies from adverse effect of pesticide and design IPM strategy for FAW management in the region.

All the insecticides tested in this study were toxic to FAW larvae, and some of them demonstrated high toxicity to the larvae both in the laboratory and green house trials. In laboratory bioassays, moderate and high larval mortality (>62%) was achieved with Karate 5EC, Tracer 480 SC, Coragen 200 SC, Ampligo 150 SC and Radiant 120SC. It has been noted that both in the laboratory and greenhouse trials percent larval mortality increased with time after insecticide application which may indicate residual toxicity of the insecticides to FAW. The results obtained in the greenhouse study demonstrated significant reduction in leaf damage to the maize compared to the control which is attributed to reduced number of larvae in treated plants. Consequently, the highest plant height, stem thickness, fresh and dry weight was obtained from insecticide treated plants as compared to un-sprayed control plants.

As it is true in many other insect pest species, insecticides are important management options in FAW control. Insecticides are applied against FAW to protect losses in different crops and pastures. In the Southern United States insecticides are applied on sweet corn against FAW, often on daily basis when the corn is at silking stage. In Florida, fall armyworm is the most important pest of corn and insecticides are applied against FAW to protect both the early vegetative stages and reproductive stage of corn (Capinera, 2001). In Mexico, chemical control of *S. frugiperda* in maize is achieved by application methyl parathion, chlorpyrifos, methamidophos, and phoxim, among other insecticides (Malo *et al*., 2004). High volume of liquid insecticide is required to obtain adequate penetration and kill of larvae feeding deep in the whorl of the plants. In situations where overhead sprinklers are used for irrigation, insecticides can also be applied in the irrigation water. Keeping plants free of larvae during the vegetative period can help to reduce the number of sprays needed at the silking stage (Foster, 1989). Application of Radiant, Orthene, Larvin, Sevin XLR Plus 4F and Tracer 480 effectively reduced FAW under field and laboratory condition ((Malo *et al.*, 2004 ; Daves *et al.*, 2009).

In the present study, the toxicity of locally available insecticidal plants showed different level of efficacy against FAW larvae. Extracts of *A. indica*, *P. dodecandra* and *S.molle*, consistently resulted in high larval mortality. In line with the present study Silva *et al*. (2015) reported high larval mortality of FAW using seed cake extract of *A. indica*. In recent studies, ethanolic extracts of *Argemone ochroleuca* Sweet (Papaveraceae) showed FAW larval mortality due to reduction in feeding and slows larval growth (Martínez *et al*., 2017). In other studies, Boldo (*Peumus boldus* Molina) (Laurales: Monimiaceae) caused toxicity which act as feeding inhibitor and repellent properties at higher concentration (Silva-Aguayo *et al*., 2017). Extracts of *Cedrela salvadorensis* and *Cedrela dugessi* caused larval mortality (Ce´spedes *et al*., 2000). These studies demonstrated the potential of insecticidal plants as a component of integrated pest management program of FAW mainly for small holder farmers. These plants are locally grown in many parts of Africa and can be used by the small-scale farmers wherever available as alternative approach to FAW management.

FAW is likely to directly affect capital costs, through increased labor needed and the type of knowledge required to deal with the pest; through yield losses and the ability of agricultural lands to respond to shocks; and financially, through increasing the cost of production due to costs of control and its effect on income (Abrahams *et al*., 2017a). The occurrence of multiple generations, the ability to migrate, and the ability to feed on a wide range of host plants makes fall armyworm one of the most difficult pest to control in Africa. Fall armyworm is a new threat to food security in the continent. Quick and coordinated action, enormous awareness creation, technological innovation, national, regional and international collaborations are required to tackling the menace of the fall armyworm pest to avoid economic adversity for smallholder farmers in Africa. Development and deployment of effective integrated pest management strategy, which can provide sustainable solutions to effectively tackle the adverse effects of the fall armyworm is required. The current study, therefore, contributes to the management of the fall armyworms in screening effective synthetic pesticides and botanical plants.
From the present study, it was observed that the application of chemical insecticides: Karate 5% EC, Coragen 200SC, Rdaiant 120SC, Dimethoate 40% EC, Tracer 480 SC and Ampligo 150 SC, were effective and significantly increased larval mortality, reduced leaf damage and increased biomass in maize. Among the botanicals, *A. indica*, *P. dodecandra* and *S. molle* provided the best efficacy in causing the highest mortality to FAW larvae.

Entomopathogenic fungi vary considerably in their mode of action and virulence. In addition to efficacy, there are advantages in using microbial control agents, such as human safety and other non-target organisms; pesticide residues are minimized in food and biodiversity increased in managed ecosystems. From the present study all tested isolates significantly increased FAW larval mortality. In other studies, different isolates of *B. bassiana* and *M. anisopliae* were tested against different larval instar of *Chilo partellus and* were found to be highly pathogenic inducing 90 to 100 % mortality seven days after treatment application (Tadele, 2004).

This study also showed that traps baited with different pheromone lures gave a promising result in trapping male FAW. Among lures tested, E,7-12 OAC, Z-9-12OAc, and Z-11-16OAc, captured significantly more FAW than the other lures tested. This result suggests that the presence of the three strains of FAW including the maize, rice and Brazilian populations. Similarly, study conducted in Kenya showed that Z-9-12OAc and Z-11-16OAc captured significantly more FAW than the other lures tested, whilst Z-7-12OAc and Z-9-14OAc caught the least number of moths (Birhanu *et al*., 2018; unpublished). Traps baited with pheromone lures can be used for monitoring and mass trapping of FAW, which are also compatible with other pest management methods in developing IPM of FAW (Hall *et al.,* 2005). FAW sex pheromone as a mixture of (Z)-9-tetradecen-1-ol acetate, (Z)-9-14: Ac; (Z)-7-dodecen- 1-ol acetate, (Z)-7-12:Ac; (Z)-9-dodecen-1-ol acetate, (Z)-9-12:Ac and (Z)-11-hexadecen-1-ol acetate, (Z)-11-16:Ac in the ratio of 81: 0.5: 0.5: 18, respectively, has been quite effective in monitoring populations of *S. frugiperda* from the USA and the Caribbean Basin (Tumlinson *et al*., 1986; Mitchell *et al*., 1989). Commercially available FAW sex pheromones have been used in the USA, and have been shown to be a useful tool for monitoring FAW males (Adams *et al.*, 1989). Malo *et al*. (2001) reported effectiveness of commercial pheromone lures and traps for monitoring male fall armyworm in Mexico. Pheromone traps can be employed for FAW monitoring, early alerts, seasonal population dynamics and informing pattern of FAW migration. For example, trap data can be used to relate adult catches to the potential scale of breeding and spread of FAW. FAW monitoring is a fundamental first step in creating a proper integrated FAW management (IPM) program. Numbers of individuals captured, however, are not directly related to damage levels in a field. The traps are for catching male FAW; however, trap catches will not inform about the number of mated females that may be flying in from elsewhere. Regular, careful scouting for signs of crop damage is imperative to be sure farms are protected.

6. SUMMARY AND CONCLUSIONS

Maize production has been threatened in America and recently it has been a new invasion and devastating pest in Africa. Recent reports on fall army worm (*Spodoptera frugiperda*) in Africa indicated rapid spread that already invaded 28 countries within a year. The pest attacks all stages of maize plant from seedling to cob. The fall armyworm was first detected in West Africa in December 2016 and has since appeared in Zimbabwe, Zambia, Malawi, the Democratic Republic of Congo (DRC), Mozambique, Lesotho, South Africa and Tanzania, and recently in Ethiopia. Ethiopia confirmed in Bench Maji, Sheka and Kefa zones of Southern Nations in January 2017 which then spread to Jimma, Sidama, East shewa, East Gojam and West Gojam zones, and recently in Tigray and Hararghe.

Recent reports showed that without control, FAW can cause maize yield losses of between 8 – 21 million tonnes, leading to monetary losses of up to US$ 6.1 billion, while affecting over 300 million people in Africa, who, directly or indirectly, depend on the crop for food and well-being. These invasion and rapid spread required multiple approaches of management that ranged from biological, chemical, and botanical control methods.

Therefore, field survey for parasitoids, evaluation of synthetic insecticides, botanicals and entomopathogenic fungi against FAW, and testing trapping efficacy of pheromone lures were undertaken during 2017 and 2018.

The survey was conducted in Jimma and Esat shewa zones of Oromia, Sidama Zone of Southern Nations, Nationalities and peoples (SNNP), and East and West Gojam zones of Amahara region of Ethiopia to determine FAW natural enemies in 2017. A total of three different species of parasitoids belonging to Hymenoptera and Diptera were recovered from FAW larvae. In Hawassa, Jimma and Awash Melkassa *Cotesia icipe* (Braconidae) was the dominant larval parasitoid with parasitism ranged from 33.8% to 45.3%.; while Tachinid fly, *Palexorista zonata* (Tachnidae), was the main parasitoid with 6.4% parasitism at Hawasa. *Charops ater* (Ichneumonidae) was commonly occurred parasitoid in Jimma with 4.6% parasitism.

Insecticides belonging to different chemical groups were tested for their efficacy against the FAW in laboratory and greenhouse conditions in Melkassa Agricultural Research Center from July to November 2017. The experiment was laid out as CRD with three replications. The treatments were; Chlorantraniprole (Coragen 200 SC), Spinetoram (Radiant 120SC), Dimethoate 40% (Agro-Thoate 40% EC), Spinosad (Tracer 480 SC), Lambda-cyhalothrin (Karate 5EC), Malathion 50% EC, Chlorantraniprole + lambda-cyhalothrin (Ampligo 150 SC), Carbaryl (sevin) and Imidacloprid (Bandit). Mortality differences were observed in the tested synthetic insecticides in laboratory. Karate 5% EC and Radiant 120SC caused 100% larval mortality 48 hr after treatment application whilst Tracer 480SC caused 100% mortality 72 hrs after treatment application. Carbaryl and Malathion 50% EC; however, were less effective causing 20-50% mortality 72 hr after treatment application. All insecticides significantly reduced foliar damage to maize compared to the untreated check in greenhouse.

Similarly, insecticidal plants (botanicals) were tested for their efficacy against the fall armyworm (FAW) under laboratory in Melkassa Agricultural Research Center in July 2017. The experiment was laid out CRD with three replications. The treatments were; *A. indica* (Neem), *M. ferruginea* (Birbira), *P. dodecandra* (Endod), *J. curcas* (Jatropha), *S. molle* (Turmanturi), *C. macrostachyus* (Bisana), *C. ambrosoids* (amadamddo) leaf extract, *M. abyssinica* (Melia), *E. globulus* (Bahar zaf), *N. tabacum* (Tobacco) and *L. camara* (Yewof kolo). Leaf parts of *C. ambrosoids* and *N. tabacum*, and seeds of the remaining plant species were used. *A. indica, S. molle* and *P. dodecandra* resulted in the highest percentage larval mortality (96-100%) 72 hr after treatment application.

In addition, entomopathogenic fungi (isolates of *Beauveria sp.*and *Metarrhizium sp.)* were tested for their efficacy against fall armyworm (FAW) under laboratory condition in Ambo Plant Protection Research Center in February 2018. The isolates were; APPRC-44BC, B4, and S #10H from *Beauveria sp. and* APPRC-34GM and DS-51-2 from *Metarrhizium sp.* The experiment was laid out CRD with five replications. APPRC-44BC was found to be highest pathogenicity inducing 100% mortality five days after treatment application. APPRC-34 GM and B4 were also resulted in higher percentage larval mortality (80%) after six days of treatment application.

Commercially available sex pheromone lures were evaluated in Hawasssa farmers maize field from August to October 2017. Since smallholder maize farmers rarely cultivate maize beyond one hectare, it was not possible to replicate each treatment in one farm; hence, each selected farm was used as a replicate. The lures were Z-7-Dodecenyl Acetate (Z-7-12OAc), Z-9-Tetardecenyl Acetate (Z-9-14OAc), Z-11-Hexadecenyl acetate (Z-11-16OAc), Z-9 Dodecadienyl acetate (Z-9-12OAc) and E,7-12 OAC. Trap without lure were used as a check. The higher number of male moths were trapped in the lure E,7-12 OAC, Z-9-12OAc and Z-11-16OAc. The lure E, 7-12 OAC, Z-9-12OAc and Z-11-16OAc can be used in monitoring and mass trapping of FAW under Ethiopian condition.

The following can be recommended for further study based on the present results. The effective synthetic insecticides, insecticidal plant extracts and entomopathogenic fungi, thus, could be recommended in management of FAW in maize. Further studies, however, are required to validate under field conditions. Similarly, studying the dose, extraction procedure, and mode of action of the botanicals, and conidial concentrations and application methods of entomopathogenic fungi is of the top priority. An integrated pest management (IPM) approach is needed to control the FAW. Reliance on pesticides spray may, in the long run, increases the likelihood of FAW resistance to pesticides.

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8. APPENDICES

Appendix Table 1. Analysis of variance showing Mean percent mortality of FAW larvae 24, 48 and 72 h after application of insecticides in laboratory test

24hrs

SV	DF	SS	MS	F- value	P- value
Treatment	9	36591.3	4065.7	41.09	0.000
Error	80	7916.5	99.0		
Total	89	44507.8			

48hrs

SV	DF	SS	MS	F- value	P- value
Treatment	9	62893	6988	52.82	0.000
Error	80	10584	132		
Total	89	73477			

72hrs

SV	DF	SS	MS	F- value	P- value
Treatment	9	40780.6	4531.2	132.9	0.000
Error	80	2728.9	34.1		
Total	89	43509.5			

Appendix Table 2. Analysis of variance showing Mean percent mortality of FAW larvae after application of insecticides in greenhouse

1st spray

SV	DF	SS	MS	F-Value	P-Value
Treatment	9	5987	665.2	4.16	0.004
Error	20	3200	160.0		
Total	29	9187			

2nd spray

SV	DF	SS	MS	F-Value	P-Value
Treatment	9	6795	755	4.49	0.268
Error	20	3360	168		
Total	29	10155			

Appendix Table 3. Analysis of variance showing mean plant height, stem thickness, leaf number, fresh and dry weight of maize under different insecticide treatments in greenhouse

Plant height

SV	DF	SS	MS	F- value	P- value
Treatment	9	9356.53	1039.61	18.07	0.001
Error	20	1150.67	57.53		
Total	29	10507.20			

Stem thickness

SV	DF	SS	MS	F- value	P- value
Treatment	9	182.4908	20.2768	22.44	0.001
Error	20	18.0725	0.9036		
Total	29	200.5633			

Leaf number

SV	DF	SS	MS	F- value	P- value
Treatment	9	19.200	2.133	0.89	0.552
Error	20	48.000	2.400		
Total	29	67.200			

Fresh weight

SV	DF	SS	MS	F- value	P- value
Treatment	9	324518.2	36057.6	74.35	0.001
Error	20	9699.3	485.0		
Total	29	334217.4			

Dry weight

SV	DF	SS	MS	F- value	P- value
Treatment	9	7133.85	792.65	68.62	0.001
Error	20	231.03	11.55		
Total	29	7364.88			

Appendix Table 4. Analysis of variance showing Mean percent mortality of FAW larvae 24, 48 and 72 h after application of botanicals in laboratory test

24hrs

SV	DF	SS	MS	F- value	P- value
Treatment	11	14446.1	1313.3	55.94	0.000
Error	24	563.5	23.5		
Total	35	15009.6			

48hrs

SV	DF	SS	MS	F- value	P- value
Treatment	11	21990.8	1999.2	54.04	0.000
Error	24	887.8	37.0		
Total	35	22878.6			

72hrs

SV	DF	SS	MS	F- value	P- value
Treatment	11	24943.9	2267.6	57.07	0.000
Error	24	953.7	39.7		
Total	35	25897.6			

Appendix Table 5. Analysis of variance showing Percentage conidial germination of entomopathogenic fungi in laboratory

SV	DF	SS	MS	F-Value	P-Value
Treatment	4	283.91	70.977	7.98	0.004
Error	10	88.95	8.895		
Total	14	372.86			

Appendix Table 6. Analysis of variance showing mean perecent FAW larval mortality after inoculation with entomopathogenic fungi in laboratory

Day one

SV	DF	SS	MS	F- value	P- value
Treatment	5	0	0	0	0.00
Error	24	0	0		
Total	29	0			

Day two

SV	DF	SS	MS	F- value	P- value
Treatment	5	1600.00	320.00	24.00	0.001
Error	24	320.00	13.33		
Total	29	1920.00			

Day three

SV	DF	SS	MS	F- value	P- value
Treatment	5	6200.00	1240.00	93.00	0.001
Error	24	320.00	13.33		
Total	29	6520.00			

Day four

SV	DF	SS	MS	F- value	P-value
Treatment	5	16800.00	3360.00	252.00	0.001
Error	24	320.00	13.33		
Total	29	17120.00			

Day five

SV	DF	SS	MS	F- value	P- value
Treatment	5	32000.00	6400.00	480.00	0.001
Error	24	320.00	13.33		
Total	29	32320.00			

Day six

SV	DF	SS	MS	F- value	P- value
Treatment	5	30466.67	6093.33	457.00	0.001
Error	24	320.00	13.33		
Total	29	30786.67			

Day seven

SV	DF	SS	MS	F- value	P- value
Treatment	5	37346.67	7469.33	112.04	0.001
Error	24	1600.00	66.67		
Total	29	38946.67			

Day eight

SV	DF	SS	MS	F- value	P- value
Treatment	5	37346.67	7469.33	112.04	0.001
Error	24	1600.00	66.67		
Total	29	38946.67			

Day nine

SV	DF	SS	MS	F- value	P- value
Treatment	5	37346.67	7469.33	112.04	0.001
Error	24	1600.00	66.67		
Total	29	38946.67			

Appendix Table 7. Analysis of variance showing Numbers of FAW males collected with traps baited with different pheromone lures

SV	DF	SS	MS	F- value	P- value
Treatment	5	16.05	3.21	15.30	0.0017
Error	12	10.73	0.26		
Total	17	26.122			