ENTOMOLOGY | RESEARCH ARTICLE

Determination of most effective insecticides against maize fall armyworm, Spodoptera frugiperda in South Western Ethiopia

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ABSTRACT: Maize FAWs, S. frugiperda, are economically important pests of maize plants in the field and cause considerable damage of up to 50% in Ethiopia. A total of six insecticides (Malathion 50 EC, Diazinon 48% EC, Alpha-cypermethrin, Deltamethrin, Lambda-cyhalothrin and Dimethoate 40% EC) were tested at laboratory, plot trails (using irrigation System) and farmers maize field (using 3 Delta-type traps) during 2019 to 2020 cropping season. Our result showed that, significant mortality of S. frugiperda was observed in the laboratory bioassay. Alpha-Cypermethrin and Deltamethrin at 24HAT and 72HAT account 76.67% and 100% and 96.67 and 100% of mortality. Highest number of larval mortalities was recorded on the treatment plot treated with Alpha-Cypermethrin (40%) at day one after insecticide application. Dimethoate and Alpha-cypermethrin (5%), Deltamethrin (3.67%) and Lambda-cyhalothrin (7.33%) significantly reduced FAWs infestation at farmers maize farm compared to that of non-treated control group/and plot (27%) at day one after insecticide application respectively. Therefore, the current finding proves that the pyrethroid class of the selected insecticides reduced the damage and infestation level of S. frugiperda in the maize field conditions. Based on the number

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PUBLIC INSTEREST STATEMENT

Fall army worm, Spodoptera frugiperda (Lepidoptera: Noctuidae), is a real threat to food security in Africa including Ethiopia. About 20–100% of yield losses caused by maize fall army worms were reported in several part of Africa. Currently management is relayed on the use of synthetic pesticides, which are often economically unviable and are extremely hazardous to the environment.

Producers in Africa have a limited knowledge and information on recently developed insecticide against maize FAWs. Therefore, this study examined the efficacy of the newly advanced pyrethroid class of the insecticides against S. frugiperda at laboratory and field condition for two years of cropping season. The insecticide, Lambda-cyhalothrin, resulted reducing maize fall army worm infestation quickly from 21.33 to 7.33% only at one spray time during 2020 cropping season.
of maize fall armyworm (the moth group) captured per pheromone traps, the percent of damaged plant and whorl infestations were significantly lowered, and the tools were appropriate to develop IPM programs in Ethiopia.

**Subjects:** Zoology; Entomology; Entomology

**Keywords:** Maize fall army worm; Insecticides; Invasive; S. frugiperda; voracious

1. Introduction

The maize fall armyworm, *Spodoptera frugiperda* (Lepidoptera: Noctuidae), is an insect pest that attacks a wide range of agricultural crops in the field, but maize is the most preferred (Rod et al., 2007; Gabriela et al., 2009; Juliana et al., 2012 Milena et al., 2014; Jarrod et al., 2015). This insect pest was a native to tropical and subtropical region of western America and recently invaded all regions of African continent in 2016 (Midega et al., 2018; Siazemo & Simfukwe, 2020).

The spreading and reproduction of this insect pest are native American to distribution of Africa and continuing to devastate maize crops even during dry seasons on the irrigated crops and/active when weather environmental condition is favorable (Hruska & Gladstone, 1988; Etienne et al., 2019). In Ethiopia, the insect was a new invasive alien species and the outbreak was recorded for the first time in early 2017 (Wondimu et al., 2021).

Despite of economic importance, *S. frugiperda* (J.E. Smith) is an economically important insect pest of various crops in Africa (Clark et al., 2007; Wilmar et al., 2016; Bariw et al., 2020; De Groote et al., 2020; Maruthadurai & Ramesh, 2020; Sharon et al., 2020). The capability of migrating long distance and feed on different host plant makes the insect was active at any of ecological variations especially due to climate change and very difficult to manage in the large scale of maize plant of high production (Belay et al., 2012; Balla et al., 2019).

Several maize damages with 20–100% yield losses caused by FAWs were reported in Africa and various researchers were strongly intensified to use selective insecticide to take urgent actions to tackle this insect pest in timely bases in the large-scale maize farm in Africa (Cruz et al., 2012; Hardke et al., 2014; Burtet et al., 2017; Early et al., 2018; Kumela et al., 2019; Kassie et al., 2020).

Several monitoring measures were testified in various countries but still difficult to overcoming the effect of maize FAWs among small scale farmers maize field. Recently, some developed insecticide against *S. frugiperda* was continuously reported in different locations of African contents and but, very slight amount is known about the efficacy of each insecticide to manage even the stages of fall army worm infestation was not demarcated (Bateman et al., 2018).

For these, Ethiopian government distributed about 100,000 liters of insecticide, Malathion 50% EC for the management of fall army worms in 2017 maize cropping season for the urgency response (FAO, 2019). However, rate and time of application practices exploit the rescue of biodiversity and environmental pollutions (Kansiime et al., 2019). Nevertheless, for the development of IPM approach, it is impervious to determine the present ecology, application practices and degree of damaged crops were taken in account before control decision making was decided (Almeida et al., 2017; Goergen et al., 2016; Montezano et al., 2018).

Consequently, it needs to be sorting and legalize effective insecticide that have relatively less impacts on/and associated with no target organisms. Therefore, objective of the present study was to determine the most effective pesticides and screening their efficacy against maize fall armyworm and at the same times to measure the infestation levels, populations density and damage levels reaches to economic threshold of the insect. And to develop the suitability of the pyrethroid class of the insecticide used as integrated pest management components in Ethiopia.
Table 1. Insecticide and rate of application used for the management of maize fall armyworm during the experimental period

| Treatment Insecticide | Trade Name          | Class               | Dos of a. I (L/ha) |
|-----------------------|---------------------|---------------------|--------------------|
| Malathion 50EC        | Ethiolathion 50% EC | Organophosphate     | 1 L                |
| Diazinon 48% EC       | Ethiozinon 60% EC   | Organophosphate     | 1.2 L              |
| Alpha cypermethrin    | Fasted 10% EC       | Pyrethroid          | 0.4 L              |
| Deltamethrin          | Ethiodemethrin 2.5% EC | Pyrethroid      | 15,000 mL          |
| Lambda-cyhalothrin    | Karate 2.5% EC      | Pyrethroid          | 200 mL             |
| Dimethoate 40%        | Agro-Thoate 40%EC   | Organophosphate     | 900 mL             |

2. Materials and methods

2.1. Laboratory experiment

2.1.0.1. Study area. The first experiments were conducted under laboratory condition of Ambo University-College of Agriculture and Veterinary Sciences, Guder campus in January 2019. The college was found in west Shewa, Oromia, Ethiopia at 110 km from Addis Ababa with 80°240 N latitude, 39°210 E longitude, and 1550 m a. s. l.

2.1.0.2. Establishing larvae of S. frugiperda. Matching neonate larvae was collected from untreated infested maize field of Guder area using a camel hair brush and maintained under controlled laboratory condition (25 ± 2 °C, 70–75% RH, and a photoperiod of 14h10 ± 2 [L: D]). Ten fall armyworms larvae (second to third instar larvae) were released in to 30-mL plastic cups. Collected fresh maize leaves (Early stage of fresh maize leaves) prior to growing at greenhouse were soaked in 4% of sodium hypochlorite, cleaned using sterile distilled water, prepare in 50 g and placed per cups in daily basis.

2.1.0.3. Preparation of tested chemicals. There are six insecticide were used in the bioassay: Malathion 50 EC, Diazinon 48 EC, Alpha cypermethrin, Deltamethrin, Lambda-cyhalothrin (Karate 5EC), Dimethoate 40% (Agro-Thoate 40% EC), and control (treated with sterile distilled water). These insecticides were collected from various sources and preserved in a safe area until the experiments were conducted.

Each insecticide was mixed with sterile distilled water according to the manufacturer recommendation (Table 1). Randomized block design with seven treatments and three replications were used during the experiment. The insecticides were applied with using small medical syringes (5 ml). The control treatments were sprayed with sterile distilled water to avoid the effect of moisture variabilities in the plastic cups. The treatment was placed in a shelf of growth chamber separately. Insect mortality were evaluated at 24 hrs, 48 hrs, 72 hrs and 96 hrs after exposure.

2.2. Field experiment using irrigation system

Study area: The second experiment, screening of insecticide, was carried out at the experimental site of Ambo University-College of Agriculture and Veterinary Sciences, Guder-experiential site in January to April 2019. The plot land was located in (latitude 8°57’ 58”, longitude 37°51’ 33” and Elevation 2175 m), the summer average temperature and RH of the area was 23 °C and 77% respectively.

2.2.1. Plant establishment

2.2.1.1 Sourcing of maize cultivars. Limmu, Shone, Argane, Wencii, Kulani, Jibat and BH-540 were collected from Ambo Agricultural research center and Oromia seed enterprise in Feb.7. 2019. Each maize cultivar was sown at College of Agriculture Guder experimental area, on a plot size of 2 m x 2.5 m, with a spacing between rows of 70 cm, 25 cm between plants and 50 cm between plot. The plot was irrigated daily until reproductive stage (3 to 4th week). All recommended agronomic practices, application of fertilizer with DAP at knees stages and hand weeding were carried out.
2.2.1.2. Scouting and detection. Plots were monitored starting of one-week seedling emergence (VE; Early Whorl), with the aim of detecting egg masses and/or small larvae (<0.5 cm) and continued for four weeks until tasseling. Two weeks after emergence, presence of egg mass, newonet larvae and early-instar FAW damage on maize leaves in the form of pinholes /damage severity or small window panes were observed (i.e., number of larvae, number damaged plant (damage severity) per plot were recorded for three days before any insecticide applications. The resultant insecticide tested at laboratory condition was again tested in the controlled experiment and field conditions.

2.2.1.3. Design of the experiment. Randomized Complete Block Design (RCBD) with three replications was used for the experiment. Damage severity caused by FAWs and number of larvae per plot was recorded based on rating scale and treatment efficacy was determined after 3 and 4-days treatment application (DAT). Also, the ability of each cultivars was assessed based on damage rating (no damages to the ear ≈ high resistant, damages on kernel (LS) or less than 5% damages ≈ resistant, damage few kernel (6-15%) or less than 10% damages to an ear ≈ resistance, damages to 16–30% kernel or less than 15% damages to an ear ≈ partially resistant.

2.2.1.4. Treatment application. Insecticide application were made after the first week of infestation and 30 days after plantation. Each insecticide was then sprayed using small hand spray (100 ml) after 30 days maize plantation. Number of larvae was recorded before (DBT) and after treatment application (DAT).

2.3. Farmers field experiment

2.3.0.4. Study area. The third experiments were tested under various farmers field condition at Bako Tib, Sibu Sire and Bilo Boshe locations in May-July 2020 cropping season. Bako Tibe district was found in the west Shewo zone of Oromia, Ethiopia. It is located at 250 km from Addis Ababa, capital city of Ethiopia with the average elevation is 1610 M.a.s.l. The location was share annual rainfall ranges 1200–1300 mm and temperature of 13.8–27.8°C respectively.

The altitude of Sibu sire district was ranges between 1360 to 2500 m a. l. It is located 281 Km in West from Addis Ababa. It lies between 8°56’- 9°23 N latitudes and 36°35’-36°56 E longitudes. The altitude of the district ranges between 1360masl to 2500masl. The average temperature of the locations was 27.30°C to 22.55°C. And Bilo Boshe district were located at 307 km West of Addis Ababa, at 08054’045”N latitude and 037° 00’136” E longitudes with an altitude ranging from 1613–1641 m. a. s. l.

2.3.0.5. Experimental design and treatment. The experiment was carried out at farmers maize field of different locations to know the level of infestation at large scale. Field location were randomly selected based on agroecological variation, which plays a vital role of spreading and quickly distribution of insect pests across large geographical areas.

Potential maize growing district locations were randomly selected across the region. In each location three district were purposely assigned for the experiment. Soon after maize seed germination, infestation was assessed using Synthetic compounds that mimic natural FAW pheromone Lure were brought from Feed the Future organization and installed at five kebeles in the centre of the experimental area (1 ha).

Moths that are caught per pheromone lure were then counted. According to (Cruz et al., 2010) assumption; cumulative number of three adults trapped per trap were enough to produce larvae to cause infestation at least in 10% of the plants and causes significant economic damages if an appropriate management measure is not taken. Number of adult fall army worm per sex pheromone and infested whorls were recorded for three consecutive days before insecticide application. Number of infested maize plants were recorded and examine the percentage of infestation using the following equation:

\[
\text{%FAW infestation} = \frac{\text{Infested plants}}{\text{Total plants}} \times 100
\]
2.3.0.6. Determination of insecticide against *S. frugiperda*. Recently developed insecticides were conducted at large scale, on the farmers field at two agro-ecological regions, West Shewa, Bako Tibe district of Gara Gona, Tulu Sangota-a, and Tulu Sangota-b kebele and East Wollega, Bilo Boshe of Sodu Berama kebele and Sibu Sire of Jalale kebele. Treatment experiments: Jalale × Plot without insecticide application, Gara Gona × Alpha cypermethrin, Tulu Sangota (b) × Deltamethrin, Bilo Boshe × Lambda-cyhalothrin (Karate5EC), Tulu Sangota (a) × Dimethoate 40% (Agro-Thoate40% EC).

Knowingly, after 28-day old maize in each location was severely damaged with maize fall army worm. Before this period the larvae are too young to cause significant damage to the plant and susceptible to the action of different species of natural enemies. The insecticide was thoroughly mixed with water according to manufacturer’s instruction and directly sprayed on to maize leaves and whorls using a pressurized knapsack sprayer.

2.3.0.7. Data management. Treatment efficacy was determined for 4 days after insecticide treatment or after spray. Within each group /plot, number of maize fall armyworm moths captured per pheromone traps and damaged plant or/and fall armyworm infested maize whorls (visual observation) were randomly selected and counted in daily basis.

2.4. Statically analysis

Data were analyzed by PROC GLM and means separated according to Turkey’s Studentized Range Test (SAS Institute 2004).

3. Results

3.1. Laboratory study of insecticide against fall army worm

The study shows, significant larval mortality of maize fall army worm was registered from (77–97%) after treatment application on 24h exposure when compared with the control group (Table 2). Deltamethrin caused 96.67% mortality followed by Dimethoate 40% and Diazinon (86.67%), Malathion and Lambda-cyhalothrin 83.33% respectively.

Deltamethrin caused the highest (97% mortality) after 24hrs treatment application, while Deltamethrin, Alpha-Cypermethrin, Diazinon caused 100% mortality after 48h treatment application. Alpha-Cypermethrin was less effective, causing 76.67% mortality after 24 h after treatments. All selected insecticide causes 100% mortality on larval of *S. frugiperda* after day three treatment exposure.

Letters sharing with the same means are not significantly different from one another.

| Table 2. Percent mean mortality of maize FAWs treated with different insecticide at laboratory condition (n = 10) |
|---------------------------------------------------------------|
| Treatment                  | Dos of a. i | % larval Mortality *S. frugiperda* (± SE) |
|                             | (L/1 m²)    | 24hrs               | 48hrs               | 72hrs               |
| Deltamethrin                | 0.002       | 96.67 ± 9.7ab      | 100.00 ± 10a       | 100.00 ± 10a       |
| Malathion                   | 0.0012      | 83.33 ± 8.3bc      | 96.67 ± 9.7a       | 100.00 ± 10a       |
| Alpha-Cypermethrin          | 0.0004      | 76.67 ± 7.7c       | 100.00 ± 10a       | 100.00 ± 10a       |
| Dimethoate                  | 0.015       | 86.67 ± 8.7cd      | 93.33 ± 9.3a       | 100.00 ± 10a       |
| Diazinon                    | 0.0002      | 86.67 ± 8.7de      | 100.00 ± 10a       | 100.00 ± 10a       |
| Lambda-cyhalothrin          | 0.0009      | 83.33 ± 8.3df      | 96.67 ± 9.7a       | 100.00 ± 10a       |
| Control                     | -           | 6.67 ± 0.7f        | 6.67 ± 0.7b        | 3.33 ± 0.3b        |
| LSD                          |             | 1.52               | 0.76               | 0.38               |
| CV                           |             | 11.7               | 5.1                | 2.53               |
Table 3. Mean larval population of *S. frugiperda* on different maize cultivars grown under plot experiment using irrigation system

| Treatment | Mean no. of larval population/Plot (±SME) |
|-----------|------------------------------------------|
|           | Day 1 BIA              | Day 2 BIA              | Day 3 BIA              |
| Argane    | 1.33 cd                | 4.00b                 | 9.67b                 |
| BH-540    | 5.00b                  | 9.33a                 | 9.33b                 |
| Jibat     | 0.67d                  | 2.33bc                | 5.67bc                |
| Kulani    | 1.00 cd                | 2.00bc                | 5.00c                 |
| Limmu     | 2.33c                  | 1.67c                 | 4.33c                 |
| Shone     | 6.67d                  | 11.33a                | 14.33a                |
| Wenchii   | 5.00b                  | 4.00b                 | 5.00c                 |
| LSD (0.05)* | 1.49                | 3.63                  | 4.11                  |
| CV        | 26.59                  | 25.69                 | 30.33                 |

Mean in which the same letters are not significantly different from one another. BIA = Before Insecticide application

3.2. Irrigated plot result

3.2.1. Recognize the prevalence of *S. frugiperda* and maize whorl damage under irrigated plot experiment

Highest mean larval population of FAWs was recorded on four weeks age of Shone cultivar (6.67) followed by BH-540 (5.00) and Wanchi (5.00) cultivar in one day pre-application of insecticide respectively. Lowest population of maize FAW larvae was registered in Jibat (0.67), Kulani (1.00) and Argane (1.33) cultivar during same sampling date.

Besides, the highest larval occurrence of maize fall army worms was reached on Shone cultivar (14.33) and least was registered in Limmu (4.33) cultivar during the third day of pre-insecticide applications (Table 3). The population of maize FAWs larvae on treatment cultivars was amazingly increased with time when any control option was not taking in an account.

During the study period, different egg mass of *S. frugiperda* and larval stage, mainly the 1st instar was highly observed within the plant aged two weeks. All maize cultivars at the knee stage was highly invaded and vulnerable to larvae of FAWs and dissimilar size of egg mass was observed across the whole plot experiment.

There was a significant variation of maize plant damages were observed under all maize cultivars (Table 4). Highest infestation of maize plant by larvae of maize fall army worm were recorded on Shone cultivars (6.00%) before day one pre-application of insecticide. Lowest infestation was accounted in Jibat and kulani (3.33%) maize cultivars on the same day.

During day three before insecticide application, shone cultivars was highly (11.67%) affected than the other cultivars. The lowest damages with less infestation were recorded in Argane (9.33%) cultivar during third day before insecticide application. The level of damaged treatment cultivars was increased before any control measures were reserved. Initial sign of infestation with first instar (L1-L3) of *S. frugiperda* were observed on to shone cultivars and major damages was recorded during thirteenth days before chemical control was conducted at plot experiment. Jibat and Kulani cultivars were less susceptible maize cultivars during one month after EIL was conducted.

3.2.1. Efficacy testing of selected insecticide under plot Experiment. The plot experiments sprayed with Alpha-Cypermethrin, Deltamethrin and Lambda-cyhalothrin significantly reduce the existence of maize fall army worm larvae after three day with compared to control treatment
Table 4. Mean percent of damaged maize cultivars (leaf, and whorls) against S. frugiperda under plot experiment, pre-insecticide applications

| Treatment | Mean no. of damaged maize plant/Plot | Mean % of damaged maize plant/Plot |
|-----------|-------------------------------------|----------------------------------|
|           | Day 1 BIA                          | Day 2 BIA                         | Day 3 BIA |
| Argane    | 4.33^ab                            | 8.00^bc                          | 9.33^b    | 7.22 |
| BH-540 (control) | 3.33^b | 9.33^ab                           | 15.33^ab  | 9.33 |
| Jibat     | 3.00^b                             | 9.00^bc                          | 14.00^bc  | 8.67 |
| Kulani    | 3.00^b                             | 9.67^bc                          | 10.33^b   | 7.67 |
| Limmu     | 4.33^ab                            | 10.67^bc                         | 14.67^bc  | 9.89 |
| Shone     | 6.00^a                             | 11.67^a                          | 18.67^a   | 12.11 |
| Wenchis   | 3.67^b                             | 5.67^c                           | 10.33^b   | 6.56 |
| LSD (0.05) * | 2.01 | 3.49                              | 6.28      | |
| CV        | 24.69                              | 19.95                            | 26.67     | |

Mean in which the same letters are not significantly different from one another. BIA = Before Insecticide application.

(Table 5). Significantly highest number of FAW larval population was recorded on non-insecticide treated plot (11.67) day three after insecticide application and cause extreme damages compared to insecticide treated maize cultivar during both sampling date. There was a significant difference were observed among treatments. The Pyrethroid class of insecticide; Deltamethrin (4.00) and Alpha Cypermethrin (3.33) was accounts significant suppression of FAW larvae and typically minimize maize plant damages after 3 days treatment application. However, Lambda-cyhalothrin (1.33), Diametot and Diazinon (1.67) was slightly weak to minimize larvae of maize fall army worms during the study season.

Alpha-Cypermethrin (9.00), Deltamethrin (6.67) and Diazinon (2.33) significantly control maize fall army worm larvae at whorl stages after 4-day treatment application and Diametot and Malathion provided a significantly suppress maize plant damaged but were a little week to suppress larvae of S. frugiperda. Not in general but tested pyrethroid insecticides were effective for the management of maize fall army worm when the crops were cultivated with irrigations system in the study area.

Table 5. Mean infestation reduction/Plot of maize plant against larvae of S. frugiperda after spraying of insecticide under irrigated plot experiment

| Treatment | Rate a.i (mL/m²) | Mean% Infestation reduction/Plot | Average infested maize plant /Plot |
|-----------|-----------------|----------------------------------|-------------------------------------|
|           |                 | Day 3 AIA                        | Day 4 AIA                          |                                  |
| Argane* Dimethoate | 2.43 ml       | 1.67^a                          | 1.33^c                             | 1.5                               |
| Jibat*Malathion    | 2.7 ml         | 2.00 cd                          | 1.00^c                             | 1.5                               |
| Kulani*Diazinon    | 3.24 ml        | 1.67^c                          | 2.33^a                             | 2                                 |
| Limmu * Deltamethrin | 40.5 ml   | 4.00^a                          | 6.67^ab                            | 5.2                               |
| Shone* Alpha Cypermethrin | 1.08 ml | 3.33^bc                        | 9.00^b                             | 6.2                               |
| Wenchis* Lambda-cyhalothrin | 0.81 ml | 1.33^d                        | 1.67^c                             | 1.5                               |
| BH-540* Check      | -              | 11.67^bc                        | 14.00^a                            | 12.81                             |
| LSD (0.05) *       |                 | 1.7                             | 2.65                               |                                    |
| CV                 |                 | 24.66                           | 28.99                              |                                    |

Numbers within columns followed by the same letter are not statistically different (LSD; P = 0.05). AIA = After Insecticide Application
3.2.1.2. Effect of selected insecticides under irrigation system. The effect of selected insecticides on larvae of maize fall army worm was investigated using correlation and regression method. Each of insecticide had significantly cause mortality on larvae of maize fall army worms during irrigation season (Figure 1). There was a highest significant positive correlation between FAW infestations were observed before insecticide application and the pyrethroid class of insecticide Alpha Cypermethrin significantly ($r^2 = 0.44465$; $p = 0.025$) decrease FAWs infestation; Figure 1d).

While the rest of the five cultivars showed negatively correlated with FAW infestation after insecticide applications. Argane and Jibt cultivar were the least susceptible to fall army worm larvae, after the plot was treated with Diametot and Malathion the average fall army worm infestation ($r^2 = 0.1402$; $p = 0.005$ and $r^2 = 0.4465$; $p = 0.024$) was decreased respectively (Figure 1b.c).

Among the cultivars were assessed; Wenchi, Limmu and Kulani were more susceptible to S. frugiperda larvae before treatment application while the plot experiment sprayed with Lambda-cyhalothrin, Deltamethrin and Diazinon were non-significantly decreased ($R^2 = 0.2141$; $P = 0.0035$, $R^2 = 0.2935$; $P = 0.005$ and $R^2 = 0.0318$; $P = 0.0024$) fall army worm infestations (Figure 1d.e.f).

3.2.1.3. Efficacy of selected insecticides under irrigation system. Mean larval mortality of S. frugiperda with different insecticides was significant different at day 3 after treatment
application (LSD = 1.50; CV = 37; P = 0.05; Table 6). The highest number of larval mortalities was recorded on the treatment plot treated with Alpha Cypermethrin (40%) at day one after insecticide application. The lowest mortality of FAW larvae were accounted from the treatment treated with control *BH-540 (1%) at 3 days after insecticide applications.

The Organophosphates class; Diazinon and Malathion was less effective and may make drying of the cultivars during study Period. But, there was no egg, larvae and Adult of S. frugiperda was looked on treated cultivars after a week of insecticide application and the maize leaves were slowly recovered.

### 3.3. Farmers field survey result

#### 3.3.0.4. Occurrence. The prevalence of maize FAWs was assessed in major maize growing locations (Bako Tibe, Sibu Sire and Bilo Boshe districts) of western Ethiopia. Among the province, the highest percent of FAWs were recorded in Tulu Sangota (b) (33%) and there are no significance differences was detected across all farmers maize field experiments during July.30.2020 sampling date (Table 7).

While the lowest percent of S. frugiperda was accounted from Bilo Boshe (21%), Tulu Sangota (a) (23%), Gara Gona (24%) and Jalale (25%) before insecticide treatment respectively. Mean number of male FAW moth captured with Delta-type trap, Pherocon 1C at Tulu Sangota (b) (36%) was decreased and there was no significant variation was noticed among districts of Bilo Boshe (20%) and Tulu Sangota (a) (24%) at the end of sampling date respectively.

However, there was a significant difference was detected in all districts of the location. This management option can limit the reproduction system of the insects during regular cropping seasons in the location.

#### 3.3.0.5. Estimation of S. frugiperda infestation level in maize growing study area. The result on the infestation level showed that, all maize field location was infested by S. frugiperda in the study areas, but diverse level of the infestation was observed across district locations (Figure 2). The highest infestation of maize plant caused by fall army worm was recorded from Tulu Sangota (b) (39.63%) and the lowest were accounted in the location of Bilo Boshe 20.75 % during maize crop planted in 2020 cropping period.

#### 3.3.0.6. Efficacy of selected insecticide against maize FAWs at large scale of farmers field. Treatment application was made 10 days after the first day of fall army worm moth captured per 1 hektar of maize plant at 4th week of crop emergence in location. Mean infestation redaction
Table 7. Mean number of S. frugiperda captured (pest density) and infestation level before the application of selected insecticide in the farmers maize field

| Location (treatment) | Mean number of FAW adult captured (± SEM) |
|----------------------|------------------------------------------|
|                      | July. 30. 2020 *D1st 28d | August. 4. 2020 *D1st 32d | August. 8. 2020 *D1st 36d |
| Tulu Sangota (b)     | 33.00b                      | 38.33a                      | 36.00a                      |
| Gara Gona            | 24.67b                      | 26.00b                      | 30.67ab                     |
| Jalale               | 25.00b                      | 24.33b                      | 25.33bc                     |
| Tulu Sangota (a)     | 23.67b                      | 29.00ab                     | 24.33c                      |
| Bilo Boshe           | 21.33b                      | 21.00b                      | 20.00b                      |
| LSD (0.05) *         | 4.99                       | 12.10                       | 6.50                        |
| CV                   | 10.39                       | 23.19                       | 12.67                       |

Mean with a same letter were sharing significantly different at (P < 0.05) using Tukey's test. *D1st 30d = during the 1st 28 days.

data recorded after day one treatment application revealed that there are no significant effects were observed among each treatment locations (Table 8).

Dimethoate 40% and Alpha-Cypermethrin (5%), Deltamethrin (3.67%) and Lambda-cyhalothrin (7%) were significantly reduce the infestation of maize leaf and whorl caused by FAWs compared to that of non-treated control group/plot (27%) at day one after insecticide application respectively. Deltamethrin also significantly reduce maize plant infestation below that in the Lambda-cyhalothrin treated location (18%).

No significant treatment effect was also detected compared to the non-treated control at 4th day after insecticide application (ATA). However, the new pyrethroid insecticide; alpha cypermethrin, were not tested in Ethiopia and but significantly reduce FAW infestation by more than 9% below that in non-treated control at farmers maize fields in South Western Oromia-Ethiopia.

Infestation stage of farmers maize fields due to maize fall army worm after treated with insecticide were effectively decreased at 4 days after treatment application and all selected chemicals showed lower plant damage by larvae of maize fall army worm when compared with untreated control (Table 8). Similarly, the average number of leaf and whorl injury was varied from 5.1 to 28.1 percent / location with percent reduction of 50 to 65.1%.

Figure 2. Infestation and severity of maize fall army worm, S. frugiperda in various locations of south western Ethiopia.
Table 8. Mean % reduction of maize leaf and whorl damage by S. frugiperda in the farmers maize plot exposed to insecticides

| TRT                        | Dose (L/ha) | Mean % reduction of maize leaf and whorl damage (mean ± SE) |
|---------------------------|-------------|-------------------------------------------------------------|
|                           |             | Day 1 1ATA* | Day 2 1ATA* | Day 3 1ATA* |
| Bila Boshe—Lambda-cyhalothrin | 320 ml      | 18 ± 7.33\(^{ab}\) | 15.67 ± 7.00\(^{b}\) | 7 ± 4.67\(^{b}\) |
| Tulu Sangota (a)- Dimethoate | 1.5 L       | 8 ± 5.00\(^{b}\) | 4.67 ± 4.00\(^{c}\) | 3 ± 2.67\(^{b}\) |
| Tulu Sangota (b)- Deltamethrin | 20–25 ml   | 5 ± 3.67\(^{ab}\) | 6.33 ± 4.67\(^{bc}\) | 6.33 ± 4.33\(^{b}\) |
| Gara Gona -Alpha-Cypermethrin | 25 ml       | 8 ± 5.00\(^{b}\) | 6 ± 4.00\(^{c}\) | 9.33 ± 5.67\(^{b}\) |
| Jalale—Control (no chemical trt) | -           | 231 ± 27.00\(^{ab}\) | 217.33 ± 26.33\(^{ab}\) | 258 ± 28.33\(^{ab}\) |

Mean

LSD (0.05) *  54  50  56.7

CV  21.52  16.72  25.21

Means within columns followed by a common letter are not significantly different (P ≤ 0.05 Tukey’s Studentized Range Test). 1ATA* (after treatment application)

4. Discussion

Nowadays, S. frugiperda was one of the most exciting factors that depressing maize production and commonly known to acquire economic threats, yield losses and attain high costs for its management (Kwamina et al., 2019). Globally, the insect was highly accountable for the threat to stable food security and timely management of the insect was a crucial aspect.

The present study was conducted during 2019/2020 in two different growing seasons (the summer and typical cropping seasons). Significant maize fall army worm infestations were observed in all the study locations. All tested insecticides cause acute toxicity, and accountable to cause larval mortality of S. frugiperda under laboratory, controlled plot experiment. The laboratory bioassay showed that, Deltamethrin cause the highest 96.67% larval mortality after 24hrs treatment application (Table 2).

Efficiency of some recently developed insecticide against larvae of fall army worm was investigated at laboratory condition. The effect showed that, 90% of larval mortality was recorded from the treatment sprayed to lambda-cyhalothrin after 72 hrs of exposure (Sisay et al., 2019). The present study confirms that, among tested insecticide; Lambda-cyhalothrin accounts 96.67% larval mortality after 48 hrs treatment application.

Malathion register less mean mortality (10.00) when compared to other tested insecticide in the plot experiment. Alpha-Cypermethrin were accounts 40% mortality of S. frugiperda after day one treatment application in the plot experiments during summer season of 2019.

Field efficacy of lambda-cyhalothrin was also assessed in the plot irrigation. The result reveals that, the larval density of S. frugiperda were significantly lower (40%) among the treatment. This finding was confirmed, the lambda-cyhalothrin treated (45.0%) plot after day 3 treatment applications were significantly reduced fall army worm infestation (Jarrod et al., 2011).

In this finding more focused on efficiency, application practice, degree of damaged maize plant and management of maize fall army worm infestation at different growth stages were assessed during 2020 usual cropping seasons in the location. One day before insecticide applications, mean number of maize infestations caused by maize fall army worm among treatment location were ranged from 21.00 to 38.33% during July 30, 2020.
After the first day of treatment applications the mean percent plant infestation reduction ranged from 3.67 to 27.00. The present finding was confirmed with the result of (Kumari et al., 2020; Mintesnot & Ebabuye, 2020) who found that spraying of insecticide reduce the larval population of FAWs at vegetative growth stage. Age based, and/or dependent of maize fall army worm infestation were reported by (Murua et al., 2009).

The level of infestation and damage on different developmental stage of the plant was also evaluated using rating scale (Hartnik et al., 2008; Makirita et al., 2019). Other study confirms 3 fall army worm moth captured per trap produce 10% infestation and economic threshold levels were measured in maize fields (Cruz et al., 2010). In this research work, highest mean number (33.00) of fall army worm moth recorded from Tulu Sangota (b) and 21.33 were accounted from Bilo Boshe district location during 1st 28 days after plant emergence (Table 7).

Likewise, percent of maize fall army worm infestation level and damaged maize plants in the surveying district were varied from 20.75 to 39.63% during 2020 regular cropping season in the area (Figure 2). Most probably, such variation of infestation between locations were due to agroecological differences of the locations. Maize fall army worm damages were reported at all stages of maize developments in the field (Goergen et al., 2016; Prasanna et al., 2018), but the insect was clearly serious at early whorl stage of the maize plant (Sonali & Nandita, 2018).

Various researchers were also reported that, 20 to 50% infestation were recorded at early whorl stage, particularly when the plant ages of 20 to 45 days after the crop emergence (Dal Pogetto et al., 2012; Matti & Patil, 2019). During these developmental stages, the insect was extremely destroyed the meristematic tissues of the maize plants, which consequences breaking the growth pathway of the plant and/or finally causing dead heart of the plant (Roger et al., 2017). Finally, significant level of infestation and damages of *S. frugiperda* were undoubtedly reducing the yield of maize crop (Ayala et al., 2013).

In this study considerable infestation of maize farm caused by *S. frugiperda* were documented in both agroecological locations at the vegetative stage (during the first 28 days); But there were no existed documents were adopted on maize FAW infestations in the surveyed district locations. Since, several studies suggested that, action threshold of fall army worm was primarily necessitating the control action were taken using selective insecticide in the maize fields based on economic effect (Canico et al., 2020; Jander et al., 2013; Santos et al., 2003).

Hence, in this work first spray of selected insecticide against *S. frugiperda* was made after 40 days plant emergence or/and early whorl stages. The Pyrethroid class of the insecticide; Lambda-cyhalothrin reducing *S. frugiperda* infestation quickly from 21.33 to 7.33% only at one spray time during 2020 cropping season. Such insecticides were efficient to managing maize fall army worm in the farmers maize field with minimum financial threat.

Among the pyrethroid class of synthetic insecticides used in the experiment; lambda-cyhalothrin were more convenient to harmonized for the development of IPM strategies and this result were agreed with the result obtained by (Igyuve et al., 2018); who reported that lambda-cyhalothrin was effective to manage *S. frugiperda* and reduce maize FAW infestation at large scale of farmers maize fields at early whorl stage.

This finding strongly introducing, only one-time application of insecticide was enough to manage at appropriate time and reduce *S. frugiperda* infestation of maize crop in the field. Thus, weekly basis of scouting provides accurate population density of the pest and number of insecticide application.

Due to substantial feeding of the insects, farmers in the study area were use un registered insecticides for six years. This study gives clue on the efficiency of currently developed synthetic insecticide and at the same time undertake the appropriate stage of *S. frugiperda* damage and application time during maize
production seasons in the area. Each insecticide reducing the population density of maize fall army worm in all district location and clearly mitigate damage caused by *S. frugiperda* at all experimental locations but, only Alpha-Cypermethrin was slightly reduce maize damage in the farmers field.

Our study adapted that, all tested insecticide was effective to manage maize fall army worm at early stages in the farmers maize field condition. Ones after efficient insecticides were identified, further research were needed to develop applicable, harmonized and dynamic approaches of maize fall army worm management in the field conditions. All tested maize cultivars were significantly susceptible to *S. frugiperda* at typical cropping season and summer season using irrigation system. So, research work was needed to test oviposition preference of *S. frugiperda* host cultivars at each study locations.

5. Conclusion
All tested insecticides were effective to manage maize fall armyworms based on their life cycle of the insect and growth stages of the maize plants without repeated application efforts, which may minimize the development of pesticide resistance. These chemicals were important when used in an integrated pest management program. Further research was needed to testing *S. frugiperda* develop resistance to each of the selected insecticide for five years.

Effectiveness of the selected insecticide during the study periods showing an interesting result for the management of FAWs, in the farmers maize field. Before insecticide spraying decision, farmers visit their maize plants frequently two wise a week. Investors also consider number of fall armyworm moth captured per trap, economic cost, the right product, biodiversity implications and damage levels were reaches to economic thresholds beyond 15%.

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Significance statement
The study has focused on the role of monitoring and thresholds level, rather than the use of insecticide application as a preventative measure of *S. frugiperda* and highlighted harmless and soft insecticide class against fall army worm in the country of large-scale maize plant. Therefore, the result helped to uncover the critical area of the need to pay attention on screening of newly recommended insecticides against *S. frugiperda* under controlled conditions and possible to exploit each insecticide at farmers field condition that some of the academician researcher not take consideration in the large scale of maize farm.

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