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Field Efficacy of Botanical and Chemical Insecticides against Maize Fall Armyworm [(*Spodoptera frugiperda* (J.E. Smith)] in Central Zone of Tigray, Ethiopia

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

Maize (*zea mays*) is one of the most important crops to feed Ethiopia's growing population and a significant source of revenue for many farmers with limited resources. However, the production of this crop is constrained by the invasion and widespread infestation of the fall army worm. Fall armyworms affect maize plant in whole from seed germination to defoliation of the leaves and damage to the ears which consequently leads to poor crop yield. Therefore the current study was initiated with a specific objective to screen effective insecticides and botanicals in controlling maize fall armyworm and thereby increase maize productivity. The experiment was carried out at Axum agricultural research center Rama research site during 2020. It was laid out in a randomized

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complete block design (RCBD) replicated three times having 5x5m2 plot size, 1.5 and 1m spacing b/n reps and plots. The treatments consisted of three synthetic insecticides Coragen 200 SC(chlorantraniliprol) at 0.25lt/ha, Karate 5%EC(lambda-cyhalothrin) at 1lt/ha, abema 3%EC (abamectin20g/l + emamectin benzoit 10g/l) at 1lt/ha and three botanical extracts Azadirachta indica, Schinnes molle and Nicotaia glauca at 50 gm/l with untreated check. The results showed that application of insecticides (coragen, abema, karate) and botanical extracts (Azadirachta indica); significantly reduced the fall armyworm larvae by (86, 82, 53 and 30)% respectively, compared to the untreated check at 7 days after spray. The least number of larvae was recorded in plots treated with coragen and abema (1.05and1.27 larvae per plot). FAW infestation was significantly decreased in plots treated with Coragen and abema (13 and 14%) compared to the infestation level in the untreated plots (56%) at 7 days after 2nd spray. Comparatively the neem seed kernel sprayed plots showed significant reduction (30.62%) than the untreated check (56.26%). Similarly a week after spray one and two these insecticides were still effective in reducing the leaf damage. The highest leaf damage (up to 7 scale) was recorded on the untreated check and the lowest leaf whorl damage (1) was recorded on coragen treated plots after spray. The other non target insects (un identified) were recorded in each plot and significantly low in all treated plots (P ≤ 0.05) than in the untreated check. The yield obtained was higher in the treated plots but statistically non significant difference with the untreated check. In the present study; coragen (chlorantraniliprole) at twice spray were recommended to control maize fall armyworm and Azadirachta indica as eco-friendly option of FAW integrated pest management.

Keywords: Fall army worm; maize; insecticides; botanicals; infestation.

1. INTRODUCTION

“Maize is an important staple food crop in Ethiopia and a major source of income to many resource-poor farmers” [1]. “In Ethiopia 88% of maize produce is used as food prepared in both grain and green cobs” [2]. It is second in area of production and first in productivity among the Staple food crops tef, wheat and sorghum [3]. “Maize possesses great genetic diversity and is grown in a wide range of environments, from the equator to about 50 north latitude and 420 south latitude and as high as 3800 meters above sea level” (Ortega, 1987). “It is one of the high priority crops to feed the ever-increasing Ethiopian population” [2]. “However, the production of this crop and consequently the livelihood of the growers is constrained by the invasion and widespread infestation of the fall army worm which has led to substantial maize yield losses” [4].

The fall armyworm (*FAW*) is a polyphagous and devastative pest of maize native to tropical and subtropical regions of the Americas [5,6,7]. It was first reported from Africa in Nigeria and Ethiopia in 2016, 2017 respectively [8,9]. The fall armyworm is likely to build permanent and significant populations in Africa based on the recent Environmental and climatic analyses of Africa [4]. Fall armyworm caterpillars were much more damaging to maize in West and Central Africa than other *Spodoptera spp*. [10].

Fall armyworms attack all crop stages of maize from seedling emergence through to ear development. They defoliate leaves and damage to the ears which consequently leads to poor crop [11]. About 100 different crops and other plants can host the insect and are susceptible to attack, but prefers maize, rice, sorghum and sugarcane [4]. Hruska and Gould (1997) reported yield losses of 15-73% when 55-100% of the maize plants were infested with fall armyworm during the mid- to late-whorl stage of maize development. “Field crops are frequently injured, including alfalfa, barley, Bermuda grass, buckwheat, cotton, clover, corn, oat, millet, peanut, rice, ryegrass, sorghum, sugarbeet, Sudangrass, soybean, sugarcane, timothy, tobacco, and wheat” [12].

Different studies were conducted in various parts of the world to control fall armyworm. Chemical insecticide control for FAW was a common practice in North and South America [13]. In some regions of Sub Sahara Africa farmers also tried to control FAW using botanical pesticides such as ground chili pepper (*Capsicum annum* L.), tobacco extracts (*Nicotiana tabacum* L.), neem tree leaves (*Azadirachta indica*), and jatropha leaves (*Jatropha curcas* L.) [14,15]. These botanical pesticides had traditionally been used to control other insect pests in field crops. These were cheaper alternatives for the resource-poor farmers and are probably less hazardous to the farmers, environment, and non-target insects [16,17,18]. Neem oil, neem seed and leaf powder were reported to have 70% mortality on FAW larvae [19,20], In Ghana, neem oil-based products (0.17−0.33%) were found to be almost as effective as Emamectin benzoate (4″-Deoxy-4″-epi-methylamino-avermectin B1) (Ema 19.2 EC) in reducing FAWdamage inmaize [21]. Chen et al. [22] stated that maize accessionMp708 and FAW7050 were resistant to fall armyworm due to enhanced defense protein, greater amino acid and glucose content, and constitutive jasmonic acid accumulation. a study conducted by Ni et al. [23] also identified maize germplasmMp708 and FAW7061 as highly resistant accession to fall armyworm infestation.

Yigezu and Wakgari [24] summarized different cultural practices in controlling FAW infestation and maize yield losses. These include handpicking and killing of larvae, placing sand or wood-ash in whorls of maize plants, drenching plants with tobacco extracts, deep plowing to kill overwintering pupae, early planting, destruction of ratoon host plants, burning infested crop residues after harvesting, intercropping with non-host plants, use of multiple cultivars, and rotation with non-host crops [25,24]. The push–pull technology developed by the International Centre of Insect Physiology and Ecology (ICIPE) for control of stem borers in maize was recommended and used in several Sub Sahara Africa countries to control FAW [26]. A study by Sisay et al. [27] in Ethiopia, Kenya, and Tanzania, identified five native species of parasitoids (*Cotesia icipe*, *Palexorista zonata*, *Coccygidium luteum*, *Charopsater* and *Chelonuscurvi maculatus*) some with parasitism levels as high as 45.3%. Scientists at ICIPE in Kenya also recommended the parasitoids *Trichogramma* and *Telenomus*, for augmentative FAW biocontrol [28]. However, as a new invading pest there was no control methods in the study area; Therefore the current study was initiated with a specific objective to screen effective insecticides and botanicals in controlling maize fall armyworm and thereby increase maize productivity.

2. MATERIALS AND METHODS

2.1 Description of the Study Area

The experiment was conducted at Axum agricultural research center Rama research site in Merebleke district during 2020. Rama research site is found at the border of Ethio-Eritrea in the north. It is located at about 1041 kms away from Addis Ababa and 67kms to the north of Aksum town, at 14^o 25’26” and 14^o18’48” N latitude, and 38^o 42’15” and 38^o48’30” E longitude with an altitude of 1390 m.a.s.l. It is found in semi-arid tropical belt of Ethiopia with “kola” agro climatic zone and the rainy season is mono - modal concentrated in one season from late June to early September receives from 400 - 600 mm of rain fall per annum. The mean minimum and maximum temperatures ranged from 13.33 ^{0}C to 33.71 ^{0}C, respectively. The soil texture is sandy clay loam textural class with bulk density of 1.72 gm cm^{-3}, very low in organic carbon (0.73%) with an alkaline pH of (8.2). The major crops produced in the area are Maize, Sorghum and Finger Millet as stable food; Vegetables such as Onion, Tomato, Hot pepper, Sweet potato and fruits Mango, Citrus Papaya and Banana. Maize is produced both in rain fed and irrigation.

2.2 Experimental Design and Treatments

The experiment was laid out in a randomized complete block design (RCBD) replicated three times having 5x5m^2 plot size, 1.5 and 1m spacing b/n reps and plots; 75 and 25 cm b/n rows and plants. maize melkasa6QPM (quality protein maize) was used as planting material. The field was ploughed using oxen and harrowed manually to bring the soil to fine tilth. Fertilizer NPS at the rate of 150kg/ha were used at sowing date and urea100kg/ha split application.

The treatments consisted of three synthetic insecticides Coragen 200 SC (chlorantraniliprol) at 0.25lt/ha, Karate 5%EC (lambda-cyhalothrin) at 1lt/ha and abema 3%EC (abamectin20g/l + emamectin benzoit 10g/l) at 1lt/ha and three botanical extracts *Azadirachta indica*, *Schinnes molle* and *Nicotaia glauca* at 50 gm/lt with untreated control. *Azadirachta indica* was collected from naturally growing neem trees at Rama and seeds of *Schinnes molle* from Axm. The active ingredients in neem, are however higher in the neem seed kernels (4-6g/kg of neem seeds) compared to the bark and leaf (Mordue and Nisbet, 2000). The fresh seeds were washed; dried under shade and grinded using electrical blender to make coarse powder. Tree tobacco leaves were collected from naturally growing in the road sides around Rama. The leaves were dried under shade and grinded. Fifty gram powder were weighed and mixed with water at a rate of 50 gm/lt for each botanical and the mixture were left to brew for 24 hours. It was filtered using muslin cloth before application following Keshav and Singh (2013). Before treatment application the existing larvae at field infestation were counted in each plot and a second instar larvae of the fall army worm were collected from other maize fields around the site and added (inoculated) on to each plant in the central rows until to have equal number of larva in the plots 40 larva per plot. Within 12hours after inoculation, candidate insecticides and botanicals were applied two sprays at weekly intervals. The untreated checks were sprayed with clean water. Two liter capacity hand sprayer were used for each insecticide to manage chemical drift among plots. Spray was done at wind free time of the day early in the morning up to 8 o'clock. Cultivation, weeding and all recommended agronomic practices were performed accordingly and no insecticides other than those included in the trial were applied.

2.3 Data Collection

Before treatment application the experiment was inspected at three days interval for natural infestation. The existing larva was counted and additional similar instar larva were collected from other maize fields around the site and inoculated in the plots to have equal distribution with in plots. After each spray, all insect data were collected. Live fall armyworm larva, infested plants per plot and Other insects (might be natural enemy) were counted. The extent of leaf damage were measured following Davis et al. [29] leaf damage score (1-9). yield was taken from the net plot area. Count and infestation data were transformed using the square root and arcsine transformation. observation data on adult moth and egg colonies of fall armyworm on maize leaves in each plot were taken.

FAW infestation % = (Number of FAW infested plants)/(Total number of plants observed) x 100

$$\text{larva reduction } \% = \frac{\text{Mean of untreated} - \text{Mean of treated}}{\text{Mean of untreated}} x100$$

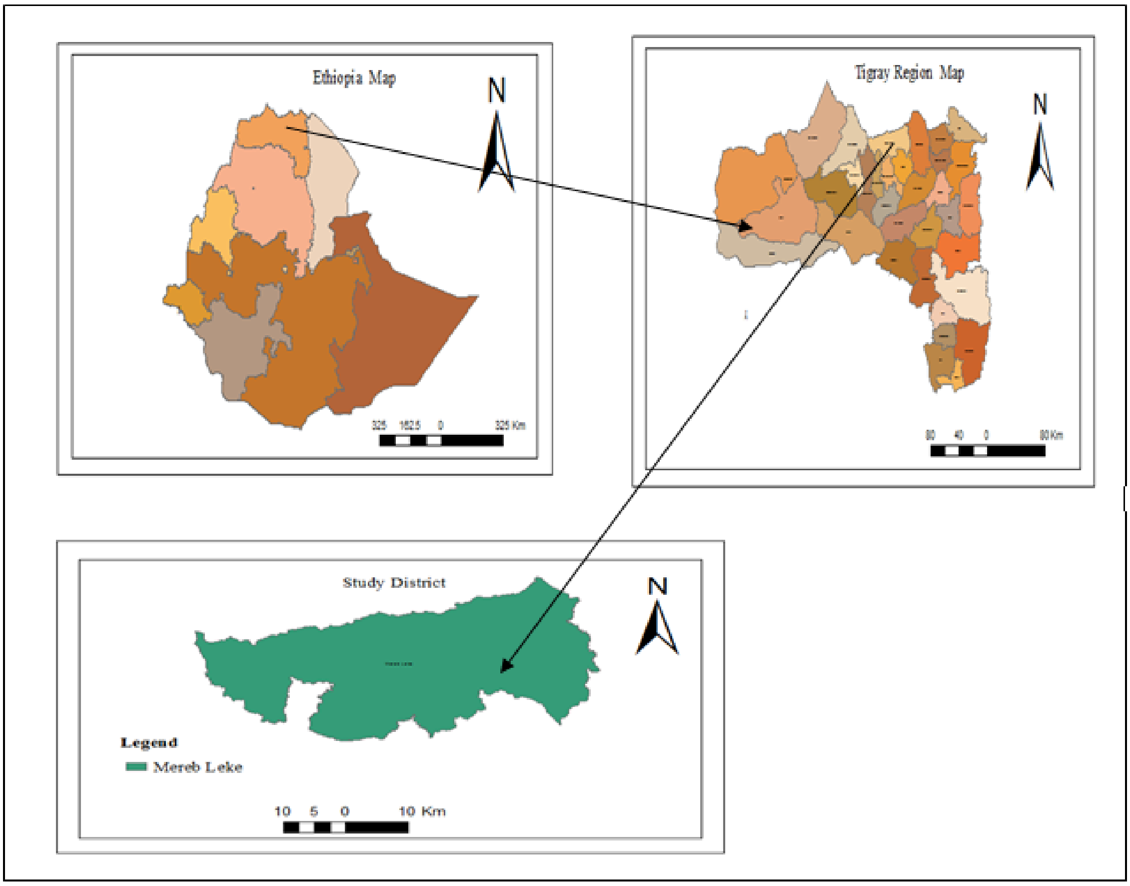

Fig. 1. Map of the study area

Table 1. Leaf damage visual rating scales 0-9 [29]

No.	Description	Scale
1	No visible leaf damage	0
2	Only pinhole damage on leaves	1
3	Pinhole and shoot hole damage to leaf	2
4	Small elongated lesions (5–10 mm) on 1–3 leaves	3
5	Midsized lesions (10–30 mm) on 4–7 leaves	4
6	Large elongated lesions (>30 mm) or small portions eaten on 3–5 leaves	5
7	Elongated lesions (>30 mm) and large portions eaten on 3–5 leaves	6
8	Elongated lesions (>30 cm) and 50% of leaf eaten	7
9	Elongated lesions (30 cm) and large portions eaten on 70% of leaves	8
10	Most leaves with long lesions and complete defoliation observed	9

2.4 Data Analysis

All collected data were analyzed for significant differences among treatments using SAS version 9.2 software [30]. Count data generated from the experiment was transformed using square root and arc sign transformation and subjected to the ANOVA procedure of SAS software. Mean separation of the number of larvae and yield was performed using LSD test ($P \leq 0.05$).

3. RESULTS AND DISCUSSION

3.1 Results

3.1.1 Effect of insecticides and botanicals on fall armyworm larva

In the 1st application all synthetic insecticides coragen abema and karate significantly reduced the fall armyworm larvae ($P \leq 0.05$) in all replications compared to the untreated check at 7 days after spray; abema and karate were also significant at 3 days after spray (Table 2). The least number of larvae was recorded with coragen, abema and karate (1.05 ,1.27,2.38 larvae per plot) respectively. From the botanical extracts only *Azadirachta indica* significantly reduced the fall armyworm larvae (2.67 larvae per plot) ($P \leq 0.05$) compared to the untreated check at 7 days after spray and were statistically at par with each other. In the 1st application the highest larval reduction percentage was recorded with coragen (73%), abema (67%), karate (39%) and*Azadirachta indica (32%)* at 7 days after spray (Table 2).

In the 2nd application all synthetic insecticides (coragen, abema, karate) and botanical extracts (*Azadirachta indica)*; significantly reduced the fall armyworm larvae ($P \leq 0.05$) compared to the untreated check at 3 and 7 days after second spray. The highest larval reduction percentage was recorded with coragen (86%), abema (82%), karate (53%) and *Azadirachta indica (30%)* at 3 days after second spray (Table 2). The next best treatment was *Nicotiana glauca* significantly reduced the fall armyworm larvae ($P \leq 0.05$) compared to the untreated control at 3 and 7 days after second spray with (34%) reduction. However *Schinnes molle* was not statistically different ($P > 0.05$) compared to the untreated control both in the 1st and2nd applications to reduced the fall armyworm larvae. The other non target insects; might be natural enemies (un identified) were recorded in each plot but significantly low in all treated plots ($P \leq 0.05$) than in the untreated control (Table 2).

3.1.2 Effect of insecticides and botanical extracts on FAW infestation and leaf damage

In the 1st application the level of infestation was significantly reduced in all insecticides (coragen abema and karate) treated plots ($P \leq 0.05$) compared to the untreated check at 7 days after spray; The lower infestation (29%) was recorded on coragen treated plots and the highest infestation (50%) on untreated check at 7 days after spray. Similarly in the 2nd treatment application, FAW infestation was significantly reduced in plots treated with Coragen (13%), abema (14%), karate (34%), *Azadirachta indica (30%) and* Nicotiana glauca (37%) compared to the infestation level in the untreated plots (56%) at 7 days after 2nd spray (Table 3). At 14 days after the 2nd spray these treatments significantly reduced infestation of the pest in the same pattern.

Table 2. Mean number of alive FAW larvae per plot after each spray transformed value

Treatment	BSP1	3DASP1	Red%	7DASP1	Red%	3DASP2	Red%	7DASP2	Red%	Other insects
Coragen	4.41	3.27abc	24	1.05e	73	0.70d	86	0.70d	85	0.07d
Karate	4.45	3.10bc	28	2.38cd	39	2.37c	53	2.09c	56	0.27d
Abema	4.46	2.93c	32	1.27de	67	0.87d	82	0.88d	81	0.33d
Azadiracta indica	4.59	3.43abc	20	2.67bc	32	3.57b	30	3.29b	31	1.2b
Schinnes molle	4.64	4.23ab	2	3.85ab	2	4.97a	2	4.55a	4	1.0bc
Nicotiana glauca	4.49	3.77abc	12	3.23abc	17	3.43bc	32	3.12bc	34	0.8c
Untreated check	4.34	4.33a	00	3.93a	00	5.10a	00	4.76a	00	2.1a
Cv	3.9	17.9		25.6		21.8		21.6		25
LSD (0.05)	NS	1.13		1.19		1.16		1.06		0.38

Note; BSP=Before spray, DASP=Days after spray, Red%=Reduction percentage, NS=Non significant, CV=coefficient of variation, LSD=least significant difference and Means followed by the same letter(s) in the same column are not significantly different from each other at 5% probability level

Table 3. Mean infestation percent per plot arcsine transformed

Treatments	BSP1	7DASP 1	7DASP 2	14DASP2
Coragen	42.65	29.99^{c}	13.55^{c}	7.15^{d}
Karate	42.89	34.24^{bc}	34.41^{b}	27.69^{b}
Abema	45	32.17^{bc}	14.15^{c}	8.56^{cd}
Azadirachta indica	43.45	42.58^{ab}	30.62^{b}	17.93^{bc}
Schinnes molle	42.69	39.61^{bc}	47.33^{a}	38.17^{a}
Nicotiana glauca	43.47	40.37^{b}	37.13^{b}	26.34^{b}
Untreated check	38.76	50.88^{a}	56.26^{a}	40.03^{a}
Cv	8.79	14.1	15.7	23.7
LSD (0.05)	NS	9.62	9.33	10.01

Note; BSP= Before spray, DASP=Days after spray, NS=Non significant, CV=coefficient of variation, LSD=least significant difference and Means followed by the same letter(s) in the same column are not significantly different from each other at 5% probability level

Table 4. Mean leaf damage score (scale 0-9)

Treatments	BSP1	7DASP 1	7DASP 2	14DASP2	Yield t/ha
Coragen	3.42	2.33^{b}	1.60^{c}	1de	5.5
Karate	3.60	2.87^{b}	4.33^{b}	2.33^{cd}	5.2
Abema	3.73	2.73^{b}	1.8o^{c}	0.73^{e}	5.6
Azadirachta indica.	3.47	3.93^{b}	3.87^{b}	1.73^{cde}	5.3
Schinnes molle	3.47	4.80^{a}	6.80^{a}	4.2^{ab}	4.8
Nicotiana glauca	3.53	4.73^{a}	4.93^{b}	3.07^{bc}	5.2
Untreated check	3.47	5.93^{a}	7.1^{a}	4.87^{a}	4.9
Cv	9.63	25	16.6	29.9	11.2
R^2	42	76	93	87	29
LSD (0.05)	NS	1.81	1.28	1.36	1(NS)

Note; BSP= Before spray, DASP=Days after spray, NS=Non significant, CV=coefficient of variation and LSD=least significant difference and Means followed by the same letter(s) in the same column are not significantly different from each other at 5% probability level

Fig. 2. maize leaf damage (A) on untreated plot and (B) on coragen treated plot

According to Davis & Williams rating scale maize leaf damage was significantly lower on plots treated with Coragen, abema, karate *and Azadirachta indica* (2.3,2.7,2.8 &3.9) at 7 days after 1st spray; (1.6,1.8,4.3 & 3.8) at 7 days after 2nd spray and (1,0.7,2.3 &1.7) respectively at 14 days after 2nd spray as compared to the higher leaf damage with untreated control (7.1) (Table 4). The highest yield was recorded in treatments with abema (5.6t/ha) and coragen (5.5t/ha) as compared to the untreated control (4.9t/ha) but no statistically difference among treatments. The result of the current study indicated that coragen 200SC at 0.25lt/ha was the first effective insecticide to control fall armyworm infestation and leaf damage on maize at two sprays. From the locally available botanical extracts *neem seed kernel (Azadirachta indica)* at 50g/lt was screened next to the synthetic insecticides in fall armyworm management.

3.2 Discussion

In the present study results showed that application of insecticides (coragen, abema, karate) and botanical extracts (*Azadirachta indica)*; significantly reduced the fall armyworm larvae by (86,82,53 and 30)% respectively, compared to the untreated check at 7 days after spray. The least number of larvae was recorded in plots treated with coragen and abema (1.05and1.27 larvae per plot). FAW infestation was significantly decreased in plots treated with Coragen and abema (13and 14%) compared to the infestation level in the untreated plots (56%) at 7 days after 2nd spray. Comparatively *Azadirachta indica* sprayed plots showed significant reduction (30.62%) than the untreated check(56.26%) Similarly a week after spray one and two these insecticides were still effective in reducing the leaf damage. The highest leaf damage (up to 7 scale) was recorded on the untreated check and the lowest leaf damage (1) was recorded on coragen treated plots after spray. The other non target insects were recorded in each plot but significantly low in all treated plots ($P \leq 0.05$) than in the untreated check. The yield obtained was higher in the treated plots but statistically non significant different with the untreated check. In general the result showed that coragen (chlorantraniliprole) and abema were the best insecticides and neem seed kernel *(Azadirachta indica)* were the best botanical against the fall army worm. In agreement with the current study; several systemic insecticides were studied against the fall armyworm of maize. among them, the application of emamectin benzoate 5 SG showed the highest acute toxicity, followed by chlorantraniliprole 18.5 SC and spinetoram 11.7 SC, whereas toxicities of flubendiamide 480 SC, indoxacarb 14.5 SC, lambda-cyhalothrin5 EC, and novaluron10 EC were at par according to the leaf-dip bioassay; However, at field evaluation application, chlorantraniliprole18.5 SC, followed by emamectin benzoate 5 SG, spinetoram 11.7 SC, flubendiamide 480 SC,indoxacarb 14.5 SC, lambda-cyhalothrin 5 EC, and novaluron 10 EC were found better [31]. Profenophos + cypermethrin and spinosad were shown to be the most efficient in killing sixth-instar larvae in whorls in another investigation, followed by profenophos + lambdacyhalothrin and indoxacarb. In another study conducted in Ethiopia by Sisay et al. [27]. Synthetic insecticides, such as Lambda-cyhalothrin 5 EC, chlorantraniliprole 20 SC, Spinetoram120 SC, Dimethoate 40 percent, Tracer 480 SC, and Ampligo 150 SC, significantlyreduced fall armyworm larval mortality, reduced leaf damage, and increased biomass inmaize when compared to an untreated control. Indian Central Insecticide Boardand Registration Committee recommends the use of chlorantraniliprole18.5 SC, thiamethoxam 12.6% + lambda-cyhalothrin 9.5% ZC, and spinetoram 11.7 SCfor fall armyworm management. According to Martinez et.al. [32] botanical extracts of neem (*Azadirachta indica*) and *Argemone ochroleuca* had an insecticidal effect against fall armyworm. Based on these recent studies, it could be inferred that the application of systemic insecticides appears to be the most promising component of integrated pest management plans for fall armyworm [33,34].

4. CONCLUSION AND RECOMMENDA-TION

The present findings indicated that insecticides (coragen, abema, karate) were the 1st, 2nd, and 3rd most effective in fall armyworm management at two spray times. These insecticides reduce the number of larvae in maize plots, infestation, damage to maize whorl leaves and give higher yield than the untreated maize. From the botanical extracts, neem seed kernel (*Azadirachta indica*) gives better result in fall armyworm management next to the synthetic insecticides. Therefore, to reduce infestation of fall armyworm and increase production of maize, selection of effective insecticides and easily available botanical extracts as part of IPM tools is required. In the present study; coragen (chlorantraniliprole) at twice spray were recommended to control maize fall armyworm and Azadirachta indica as eco-friendly option of FAW integrated pest management.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author (s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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