American Journal of Entomology
2023; 7(3): 109-119
http://www.sciencepublishinggroup.com/j/aje
doi: 10.11648/j.aje.20230703.15
ISSN: 2640-0529 (Print); ISSN: 2640-0537 (Online)

Integrated Management of Fall Armyworm (*Spodoptera Frugiperda*) (J. E. Smith) (Lepidoptera: Noctuidae) in Maize

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To cite this article:
Seid Ahmed. Integrated Management of Fall Armyworm (*Spodoptera Frugiperda*) (J. E. Smith) (Lepidoptera: Noctuidae) in Maize. *American Journal of Entomology*. Vol. 7, No. 3, 2023, pp. 109-119. doi: 10.11648/j.aje.20230703.15

Received: June 12, 2023; **Accepted**: September 6, 2023; **Published**: September 27, 2023

Abstract: Fall armyworm (FAW), Spodoptera frugiperda (Lepidoptera: Noctuidae), is a key pest of maize worldwide. Its damages on yield vary between 30 and 70% in the America, 11 to 100% in Africa and 32% in Ethiopia; the yield losses have been identified. In this study, we evaluated two types of bioassay and synthetic chemicals efficacy against fall armyworm during high infestation year under laboratory and field. Those five types of plant extracts, four types of synthetic chemicals, and two types of EPF were evaluated against fall armyworm. Among botanicals lantana camara, Azadirachta indica, Jatropha carcus, Candle bush, and Grewinia tenax were showed that the percent of larval mortalities were, 65%, 71%, 76%, 81% and 85% respectively after 72hrs. While the evaluated insecticides of Dursban 48%, Best 5EC, Karate 5 EC, and Bravo 5EC (80%, 83%, 90% and 93.3%) caused larval mortality of FAW after 72hrs. The efficacy evaluations of Matarhizium anisopliae and Beauveria bassiana were showed that the mortality of larvae caused 70% & 81% respectively after 72hrs. Three treatments that showed potent effect on mortality of FAW in vitro (Bravo 5EC, Beauveria bassiana and Grewinia tenax) were evaluated in the field condition in IPM strategy integrating with host resistance. The results of the IPM study showed that the combinations of CZH132150 x Bravo 5EC, CZH1270 x Beauveria bassiana, CZH1270 x Grewinia tenax, CZH132150 x Grewina tenax, CZH1261 x Bravo 5EC, and CZH1270 x Bravo 5EC treatments when evaluated on the field were highly and significantly reduced yield losses recorded, 20%, 21%, 24%, 25%, 31% and 32% respectively.

Keywords: Botanicals, Entomopathogen, Fall Armyworm, Insecticides, IPM

1. Introduction

Fall armyworm (FAW), Spodoptera frugiperda (Lepidoptera: Noctuidae), is an insect native to tropical and subtropical regions of the Americas and was found in Africa for the first time in 2016. This insect pest was first reported in Ethiopia by 1st March 2017 [14]. Since its first introduction to Ethiopia in 2017, FAW has spread to all maize growing areas across the country and cause severe damage of up to 100% on smallholder farmers maize field [13, 14]. It is the most invasive and major economical important, newly introduced insect pests. Fall armyworm is a non-selective (a polyphagous) pest, it can feed on more than 80 plant species, including maize, rice, sorghum, millet, sugarcane, vegetable crops and cotton but it prefers maize more than other crops [27]. It has two morphologically identical but genetically different strains of FAW. Those are, the rice strain is associated with rice and Bermuda grass, while the corn strain predominates on corn, sorghum, and cotton [15, 1, 8].

Given the appropriateness indices and favorable climatic conditions, the situation of the FAW damage could be extremely serious in Ethiopia [11]. The damage results are in both quantitative and qualitative losses [21, 10]. FAW has the potential to causes of quantitative losses are estimated 8.3 to 20.6 million tons of maize per annum [1, 10]. During FAW infestation of the maize fields without controlling/management measures, it contributed to grain yield reduction was 32% and 47% in Ethiopia and Kenya respectively [20].

Management of fall armyworms used through only one approach is unimaginable, different methods should be used. Botanicals, chemicals, and entomopathogenic fungi were, the way to control fall armyworm infestation [5]. Integrated Pest Management (IPM), a cornerstone of sustainable agriculture, seeks to improve farmer practices to support higher income [4].

These practices should be used environment friendly, sustainable agricultural production, minimize insecticide resistance, economically feasible and minimize risks on human beings and animals [4]. Thus, the present study aimed to evaluate the effect of integrated pest management of FAW in maize under field conditions.

2. Materials and Methods

2.1. Laboratory Experiment

All laboratory and field experiments in this study were evaluated at Assosa University. Assosa University is situated in the Benishangul Gumuz Regional State of Ethiopia in Assosa town, approximately far 662 km west of the capital city of Addis Ababa.

2.2. In Vitro Evaluation of Insecticides Against Faw

Four selected insecticides namely Best 5 EC, Bravo 5EC, Dursban 48%, and Karate 5 EC (Table 1) were tested against fall armyworms following the method employed in [26]. Fresh leaves of a highly susceptible BH546 maize variety were collected and placed in a beaker after cutting the middle parts of leaves at 10cm height and 60gm weighed. Then five 3rd instar larvae were collected and inserted into the beaker on prepared leaves as feed and calculate feeding damage level in percent. After evaluation larval feeding of leaves for 48hrs, then applied 20ml insecticides on the released larvae in the beaker. Experiments were laid completely randomized design (CRD) with three replications. Then finally the insect mortality in percent was assessed after applications of 24, 48, and 72 hrs.

Table 1. *List of evaluated insecticides and application rate.*

Trade name	Active Ingredient	Formula-n	Manufacture	Rate of application/ha	
				Insecticide	Water
Karate 5 EC	lambda-cyhalothrin	EC	Syngenta	320 ml	500 L
Bravo 5EC	lambda-cyhalothrin2.5%	EC	India limited	400 ml	250 L
Best 5 EC	Lambda- cyhalothrin	EC	Bharat lim india	450 ml	300-850 L
Dursban 48%	Chlorpyrifos	EC	Shangai bosman	1.25l	300 L

2.3. In Vitro Evaluation of Botanicals Against Faw

2.3.1. Collection and Preparation of Bioassay

Effect of five selected botanicals namely Grewnia tenax, Candle bush, Lantana camara, Azadirachta indica, and Jatropha carcus were tested against fall armyworm in Plant protection laboratory based on their previous insecticidal report (Table 2). Botanicals were collected from different locations in the Benishangul Gumuz Region (Assosa town, Amba 18 village, and Gumu village. Collected plants were dried under shaded, chopped, and ground with mortal and pistle to fine fermentable powder. The powder of each botanical/plant extracts were well-fermented botanical extracts for 24 hrs.

Table 2. *List of botanical plants and recommended dose.*

Botanicals	Common name	Parts	Dose (gm)	References
Azadirachta indica	Neem	Seed	5	Feyissa, Tebkew (2015) [29]
Lantana camara	Lantana	Seed	40	Raghavendra (2016) [30]
Sena alata L.	Candle bush	Leaf	10	Kokwaro, j. o.(1993) [18]
Grewinia tenax	Drone fly	Leaf	8	Kokwaro, j. o. (1993) [18]
Jatropha curcas	Physic nut	Seed	11.5	Kokwaro, j. o. (1993) [18]

2.3.2. Preparation of Bioassay

Figure 1. *Fermented plant extracts (A) Grewinia tenax (B) Candle bush (C) Lantana camara (D) Jatropha carcus (E) Azadirachta indica.*

Fresh leaves of a highly susceptible BH546 maize variety were collected and placed in a beaker after cutting the middle parts of leaves at 10cm height and 60gm weighed. Then five 3rd instar larvae were collected and inserted into the beaker on prepared leaves as feed, then after feeding leaves to apply 20 ml of fermented plant extracts into the beaker on larvae, following the method of [26]. The experimental design was a completely randomized design (CRD) with three replications. Monitor and count the number of insect mortality was assessed at 24, 48, and 72 hrs (Figure 1).

2.4. Evaluation of Entomopathogenic Fungi (EPF)

The experiment was conducted to evaluate the efficacy of *Metarhizium anisopliae* and *Beauveria bassiana* against fall armyworms. EPF were obtained from Ambo Agricultural Research Center and determined their antagonistic activity (Table 3).

Table 3. *List and description of entomopathogenic fungi in the study.*

Type of fungal spp	Isolates	Obtained from	Host	Year
Beuveria bassiana	APPR-1	AARC	soil	2021
Matarhizium Anisopliae	APPR-2	AARC	soil	2021

APPR-1 (Ambo plant protection research isolate -1), APPR-2 (Ambo plant protection research isolate -2, AARC (Ambo agricultural research center)

2.4.1. Spore Preparation

Inoculums of each of the Entomopathogenic fungi were prepared separately by sub-culturing on potato dextrose agar (PDA). The pathogen spores grew for one week in Incubator at 25ºC and were harvested spores from the stock, mixed with distilled water in the required amount. Then adjusted the required amount of spore suspensions, by using a hemocytometer on a standard concentration of 10^8 conidial/ml and applied 20ml fungal suspension on five 3rd instars of larvae.

2.4.2. Pathogenicity Test Against Faw

Evaluate the effects of EPF namely *Beuveria bassiana* and *Matarhizium Anisopliae* were tested against fall armyworm. Applied adjusted fungal suspensions at 10^8 spore/ml and apply 20ml suspensions for 5, 3rd instar of larvae per beaker. The experimental design was laid out in a completely randomized design (CRD) with three replications. Mortal indications were, identified in the larvae inverted to dorsal.

2.5. Integrated Management in Field

2.5.1. Experimental Materials

Three NVT maize cultivars combined with synthetic insecticides (Bravo 5EC), Botanical (*Grewinia tenax*) and EPF (Entomopathogenic fungi) *Beauveria bassiana* selected from best-performed insecticides from evaluations of in vitro-studies and used as components of IPM. Description of Maize cultivars were stated below in (Table 4).

Table 4. *List of evaluated maize cultivars on IPM in Assosa at 2022.*

Cultivars	Obtained from	Research center	Status
CZH132150	CIMMYT (Zimbabwe)	Hawassa NMRC	NVT
CZH1270	CIMMYT (Zimbabwe)	Hawassa NMRC	NVT
CZH1261	CIMMYT (Zimbabwe)	Hawassa NMRC	NVT

2.5.2. Treatment Preparation and Application Method

Beauveria bassiana: The fungus was grown in potato dextrose agar (PDA) in the laboratory for one week and harvested fungal spores were at a standard suspension concentration of 10^8 conidia/ml. Then applied the adjusted suspension concentration to inoculate the maize funnel and side leaves on the third larval stage.

Application of Bravo5 EC (lambda-cyhalothrin 2.5%) chemical as standard check used at the recommended rate of 400ml /ha of chemical and 250 liters of water/ha. Application intervals after 15 days were first application start at early whorl crop stage or 2 months after sowing, up to crop tasselling stage.

Applications of Botanicals (*Grewinia tenax*) collected plant parts dried under a shaded area and grind by using a pestle and mortar to a fine powder and fermented for 24hrs. The fermented botanical powders are distilled by sheath cloth and applied on maize funnels and side leaves to protect the landing of moths on maize crops and kill the larva of fall armyworm.

2.5.3. Treatments Combination for IPM

Experiments were laid out in RCBD in a factorial arrangement with three replications. Each three maize cultivars were evaluated with four treatments (*Grewinia tenax*) under botanical extract, (*Beauveria bassiana*) from Entomophagus fungi, Bravo 5EC as a standard check, and with sole/Untreated check cultivar, the total treatment combinations were 12.

Table 5. *Treatment combinations.*

T1- CZH1261x*Grewinia. t*	T5-CZH132150 x *Grewinia. t*	T9-CZH1270 x *Grewinia. t*
T2- CZH1261 x untreated	T6-CZH132150 x untreated	T10-CZH1270 x untreated
T3- CZH1261 x Bravo 5EC	T7-CZH132150 x Bravo 5EC	T11-CZH1270 x Bravo 5EC
T4-CZH1261 x *Beauveria. b*	T8-CZH132150 x *Beauveria. b*	T12-CZH1270 x *Beauveria. b*

2.5.4. Experimental Design

The design was a randomized complete block design (RCBD) factorial arrangement in three replications. Spacing between inter and intra spacing 75cm x 25cm, plot size 3m length and 3.75m width =11.25m^2, experimental area 56m length x 13.25m width =742m^2, and path b/n plots and replications were 0.5m. Experimental units contained 5 rows including border rows, 12 plants per row, and three harvestable net plot rows.

2.5.5. Data Collected on Yield and Yield Component

Grain moisture content (%): The percent moisture content of grain at harvest was measured after shelling using moisture meter.

GY =Fresh ear weight (kg/plot) x (100-MC) x shelling% x

10 (100-12.5) x area harvested.

$$\text{YLR\%}= \frac{(Untreated-IPM}{Untreated}) \times 100$$

Where YLR%=Yield loss reduced due to FAW damage and IPM=integrated pest management.

$$\text{Mo\%}= \left(1-\frac{\text{n in Treated after}}{\text{n in Control after}}\right) \times 100$$

Where, n in T = Population in treated, n in Co = Population in control and Mo =percent of larvae mortality.

2.5.6. Data Analysis

Laboratory data were analyzed using the SAS version 9.4 Computer software (PROC GLM procedure) followed by fishery least significant different (LSD) test (α = 0.05) for mean separation of statistical agricultural software (SAS, 210).

IPM experiments were analyzed a two-way analysis of variance (ANOVA) followed by honest significant different (HSD) test was performed using the relating to, the principles of statistics statistical analysis software (stat version 10). Multiple comparisons using rank sums were made to determine significant differences between means. Correlation of interaction effect of the treatment combinations were performed using the model of polynomial, linear, exponential and logarithm.

The model was (RCBD) factorial experiment $Yijk = Yijk = \mu + \beta j + \tau i + ij + \gamma k + (\gamma\tau) jk + \varepsilon ijk$. Where μ is the overall mean effect, Ti is the effect of the ith level of the row factor A, Bj is the effect of the jth level of column factor B, (TB) ij is the effects of the interaction between Ti and Bj, and εijk is a random error component.

3. Results

3.1. Evaluation of Synthetic Chemicals Against Faw

There were highly significant differences between chemicals in terms of mortality of larvae in percent at P value (<0.001). Among treatments, the highest larval mortalities were verified. The mean difference of larval mortality showed that the treatment Bravo 5EC: 3% from karate 5EC: 7% larval mortality mean difference from Best 5EC: 3% larval mortality difference from Dursban 48% after 72hrs stated in (Table 6).

Table 6. *Mean percentage (±SEM) of FAW mortality response of chemicals.*

Synthetic chemicals	Percent mortality of the larva after		
	24hr	**48hr**	**72hr**
Bravo5 EC	48.3±1.6^{a}	75.0±2.8^{a}	93.3±3.3^{a}
Best 5 EC	51.6±6.0^{a}	61.6±6.0^{b}	83.3±1.6^{bc}
Karate 5 EC	51.6±1.6^{a}	68.3±1.6^{ba}	90.0±2.8^{ba}
Dursban 48%	50.00±2.8^{a}	66.6±4.4^{ba}	80.0±2.8^{c}
Untreated Control	3.6±1.3^{b}	8.3±1.6^{c}	16.6±1.6^{d}
Mean	41.0	56	72.66
LSD *(α = 0.05)*	10.1	11.7	8.1
CV%	13.5	11.5	6.1

Means within a column followed by different letters are significantly different and the same letters are not significant different at P <0.05 (LSD test).

3.2. Mortality Evaluation of Entomopathogenic Fungi

The highest larval mortality was observed from *Beauveria bassiana*/APPRC-1 showed that the mean larval mortality difference b/n treatments were, 11.6% from *Matarhizium anisopliae*/APPRC-2, and larval mortality after inoculation of 72hrs described in (Table 7). There was a significantly difference at (P<.0001).

Table 7. *Mean percentage (±SEM) mortality response of EPF.*

Entomopathogenic fungi	Percent mortality of the larva after		
	24hr	**48hr**	**72hr**
Beauveria bassiana /APPR-1	26.6±1.6^{a}	43.3±3.3^{a}	81.6±1.6^{a}
Matarhizium anisopliae/APPR-2	18.3±1.6^{b}	38.3±1.6^{a}	70.0±2.8^{b}
Untreated/check	2.00±1.5^{c}	5.00±2.8^{b}	8.3±4.4^{c}
Mean	15.66	28.88	53.33
LSD *(α = 0.05)*	5.6	9.4	11.0
CV%	17.9	16.3	10.3

Different letters within a column significant and the same letters were not significantly different at P < 0.05 according to LSD test

3.3. Efficacy Evaluations of Botanicals Against FAW Under Laboratory

There was a significant difference at (P<0.001) between botanicals to causing larval mortality. The highest mean difference larval mortality was caused by extracts of *Grewinia tenax*, 4% from *Candle bush*, 5% from *Jatropha carcus*, 5% from Neem, 6% from *Lantana camara* respectively showed that the mean larval mortality difference b/n botanical treatments after 72hrs described in (Table 8).

Table 8. *Mean percentage (±SEM) mortality of FAW.*

Botanical Extracts	Larval mortality in percent after		
	24hrs	**48hrs**	**72hrs**
Jatropha carcus	36.6±1.6^{b}	60.0±2.8^{bc}	76.6±1.6^{ba}
A. indica	31.6±1.6^{b}	53.3±4.4^{c}	71.6±3.3^{bc}
Lantana camara	33.3±4.4^{b}	53.3±3.3^{c}	65.0±2.8^{c}
Candle bush	46.6±3.3^{a}	65.0±5^{ba}	81.6±3.3^{ba}
Grewia Tenax	48.3±3.3^{a}	71.6±3.3^{a}	85.0±5.7^{a}
Untreated/check	3.6±1.3^{c}	10.0±2.8^{d}	15.0±2.8^{d}
Mean	33.38	52.22	65.83
P-value	<.0001	<.0001	<.0001
LSD *(α = 0.05).*	8.8	11.4	10.8
CV%	14.8	12.3	9.3

*Values in columns different letters are significantly (P < 0.05) different with each in LSD test.

3.4. Mean Interaction Effects of IPM on Yield Ton/Ha

Treatment x cultivars interaction showed that a highly significant difference at (P=0.0048) between combined treatments based on maize yields. The highest grain yield was obtained from the national variety trial CZH132150 x *Grewinia tenax* showed that 0.42 ton/ha mean yield difference from the treatment of NVT CZH132150 x Bravo 5EC, 0.86 ton/ha showed that the yield difference from NVT CZH132150 x *Beauveria bassiana* and 1.47 ton/ha showed yield difference from the treatment of CZH132150 x Untreated check. The following CZH1270 x Bravo5EC showed that the yield difference of 0.56ton/ha from the treatment of CZH1270 x *Beaveria bassiana*, 0.39 ton/ha from the treatment of CZH1270 x *Grewinia tenax*, and 1.39 ton/ha from the treatment of CZH1270 x untreated check respectively. Among NVT CZH1261, CZH1261 x Bravo 5EC showed that 1.25ton/ha from the treatment of CZH1261 x *Beaveria bassiana*, 0.33ton/ha from the treatment of CZH1261 x *Grewinia tenax* and 1.35ton/ha from the treatment of CZH1261 x untreated check stated in (Table 9).

Table 9. *Mean interaction effects of cultivars and treatments on yield.*

Treatments	Maize Cultivars			
	CZH132150	**CZH1270**	**CZH1261**	**Mean**
Bravo 5EC	5.25^{ab**}	4.25^{bcde*}	4.32^{abcd*}	4.60
Beauveria bassiana	4.81^{abc}	3.69^{cde}	3.07^{de}	3.85
Grewinia tenax	5.67^{a***}	3.84^{cde}	3.99^{bcde}	4.50
Control	4.20^{bcde}	2.89^{e}	2.97^{de}	3.35
Mean	4.98	3.91	3.58	4.16
HSD (0.05)				1.38
CV (%)				11.4

Means within a columns and rows followed by different letters are significantly different and the same letters are not significant different at P < 0.05 (HSD test).

3.5. Interaction Effects of IPM on Larval Mortality in Percent

Treatment x cultivars interaction showed a highly significant difference at (P=0.0048) between combined treatments based on larval mortality. The highest larval mortality was obtained from national variety trial CZH132150 x Bravo5EC showed that 11% mean percent larval mortality difference from the treatment of NVT CZH132150 x *Beauveria bassiana*, 4.66% larval mortality showed that the mortality difference from NVT CZH132150 x *Grewinia tenax* and 21% showed mortality difference from the treatment of CZH132150 x Untreated check. The following CZH1270 x Bravo5EC showed that the yield difference of 1.67% mortality from the treatment of CZH1270 x *Beaveria bassiana*, 2.33% larval mortality from the treatment of CZH1270 x *Grewinia tenax*, and 10% larval mortality from the treatment of CZH1270 x untreated check respectively. Among NVT CZH1261, CZH1261 x Bravo 5EC showed 3.66% larval mortality from the treatment of CZH1261 x *Beauveria bassiana*, 0.33% larval mortality from the treatment of CZH1261 x *Grewinia tenax* and 10.33%larval mortality from the treatment of CZH1261 x untreated check stated below in (Table 10).

Table 10. *Mean interaction effect on larval mortality in percent.*

Treatments	Maize cultivars			
	CZH132150	**CZH1270**	**CZH1261**	**Mean**
Bravo 5EC	25.33^{a***}	13.33^{c}	14.33^{bc}	17.67
Beauveria bassiana	14.33^{bc}	11.67^{c}	10.67^{cd}	12.23
Grewinia tenax	20.67^{ab**}	11.00^{c}	14.00^{c}	15.23
Control	4.33^{de}	3.33^{e}	4.00^{e}	3.88
Mean	16.1	9.8	10.75	12.25
HSD (0.05)				6.5
CV (%)				18

Means within a columns and rows followed by different letters are significantly and the same letters are not significant at P < 0.05 (HSD test).

3.6. Mean Interaction Effects of IPM on Cob Length (cm)

The highest cob length was obtained from the national variety trial CZH132150 x Grewinia tenax showed that, 2cm mean cob length difference from the treatment of NVT CZH132150 x Bravo 5EC, 3.67 cm cob length difference from NVT CZH132150 x *Beauveria asiana* and 5.67cm cob length difference showed from the treatment of CZH132150 x Untreated check. The following CZH1270 x Bravo5EC showed that the yield difference of 0.33cm cob length difference from the treatment of CZH1270 x *Beaveria bassiana*, 0.33cm cob length difference from the treatment of CZH1270 x *Grewinia tenax*, and 2cm length from the treatment of CZH1270 x untreated check respectively. Among NVT CZH1261, CZH1261 x *Grewinia tenax* showed that 2.33cm cob length from the treatment of CZH1261 x Bravo 5EC, 2.33cm cob length from the treatment of CZH1261 x *Beauveria bassiana* and 2.67cm cob length from the treatment of CZH1261 x untreated check stated below in (Table 11).

Table 11. *Mean interaction effect of treatments on cob length (cm).*

Treatments	Maize cultivars			
	CZH132150	**CZH1270**	**CZH1261**	**Mean**
Bravo 5EC	28.00^{ab}	25.00^{bcd}	22.67^{d}	25.22
Beauveria bassiana	26.33^{bc}	24.67^{bcd}	22.67^{d}	24.5
Grewinia tenax	30.00^{a*}	24.67^{bcd}	25.00^{bcd}	26.5
Control	24.33^{cd}	23.00^{cd}	22.33^{d}	23.2
Mean	27.1	24.3	23.1	24.8
HSD (0.05)				3.5
CV (%)				4.8

Means within a columns and rows followed by different letters are significantly different and the same letters are not significant different at P = 0.05 (HSD test).

3.7. Mean Interaction Effects of IPM on Cob Diameter (cm)

The highest cob length was obtained from the treatment of CZH132150 x Grewinia tenax showed that, 0.66cm mean cob diameter difference from the treatment of NVT CZH132150 x Bravo 5EC, 0.66 cm cob diameter difference from NVT CZH132150 x *Beauveria bassiana* and 0.66cm cob diameter difference showed from the treatment of CZH132150 x Untreated check. The following CZH1270 x *Grewinia tenax* showed that the yield difference of 2.67cm cob diameter difference from the treatment of CZH1270 x Bravo 5EC, 4.33cm cob diameter difference from the treatment of CZH1270 x *Beauveria bassiana* and 5cm cob diameter from the treatment of CZH1270 x untreated check. Among NVT CZH1261, CZH1261 x *Beauveria bassiana* showed that 2cm cob diameter from the treatment of CZH1261 x Bravo 5EC, 0.67cm cob diameter from the treatment of CZH1261 x *Grewinia tenax* and 3.67cm cob diameter from the treatment of CZH1261 x untreated check stated in (Table 12).

Table 12. *Mean interaction effect of IPM on cob diameter (cm).*

Treatments	Maize cultivars			
	CZH132150	**CZH1270**	**CZH1261**	**Mean**
Bravo 5EC	21.67^{cd}	26.33^{ab}	21.00^{cd}	23.0
Beauveria bassiana	21.67^{cd}	24.67^{bc}	23.00^{bcd*}	23.1
Grewinia tenax	22.33^{bcd*}	29.00^{a*}	22.33^{bcd}	24.5
Control	21.67^{cd}	24.00^{bc}	19.33^{d}	21.6
Mean	21.8	26.0	21.4	23.08
HSD (0.05)				4.2
CV (%)				6.21

Means within a columns and rows followed by different letters are significantly and the same letters are not significant at P < 0.05 (HSD test).

3.8. Interaction Effects of IPM on the Number of Ears Harvested Per Plot

Highly significant difference (p<0.001) between treatments was recorded on number of ear harvested. The highest number of ear was harvested from CZH132150 x Bravo 5EC (29.00), C and ZH132150 x *Grewinia tenax* (27.667) followed by CZH132150 x *Beauveria bassiana* (26.00). The number of harvested cob of the other treatment ranged from 22.67 to 24.33 (Table13).

Table 13. *Mean interaction effect of IPM on number of ears harvested.*

Treatments	Maize cultivars			
	CZH132150	CZH1270	CZH1261	Mean
Bravo 5EC	29.00^{a}**	24.00^{cd}	24.33^{cd}	25.7
Beauveria bassiana	26.00^{bc}	24.00^{cd}	24.33^{cd}	24.7
Grewinia tenax	27.67^{ab}*	24.00^{cd}	23.67^{d}	25.1
Control	24.33^{cd}	23.00^{d}	22.67^{d}	23.3
Mean	26.7	23.7	23.7	24.7
HSD (0.05)				2.0
CV (%)				2.84

Means within columns and rows followed by different letters are significantly different and the same letters are not significant difference at P < 0.05 (HSD test).

3.9. Interaction Effects of IPM on Number of Ear Damaged Per Plot

Highly significant difference at (P<0.01) between treatments was recorded on number of maize cob damage. Based on mean value evaluations, highest significant damage was recorded from CZH1270 x control (7.667) followed by CZH1261 x control (3.33) and CZH1270 x *Beauveria bassiana* (3.00). The lowest numbers of ear damaged were recorded from CZH132150 X *Grewinia tenax* (1.00), CZH1261 x *Grewinia tenax* (1.33), CZH1270 x *Grewinia tenax* (1.33), CZH132150 x Bravo 5EC (1.33) and CZH1261 x Bravo 5EC (1.33) on average described (Table 14).

Table 14. *Mean interaction effect of IPM on number of ear damaged.*

Treatments	Maize cultivars			
	CZH132150	CZH1270	CZH1261	Mean
Bravo 5EC	1.33^{de}	1.67^{cde}	1.33^{de}	1.4
Beauveria bassiana	1.67^{cde}	3.00^{bc}	2.67^{bcd}	2.4
Grewinia tenax	1.00^{e}	1.33^{de}	1.33^{de}	1.2
Control	2.67^{bcd}*	7.67^{a}***	3.33^{b}	4.5
Mean	1.66	3.4	2.16	2.4
HSD (0.05)				1.6
CV (%)				2.4

Means within columns and rows followed by different letters are significantly different and the same letters are not significant different at P < 0.05 (HSD test).

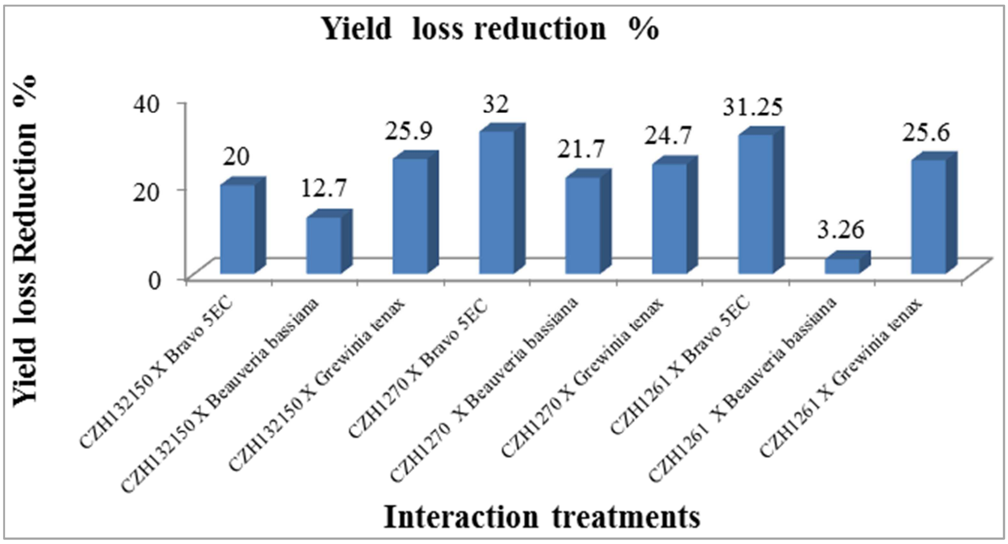


Figure 2. *Interaction effects of treatments on yield loss maintained in percent from IPM experiment analyzed by column –chart.*

3.10. Yield Losses Reduced by Integrated Pest Management

There was a significant ($p<0.05$) among treatment in reduction of yield loss due to FAW. The highest reduction of yield losses was recorded from interaction treatment of CZH1270 x Bravo5EC (32%/ha) and CZH1261 x Bravo5EC (31.25%/ha) followed with statistically significant different from CZH132150 x *Grewinia tenax* (25.9%/ha), CZH1261 x *Grewinia tenax* (25.6%/ha), CZH1270 x *Grewinia tenax* (24.7%/ha), CZH1270 x *Beauveria bassiana* (21.7%/ha, CZH132150 X Bravo 5EC (20%), CZH132150 x *Beauveria bassiana* (12.7%/ha) on average. The lowest yield was obtained from CZH1261 x *Beauveria bassiana* (3.26%/ha) compared from untreated control (Figure 2).

4. Correlation Analysis

4.1. Effect of Integrated Pest Management

The two way correlation analysis revealed that larval mortality was found to be positively and significantly correlated with yield ($r = 0.764$), number of ear harvest with grain yield ($r = 0.75$), number of ear damaged correlated with yield negatively and significantly correlated ($r = -0.57$).

4.2. Correlation Analysis of Larvae Mortality with Maize Grain Yield

The results of the correlation analysis of larval mortality with the grain yield on maize were polynomial models. The R^2 value was 0.6819. Analysis of the correlation description between larval mortality and grain yield was carried out by scatter plot analysis. The most depicting form of the model is polynomial (Figure 3). The formula is: $y = 0.6101x^2 + 1.0317x-2.5413$with a value of $R^2 = 0.6819$. This means that the larvae mortality (y) increase as the grain yield increase (Figure 3).

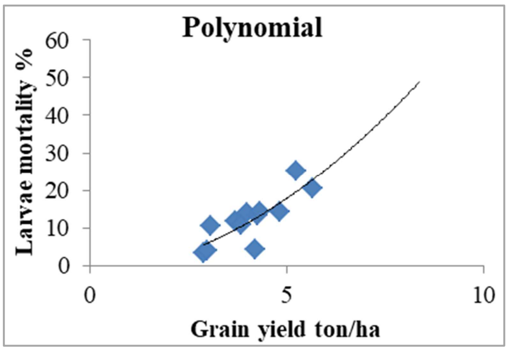


Figure 3. *The relationship between larval mortality and Maize grain yield.*

4.3. Correlation with Number of Ears Harvested and Maize Grain Yield

The results of the correlation analysis of number on ears harvested with the grain yield on maize were liner models. Analysis of the correlation description between number of ear harvested and grain yield was carried out by scatter plot analysis. The most depicting form of the model is linear (Figure 4). The formula is: $y = 6.148x – 1.8595x +17.164$ with a value of $R^2 = 0.7467$. This means that the number of ear harvested increase (y) is influenced the grain yield increase (x).

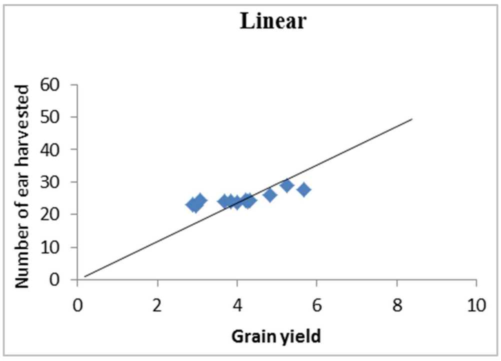


Figure 4. *Relationship between numbers of ear harvested and grain yield.*

5. Discussions

5.1. Screening of Synthetic Chemicals Against FAW

Insecticides tested in this study were toxic to FAW larvae, and some of them recorded high toxicity to the larvae in in laboratory evaluation. The highest larval mortality affected Bravo 5EC 93.3%, Karate 5EC 90.0%, Best 5EC (83.3%) & Dursban 48% (80.0%) after application of 72hrs. The results were obtained in *in vitro* study demonstrated significantly increase larvae mortality compared to untreated. Similar to the present study different insecticides have been reported to be effective against FAW [24, 27, 16]. [24] Reported 86.7% larvae mortality in laboratory and green house by karate. [28] Also recorded 77.8%, 96.7% and 96.7% of FAW larvae mortality after 24, 48 and 72hrs application of synthetic insecticides, respectively. Globally, FAW is one of the most important sweet corn pests, and synthetic insecticides are applied against FAW to protect both the vegetative stages and reproductive stage of corn [6]. Ecological and climatic conditions within a given terrestrial district are also important factors that decide the necessity of insecticide application for the control of FAW larvae [2].

5.2. Mortality Evaluation of Entomophagus Fungi Against (FAW)

During the present study *Beauveria basiana* resulted in highest mortality of FAW larvae (81.6%) 72 hrs after application. *Matarhizium anisopliae* showed relatively lower larvae mortality (70.0%) as compared with the previous treatment after application of at concentration of $1x10^8$ conidial/ml on 3rd instars larvae. [12] reported 96.6% and 78.6% mortality with *B. bassiana* and *M. anisopliae* strains, respectively on 2nd instars larvae of the FAW at a concentration of 1×10^9 conidia/ml. [3] reported that, *M. anisopliae and B. bassiana* isolates showed 92% and 97% mortality on FAW eggs and neonate larvae, respectively on 2nd instars larvae, whereas only *B. bassiana* showed 30% mortality on 3rd instars larvae of FAW in Kenya. [9] Reported that, *M. anisopolioe* and *B. bassiana* isolates showed 19 and 100% mortality on FAW eggs and neonate larvae, respectively. [23] Reported that *M. anisopliae* and *B. bassiana* at 10^6, 10^7 concentrations showed in the range of 45 to 65% mortality, respectively, on the 3rdinstar larvae of FAW in laboratory bioassay.

5.3. Efficacy of Plant Extracts Against Faw in Laboratory

Botanical pesticides are environment-friendly, less harmful to farmers, consumer and safe for natural enemies of the pest. In this study plant extracts of *Grewina tenax* recorded the highest larval mortality evaluations showed that 85%, followed Candle bush extracts also showed that 81% larval mortality, *Jatropha carcus* 76.6%, of larval mortality, *A. indica* 71.6%, larval mortality and *Lantana Camara* 65% larval mortalities were evaluated after 72hrs. Similar findings with the present study application of 0.25% Neem oil extract under laboratory conditions showed 80% larval mortality [26]. Also closely the same findings reported that Neem seed powder was very effective to control fall armyworms that can cause over 70% of larval mortality in the laboratory [21]. A little beat contradict findings from the present study reported Lantana camara 46.7% larvae mortality at 72hrs. *Jatropha carcus*, 90% mean percent larvae mortality was recorded at 72 hrs [26].

5.4. Effect of Integrated Management on Fall Armyworm

In these studies, Treatment x cultivars showed FAW mortality from the interaction effects on treatments of CZH132150 x Bravo 5EC, CZH1270 x Bravo 5EC, CZH1261 x *Beauveria bassiana*, CZH132150 x *Beauveria bassiana*, CZH132150 x *Grewinia tenax*, CZH132150 X Bravo 5EC (12%-25%). The interaction treatments at grain yields were fromCZH132150 x *Beauveria bassiana*, CZH132150 x Bravo 5EC, and CZH132150 x *Grewinia tenax* (4.81t/ha up to 5.6t/ha. Generally during this study among maize cultivars CZH132150, the response of FAW damage was better to tolerate under untreated plot on the parameter of ear damage 2.6% and followed by CZH1261 3.3% moderately tolerant but CZH1270 is highly susceptible to FAW damage. The present study showed [17] reported several factors of larvae may consume more of a plant low in protein or high in protein inhibitors to compensate for its lower nutritional value. [7] Also showed Characters of cultivars that confer their partial resistance to insects, often have effects on their biology and further success. Fall armyworm insect pests classified under polyphagus, it can consume more than 80 plant species but some modified crops can tolerate their effects, this findings reported by [22]. In Ethiopia, 26% of the farmers combined handpicking larvae with insecticide sprays, while 15% of the farmers practiced only handpicking for FAW management [19].

5.5. Yield Loss Reduced by Using IPM

Integrated pest management is the best strategy for FAW management that involves integrating two or more than two control option. The present study revealed that integrating host resistance with synthetic chemical, botanicals and entomopathogenic fungi significantly reduces yield loss. Yield loss of 12.7%/ha up to 32%/ha was minimized by integrated application of CZH132150 x *Beauveria bassiana,* CZH132150 X Bravo 5EC, CZH1270 x *Beauveria bassiana*, CZH1270 x *Grewinia tenax*, CZH1261 X *Grewinia tenax*, CZH132150 x *Grewinia tenax*, CZH1261 x Bravo 5EC and CZH1270 x Bravo5EC. Previous research scholars have estimated yield loss of 22 and 67% maize due to FAW in Ghana and Zambia, respectively [10]. [20] Reported maize yield loss between 32% and 47% in Ethiopia and Kenya respectively without management practice. Similar to the present study previous researchers are indicating the effectiveness of integrated management strategy for FAW [10, 24, 5]. Host plant resistance is an important component of integrated pest management. Similarly [21] finding any maize cultivars that are FAW-resistant could be a key aspect for developing sustainable strategies. [24] indicated the effectiveness of synthetic insecticides and botanicals on FAW larvae a suggested to be considered in integrated pest management. It was also indicated that proper timing, selection of crop variety, crop management and proper use of bio-pesticides, and synthetic pesticides are important parameter of IPM [5].

6. Conclusions and Recommendations

Results of the present study revealed that application of Bravo 5EC, karate 5 EC, Best 5EC and Dursban insecticides was effective and significantly increased percentage FAW mortality treated after 72hrs. Among botanicals tested *Grewinia tenax*, *Candle bush*, *Jatropha carcus* and *A. indica* showed potent insecticidal activity. In addition the utilization of entomophagus fungi *Beauveria basiana* caused the highest (81.6%) larval mortality. The IPM study showed that integrating host resistance with synthetic chemical, botanicals and entomopathogenic fungi visa vis CZH1261X *Beauveria bassiana* CZH132150 X Bravo 5EC, CZH1270 X *Beauveria bassiana*, CZH1270 X *Grewinia tenax* and CZH132150 X *Grewinia tenax* and CZH1270 X Bravo 5EC significantly reduces yield loss. Based on this study results, utilization of Bravo 5% EC, *Grewinia tenax* and *Beauveria bassiana* in combination national variety trial (NVT) cultivar could be recommended for the management of FAW in maize after validation under different field condition. Moreover, familiarizing and demonstrating IPM approach against FAW should be worked out. In addition, identifying critical time of FAW infestation and favorable environmental circumstance and seasons needed to be investigated in the future.

Declarations

Funding Source: Ethiopian Institute of Agricultural Research provide the finance for this research work.

Conflict of interest: The authors declare that they have no conflict of interest.

Ethical approval: This article does not contain any studies with human participants or Animals performed by authors.

Consent to participant: All authors read the manuscript and gave final approval for Publication.

Availability of Data and Material: The datasets used and/or analyzed during the current Study is available from the corresponding author on reasonable request.

Additional Information: No additional information is available for this paper.

Acknowledgments

We would like to express my sincere gratitude to Plant Protection Research Directorate of Ethiopian Institute of Agricultural Research (EIAR) Dr. Mohamed Yusuf for his kind support and permission to undertake our study to raise fund for the accomplishment of this original research work. Also great thanks for all authors their valuable supports, comments, corrections and guidance, the completion of this work would have been possible. Their helpful advice with reviewing the manuscript, providing constructive comments, provision of relevant literatures and guidance from the initial stage of proposal development to the final writing was greatly appreciated.

References

[1] Abrahams P. Bateman, M., Beale, T. Clottey, V. Cock, M., Colmenarez, Y. Godwin, J. (2017), fall armyworm: Impacts and implications for Africa. Evidence Note.

[2] Aguirre, L. A.; Hernández-Júarez, A.; Flores, M.; Cerna, E.; Landeros, J.; Frías, G. A.; Harris, M. K. Evaluation of foliar damage by Spodoptera frugiperda (Lepidoptera: Noctuidae) to genetically modified corn (Poales: Poaceae) in Mexico. Fla. Entomol. 2016, 99, 276–280. [CrossRef]

[3] Akutse KS, Kimemia JW, Ekesi S, Khamis FM, Ombura OL, Subramanian S (2019) Ovicidal effects of entomopathogenic fungal isolates on the invasive fall armyworm Spodoptera frugiperda (Lepidoptera: Noctuidae). J Appl Entomol. https://doi.org/10.1111/jen.12634

[4] Bateman, M. L. Day, R. K., Luke, B., Edgington, S. Kuhlmann, U. and Cock, M. J. (2018), Assessment of potential biopesticide options for managing fall armyworm (Spodoptera frugiperda) in Africa. Journal of Applied Entomology, 142 (9): 805-819, https://doi.org/10.1111/jen.12565

[5] Bista, S. Thapa, M. K and Khanal, S. (2020), Fall armyworm: Menace to Nepalese farming and the integrated management approaches. International Journal of Environment, Agriculture and Biotechnology, 5 (4): 1011-1018, https://doi.org/10.22161/ijeab.54.21

[6] Capinera, J. L. Fall Armyworm, Spodoptera frugiperda (J. E. Smith) (Insecta: Lepidoptera: Noctuidae), (2017). Available online: http://edis.ifas.ufl.edu/in255 (accessed on 10 October 2017).

[7] Chen Y, Gols R, Benrey B, crop domestication and its impact on naturally selected trophic interactions. Annual review of entomology (2015): 60: 35-58. pmid: 25341108.

[8] Cock, M. J. W., Beseh, P. K., Buddie, A. G., Cafá, G., and Crozier, J.(2017). Molecular methods to detect Spodoptera frugiperda in Ghana and implications for monitoring the spread of invasive species in developing countries, Scientific Reports, DOI: 10.1038/s41598-04238-y, 7 (1): 4103.

[9] Cruz-Avalos AM, Bivián-Hernández MA, Ibarra JE, Rincón-Castro MCD (2019) High virulence of Mexican entomopathogenic fungi against fall armyworm, (Lepidoptera: Noctuidae). J Econ Entomol 112: 99–107.

[10] Day, R. Abrahams, P. Bateman, M., Beale, T. Clottey, V. Cock, M, Colmenarez, Y, Corniani, N, Early, R. Godwin, J. Gomez, J. Moreno, P. G. Murphy, S. T. Oppong Mensah, B., Phiri, N., Pratt, C. Richards, G., Silvestri, S., Witt, A., (2017). Fall armyworm: impacts and implications for Africa. Outlooks Pest management 28, 196–201, https://doi.org/10.1564/v28

[11] FAO (2017), fall armyworm continues to spread in Ethiopia's maize fields. Facilitates national awareness training for key partners and field offices. Retrieved from http://www.fao.org/food-chain-crisis/howwe-work/plant-protection/fall-armyworm/en/

[12] García C, González MB, Bautista N (2011) Pathogenicity of isolates of entomopathogenic fungi against Spodoptera frugiperda (Lepidoptera: Noctuidae) and Epilachna varivestis (Coleoptera: Coccinellidae). Rev Colomb Entomol 37: 217–222.

[13] Girma Demissie. 2018. Fall Armyworm *Spodoptera frugiperda* Smith (Lepidoptera, Noctuidae): The New Catastrophic Insect Pest in Ethiopia. Dagnachew L., Tesfaye A., Tilahun G., Dereje W., Tafa J., Tesfaye L., Teha M., Kamil A., Tilahun G. and Shure S. (Eds.) 2018. Workshop Proceedings on Participatory Identification of Agricultural Production Constraints: The case of Oromia, Harari and Dire Dawa City Administration, 23-24 Nov 2017, Addis Ababa, Ethiopia.

[14] Girma, D., Zebdewos, S., Gashawbeza, A., Fentahun, M., Birhanu, S. 2019. Fall Armyworm, *Spodoptera frugiperda* (J. E Smith): A new threat to maize production in Ethiopian (status, impact, interventions, lessons learned and prospects). In, Belay. H (Ed.). Proceedings of the 24th Annual Conference on "Emerging and re-emerging plant pests of Ethiopia: status, interventions and future prospects in a changing climate", 16-17 March 2018, Haramaya University, Dire Dawa, Ethiopia. Pp. 137-158.

[15] Goergen, G. Kumar, P. L, Sankung, S. B., Togola, A. and Tamo, M, (2016). First report of outbreaks of the fall armyworm Spodoptera frugiperda (JE Smith)(Lepidoptera, Noctuidae), a new alien invasive pest in West and Central Africa. PloS one, 11 (10): 0165632.

[16] Khatri, S., Pakuwal, P. and Khanal, S. (2020). Integrated pest management of fall armyworm infestations in maize fields in Nepal: A review. Archives of Agriculture and Environmental Science, 5 (4): 583591, https://dx.doi.org/10.26832/24566632.2020.0504023

[17] Knolhoff, L. M. Heckel, D. G. Behavioral assays for studies of host plant choice and adaptation in herbivorous insects. Annu. Rev. Entomol. 2014, 59, 263–278.

[18] Kokwaro, j. o. Medicinal plants of east Africa 1993. Kenya literature bureau, Nairobi.

[19] Kumela, T. Simiyu, J. Sisay, B. Likhayo, P. Mendesil, E. Gohole, L. Tefera, T. Farmers' knowledge, perceptions, and management practices of the new invasive pest, fall armyworm (Spodoptera frugiperda) in Ethiopia and Kenya, Int. J. Pest Manag, (2019), 65, 1–9. [CrossRef]

[20] Lima, M. S.; Silva, P. S. L.; Oliveira, O. F.; Silva, K. M. B.; Freitas, F. C. L. Corn yield response to weed and fall armyworm controls. Planta Daninha Viçosa-MG 2010, 28, 103–111. [CrossRef]

[21] Maredia, K. Segura, O. and Mihm, J. (1992), Effects of neem, Azadiracta indica on six species of maize insect pests, Tropical Pest Management, 38 (2): 190-195, https://doi.org/10.1080/09670879209371682

[22] Mihm, J. A.; Smith, M. E.; Deutsch, J. A. Development of Open-Pollinated Varieties, Non-Conventional Hybrids and Inbred Lines of Tropical Maize with Resistance to Fall Armyworm, Spodoptera frugiperda (Lepidoptera: Noctuidae), at CIMMYT. Fla. Entomol. (1988), 71, 262–268. [CrossRef]

[23] Morales-Reyes C, Rodriguez-Contreras J, Sanchez-Pedraza F, E. Rosales-Escobar O, Hernandez-Juarez A, Felipe-Victoriano M, Sanchez-Peña RS (2013) Activity of entomopathogenic fungi against fall armyworm, Spodoptera frugiperda: comparison of conidia produced on artificial media and insect hosts. Entomological Society of America Annual Meeting, Austin, 10-13 November 2013.

[24] Noni N, Kalqutny SH, Mirsam H, Muis A, Azrai M, Aqil M. (2019), Pengenalan Fall Armyworm (Spodoptera frugiperda J. E Smith): Hama Baru pada Tanaman Jagung di Indonesia. Maros: Balai Penelitian Tanaman Serealia. Badan Penelitian dan Pengembangan Pertanian. Kementerian Pertanian, Jakarta. (Indonesian).

[25] Roger, D., P. Abrahams, M. Bateman, T. Beale, V. Clottey, M. Cock, Y. Colmenarez, N. Corniani, R. Early, J. Godwin, J. Gomez, P. G. Moreno, S. T. Murphy, B. Oppong Mensah, N. Phiri, C. Pratt, S. Silvestri, and A. Witt. 2017. Fall armyworm: impacts and implications for Africa. Journals of Outlooks on Pest Management, 28 (5): 196201.

[26] Sisay, B. Tefera, T. Wakgari, M. Ayalew, G. Mendesil, E. The Efficacy of Selected Synthetic Insecticides and Botanicals against Fall Armyworm, Spodoptera frugiperda, in Maize, Insects (2018 and 2019), 10, 45, [CrossRef].

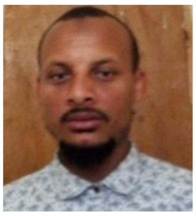
[27] Tadele et al (2019). Efficacy of Selected Synthetic Insecticides and Botanicals against Fall Armyworm, Spodoptera frugiperda, in Maize.

[28] Tavares, W. Costa, M. Cruz, I., Silveira, R. Serrao, J. and Zanuncio, J. (2010) Selective effects of Natural and Synthetic insecticides on mortality of Spodoptera frugiperda (Lepidoptera: Noctuidae) and its predator Eriopis connect (Coleoptera: Coccinellidae). Journal and Environmental Science and Health PartB, 45: 557-561, https://doi.org/10.1080/03601234.2010.493493

[29] Feyissa Begna and Tebkew Damtew (2015). Evaluation of four botanical insecticides against Diamondback Moth, Plutella Xylostella (Lepidoptera: Plutellidae) on head cabbage in the central rift valley of Ethiopia. Sky Journal of Agricultural Research 4 (5): 97–105.

[30] Raghavendra K. V, Gowthami, R., Lepakshi, N.M., Dhananivetha, M. and Shashank, R. (2016). Use of Botanicals by Farmers for Integrated Pest Management of Crops in Karnataka, Asian Agri-History, 20 (3): 173-180.

Biography



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