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Insecticide Spray Guide for the Control of Spodoptera Frugiperda JE Smith (Lepidoptera: Noctuidae) Basing on Maize Crop Injury Signs

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ABSTRACT

Fall armyworm, *Spodoptera frugiperda* (J. E. Smith), is a polyphagous migratory pest that attacks more than 353 plant species among which are major crops in Africa. Farmers have been opting for insecticide-based control despite the lack of clear guides on the suitable insecticides and right timing for application. Farmers respond to *S. frugiperda* through injury signs inflicted on maize crop but it's less known how effective is the injury signs-based decisions. This study aimed at establishing the right choice of insecticides and timing of application based on crop injury signs. Ten farmer-preferred insecticides were used against *S. frugiperda* on damaged maize crop in the field. Obtained results suggested that injury sign-based application of insecticides has significant ($p < 0.001$) effect on mortality of *S. frugiperda* larvae. Ninja plus 5EC, Profecron 720 EC, Multi alpha plus 150 EC and Duduba 450 EC, caused highest mortality of *S. frugiperda* in all experiments while Thunder 145 OD and Attakan 350 SC were the least effective. The obtained yields suggested a significant impact of applied insecticides whereby plots treated with Duduba 450 EC produced highest yield (4tons/ha) compared to non-treated plot (2.2 tons/ha). The findings from this study proves for the first time that *S. frugiperda* can be effectively managed through tallying of insecticide spray with injury signs manifested on maize crop. The developed insecticides advisory spray guide should be recommended as *S. frugiperda* field management option which is easily understandable by the farmers.

Keywords: Fall armyworm, crop injury signs, pest management, Insecticide spray guide.

INTRODUCTION

Fall armyworm (FAW), *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae) is a relatively new pest of maize in Africa (FAO and CABI, 2019). The pest is native to tropical and subtropical regions of the western hemisphere from the United States of America to Argentina (Day et al. 2017; Midega et al. 2018; CABI, 2020). Currently, *S. frugiperda* has spread to several counties in Africa, that include East and Central African countries and caused significant yield losses on maize (*Zea mays* L.) of around 8.3 to 20.6 million metric tons per year under the absence of control methods, while affecting over 300 million people in Africa, who, directly or indirectly, depend on the crop for food and well-being (Abrahams et al. 2017; Midega et al. 2018). The pest is polyphagous and migratory and has a wide host range of over 353 different plant species (Firake and Behere 2020) many of which are important crops in Tanzania and the rest of Africa including Maize (*Zea mays*), Sorghum (*Sorghum bicolor*), Rice (*Oryza sativa*), Sugar cane (*Saccharum officinarum*), Cowpea (*Vigna unguiculata*), Soybean (Glycine max), Groundnut (*Arachis hypogaea*), Cotton (*Gossypium hirsutum*), Round potato (*Solanum tuberosum*), Amaranthus (*Amaranthus tuberculatus*), Grape (Vitis spp), Orange (*Citrus sinensis*), Papaya (*Carica papaya*), Napier (*Pennisetum purpureum*), Desmodium (*Desmodium uncinatum*) and various ornamental plants.

Due to its polyphagous and migratory nature, *S. frugiperda* has become a pest of concern wherever is reported to occur. The pest was first detected in West Africa in 2016 and later spread to the whole of Central, Southern, Eastern, and Northern Africa in early, 2017 (Midega et al. 2018). By 2018 the pest was present in more than 44 countries in Africa which suggested a major threat to food security in the continent (Day et al. 2018). In February 2017 *S. frugiperda* was first detected in Rukwa, Tanzania and thereafter found in the other border regions including Ruvuma and Mbeya. It is believed that the pest may have come into Tanzania through self-flight from the neighboring Zambia. The pest always occurs in high numbers, have ability to migrate long distances and feed on broad host range which makes other control options less efficient and instead use of insecticides have been found to be more effective (Belay et al. 2012).

Experiences in its native ranges of Americas indicates that, the common management strategy for the *S. frugiperda* has been the use of insecticides spray and genetically modified crop (*Bt* maize) (Sisay, 2018). In Africa insecticides have been widely used as emergency response to deal with the distribution of the pest and minimize damage on maize (Abraham et al. 2017; Sisay, 2018). Despite the current use of insecticides, there have been reports of high resistance ratio to flubendiamide, chlorantraniliprole, chlorpyrifos, thiodicarb, methomyl, triflumuron, spinetoram, permethrin, deltamethrin and zeta-cypermethrin (Gutierrez-Moreno et al. 2017). The research report by Fernandez et al. (2019) confirmed that the combination of Flubendiamide with a pyrethroid showed better efficiency in the control of *S. frugiperda* (Santos et al. 2016).

The outbreak of *S. frugiperda* in Tanzania found the country unprepared which led to the country's pesticide regulatory authority (The Tanzania Plant Health and Pesticide Authority-TPHPA) to bank on few choices among the available insecticides to establish a list of advised insecticides for use. Unfortunately, the recommended insecticides were not available to every location and distribution of elite products could not match with the pace at which *S. frugiperda*

was spreading (Kiva et al. 2023). Consequently, farmers opted for whatever was available at their disposal in attempt to rescue some harvest from their maize crop. Some unscrupulous traders took advantage of the observed vacuums and prescribed whatever they had to unsuspecting farmers. The outcome of using insecticides was disappointing and could not satisfy farmers because most of them proved ineffective against *S. frugiperda* (Kiva et al. 2022). While farmers feared of most products being counterfeit, quick survey (Prof. Rwegasira G. M, unpublished data) indicated that most insecticides were genuine although not recommended for use against *S. frugiperda.* Poor application techniques including dosages and timing of application as well as resistance against the used insecticides previously reported on *S. frugiperda* were suspected to be among causes of insecticides inefficacy. Fernandes *et al*. (2019) reported that the six instar stages of *S. frugiperda* have varied responses to insecticides and the more advances the stage the higher the chances of resistance against insecticides. Farmers in Tanzania apply insecticides as response to pests' injuries on crop. Very often, the need to apply insecticides is determined by the magnitude of crop injury such that the pest is never controlled until the inflicted injuries on crops become unbearable. Moreover, there has been no crop injury-based guide that would help farmers to make rational decision on when and which insecticide to apply. Practical advice on insecticide spray guide would be the one that primarily considers crop injury signs and less on pest characteristics. Objectives of this study were to; (i) document the injury signs caused by *S. frugiperda* on maize crop, (ii) to determine the reliability of injury signs in guiding choices of insecticides to apply and (iii) to determine field efficacy of selected insecticides on *S. frugiperda*

MATERIALS AND METHODS

Study Location

The study was conducted under field condition at Mikese in Morogoro, Tanzania (Fig 1) located at latitude 83⁰46'S, longitude of 30⁰38'E and altitude of 394m above sea level. The soil of the area was Sandy loam.

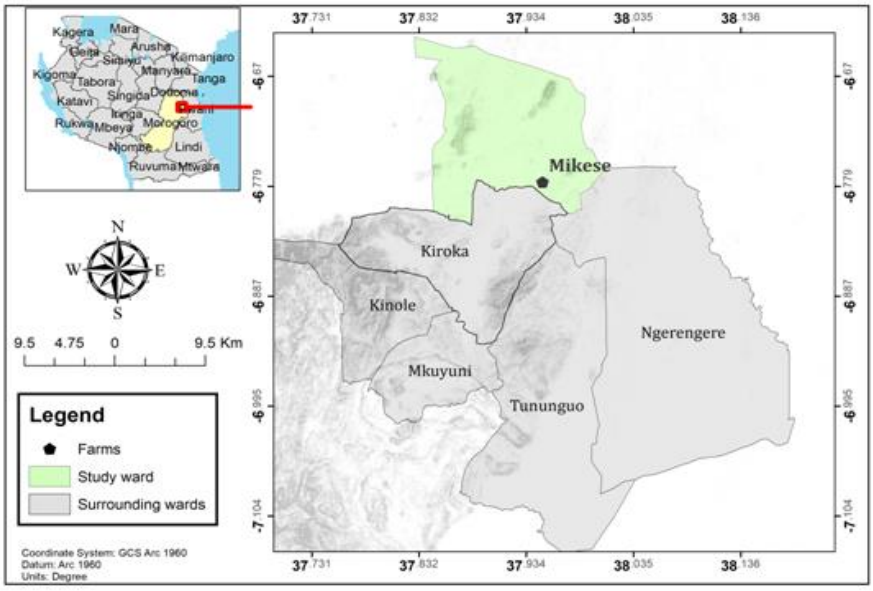


Figure 1: Study sites as extracted from Tanzanian map (Top left)

Establishment of *Spodoptera frugiperda* Colony

Spodoptera frugiperda larvae and eggs were collected from maize plots at Sokoine University of Agriculture (SUA) Edward Moringe Campus and some farms in villages around the campus. About 300 fourth instar *S. frugiperda* larvae were collected, preserved live and kept in different containers. The larvae were reared in cages of 100 cm x 50 cm x 50 cm in dimension. The cages were covered with wire mesh to allow good ventilation for the larvae to survive. Larvae were fed daily on tender maize leaves of about 10-15 days old obtained from a side plot established to serve as source of forage for reared colonies. The leaves were changed daily.

At pre-pupal stage the larvae were transferred to other containers filled with one-third of soil to support pupation. Sterile cotton soaked in a honey solution was placed in a petri dish inside the oviposition cage as a food source for the emerging adults. Newly emerged moths were allowed to mate. Adults that emerged on the same day were counted and isolated into cohorts of 30 individuals at a ratio of 15 :15 (male: female) and placed in rearing cages. A cohort was established following the protocols described by Prasanna et al. (2018) and maintained for three generations. About 2-3 days old egg batches were collected from the oviposition cages and placed in a sterile plastic containers. Eggs were monitored daily for hatching; as soon as the first instars emerged, they were provided with tender and fresh maize leaves (Deryck, 1979). The rearing was done at room temperature 26°C and 76% RH. Insect rearing was done in several batches until sufficient population was obtained and maintained to run the experiment. Second generation (F2) larvae were used for the study (Deryck, 1979; Cruz et al. 2010; Hardke et al. 2011).

Preparation of Insecticides

Ten different insecticides were used as detailed (Table 1). Each insecticide was thoroughly mixed with water as per manufacturer's recommendation for 5-10 minutes prior to application.

Experimental Design and Maize Crop Establishment

The study was laid out as factorial experiment in Randomized Complete Block Design (RCBD) with 44 treatment combinations replicated three times. Factor A consisted of four maize crop injury signs (window pane, circular holes, irregular holes and extensive defoliation) and Factor B consisted of ten insecticides and a control making 11 treatments. Land preparation was done by a tractor and leveling by using a hand hoe. Each plot had three rows, five plants per row. Dimension of each plot was 3.375 m^2 (2.25m x 1.5m). The distance from one replication to another was 2m, from one plot to another was 1m and the total experiment area was 1589.5m^2. Maize seeds of the variety DKC 90-89 was purchased from agro-dealers and planted at a spacing 75cm by 30cm. Insecticides were likewise purchased from trusted agro-dealer with batch numbers confirmed with TPRI through an official toll-free number 0800110031. The eleven treatments were applied as per randomization plan. All agronomic practices including thinning, gap filling, weeding, and fertilizer application were carried out in the field as per standard recommendations.

Artificial Infestation

Artificial infestation of 10 *S. frugiperda* larvae (1^{st} instar) was done to all maize seedlings two weeks after emergency. This activity was done early in the morning (between 7:00 am to 9:00

am) to avoid exposing the neonate to harsh environment (Prasanna et al. 2018). Monitoring for injury signs was done on daily basis and insecticides were applied after at least 50 of target plants had manifested the respective injury signs. Field incidence was determined by counting the observed infested plant leaves over the total number of maize plants per plot times a hundred, whereas the damage severity was determined by assessing the damage severity on maize plant following damage score (1-5) as described by Fotso et al. (2019) (Table 2).

Table 1: List of insecticides used in the experiment against *Spodoptera frugiperda*

Trade name	Active ingredient (a.i)	Insecticide group	Dosage (mls/l) of water)	Mode of entry
Belt 480 SC	Flubendiamide	Diamide	10mls/20l	Contact
Ninja plus 5EC	Lamdacyhalothrin 50g/l	Pyrethroid	50mls/20l	Contact
Duduba 450EC	Cypermethrin 150g/l and Chloropyrifos 300g/l	Pyrethroid and Organophosphate	48mls/20l	Contact and Systemic
Thunder 145 OD	Imidaclopride 100g/l-Betacyflurine 45g/l	Neonicotinoids and Pyrethroid	10mls/20l	Contact and Systemic
Snow Thunder16EC	Theamethoxam Emamectin-benzoate	Neonicotinoids and Avermectins	38mls/20l	Contact and Systemic
Multi-Alpha plus 150EC	Emamectin Benzoate 50 g/l Alphacypermethrin 100 g/l	Avermectins and Pyrethroid	20mls/20l	Contact and Systemic
Dudu acelamectin 5 EC	Alphacypermethrin, Acetamiprid 100 g/l	Phosphine and Neonicotinoids	30mls/20l	Contact
Attakan 350 SC	Imidacloprid	Neonicotinoids	20mls/20l	Contact
Liberate 200 EC	Emamectin benzoate, Indoxacarb 140.5g/l	Avermectins and Indoxacarb	10mls/20l	Contact and Systemic
Profecron 720EC	Profenophos 720g/l	Organophosphate	20mls/20l	Contact

Treatment Application

Eleven treatments (Ten insecticides plus water as control) were used. These insecticides were well mixed with water according to manufacturer's recommendation. A knapsack sprayer (Matabi Super Agro 16) calibrated to deliver 87.90 L per hectare through a hollow cone nozzles was used for insecticide application. Spray of insecticides was done 24 to 48 h after maize crop injury signs namely; window pane, circular holes, irregular holes and extensive defoliation caused by (1^{st} and 2^{nd} instar), (2^{nd} and 3^{rd} instar), (3^{rd} and 4^{th} instar) and (4^{th} to 6^{th} instar) of *S. frugiperda* was observed. Insecticide spray was done twice at a 14 days interval.

Data Collection

Five days after first spray, destructive sampling of five randomly selected maize plants from each plot was done and the number of dead larvae and live larvae were recorded. Seven days after each of the insecticide applications, number of infested leaves and total number of leaves per plants were recorded from the remaining ten plants per plot. Incidence was calculated using formula described by Sisay et al. (2019).

$$\%\ \text{FAW incidence} = \frac{\text{Number of FAW infested plants}}{\text{Total number of plants observed}} \text{x } 100$$

Damage severity score was recorded at seven days intervals by visual aid using a rating scale from 1 to 5 for scoring damage severity on whorl-stage plants as described by Fotso et al.

(2019) (Table 2). Plant height and leaf number were recorded at 70 days after seed emergency. After maize plant has attained maturity, maize cobs were sun dried for 5 days, threshed and sun dried again for 3 days and the moisture content of maize grain was measured by using moisture meter and the yield (kg/plot) of dry maize grain at 14% moisture content was obtained per each plot and recorded.

Table 2: Visual rating scale for *Spodoptera frugiperda* damage severity

Rating scale	Description
1.	Healthy maize without damage.
2.	1-10% leaf damage or presence of damage from FAW limited to characteristics window or < 5mm diameter and or destruction of only the leaf cuticle.
3.	11-25% leaf damage with presence of chewed areas < 5mm, funnel leaves still intact.
4.	26-50% leaf damage with presence of chewed areas larger than 1 cm, the funnel slightly damaged or less severe.
5.	> 50% leaf damage, plant stunting and funnel damaged severely.

Source: Fotso *et al*., 2019.

Data Analysis

Data were for tested for normalization and found to be not normally distributed and therefore were normalized using the arcsine formula: arcsin [$\sqrt{}$(xi/100)] was used, where 'xi' is each observation score (Gomez and Gomez, 1984). Two-way ANOVA was performed using Genstat software 16th edition on the data collected and Tukey 's honest significance difference was used for means separation at $p \leq 0.05$.

RESULTS

Spodoptera frugiperda Larval Mortality After Insecticide Application

The results showed that there were highly significant ($p < 0.001$) difference among maize crop injury signs for the percentage mortality caused by different insecticides (Table 3). Circular holes showed the highest mortality rate with no significant difference from window pane and irregular holes, but extensive defoliation had the lowest mortality rate of S. frugiperda larvae. Extensive defoliation is associated with advanced injury level often inflicted by the instar 4-6 stages.

Table 3: Spodoptera frugiperda larvae mortality 5 days after insecticides application based on crop injury signs on maize

Crop injury sign	% Mortality (Recovered)	% Mortality (Unrecovered)
Extensive defoliation	77.27a	22.73a
Irregular holes	84.85b	15.15b
Window pane	86.36b	13.64b
Circular holes	88.89b	11.11b
Mean	84.34	15.66
SE	1.769	1.312
CV	12.1	10.3
p-value	0.001	0.001

Means within a column followed by different letters are significantly different at ($p < 0.05$) (Tukey´s Test). CV= Coefficient of variation, SE= Standard error mean.

Interaction between Maize Crop Injury Sign and Insecticides on *S. frugiperda* Mortality

The results (Table 4) suggested that, treatment combination of maize crop injury sign and insecticides had significant effect (F = 1.2, Df = 30, $p \leq 0.001$). Treatment combination between window pane with (Belt 480 SC, Duduba 450 EC, Multi alpha plus 150 EC, Profecron 720 EC and Snow Thunder 16 EC) had the highest mortality (100%) five days after insecticide application. Window pane with Attakan 350 SC had the lowest mortality (72.22%). Treatment combination between Circular holes with Multi alpha plus 150 EC, Profecron 720 EC and Snow Thunder 16 EC, Liberate 200 EC and Dudu acelamectin 5EC had the highest mortality (100%) whereas treatment combination between circular holes with Thunder 145 OD had lowest mortality (88.88%). Treatment combination between irregular holes with multi Alpha plus had the highest mortality (100%) whereas with Snow thunder 16EC had the lowest mortality (77.78%). Extensive defoliation with Multi Alpha Plus 150 EC had the highest mortality (100%) whereas the lowest mortality (66.67%) was recorded when combined with Attakan 350 SC.

Table 4: Interaction effect of maize crop injury sign and insecticides on mortality of Spodoptera frugiperda under field condition

Crop injury sign-insecticide	Mortality (%)
Circular Holes xWater	16.67a
Extensive Defoliation xWater	16.67a
Irregular Holes xWater	16.67a
Window Pane xWater	16.67a
Extensive Defoliation xAttakan 350 SC	66.67b
Extensive Defoliation xThunder 145 OD	66.67b
Window Pane xAttakan 350 SC	72.22b
Extensive Defoliation xNinja Plus 5 EC	77.78b
Extensive Defoliation xBelt 480 SC	77.78b
Irregular Holes Snow xThunder 16 EC	77.78b
Window Pane Thunder x145 OD	77.78b
Extensive Defoliation xDudu Acelamectin 5 EC	83.33b
Extensive Defoliation xLiberate 200 EC	83.33b
Irregular Holes xNinja Plus 5 EC	83.33b
Extensive Defoliation xSnow Thunder 16 EC	88.89b
Circular Holes xThunder 145 OD	88.89b
Irregular Holes xBelt 480 SC	88.89b
Irregular Holes xDudu Acelamectin 5 EC	88.89b
Irregular Holes xThunder 145 OD	88.89b
Circular Holes xAttakan 350 SC	88.89b
Circular Holes xNinja Plus 5 EC	94.44b
Extensive Defoliation xDuduba 450 EC	94.44b
Extensive Defoliation xProfecron 720 EC	94.44b
Window Pane Dudu xAcelamectin 5 EC	94.44b
Window Pane xLiberate 200 EC	94.44b
Window Pane xNinja Plus 5 EC	94.44b
Circular Holes xBelt 480 SC	94.44b
Circular Holes xDuduba 450 EC	94.44b
Irregular Holes xAttakan 350 SC	94.44b

Irregular Holes xDuduba 450 EC	94.44b
Window Pane xProfecron 720 EC	100b
Circular Holes xDudu Acelamectin 5 EC	100b
Circular Holes xLiberate 200 EC	100b
Circular Holes xMulti Alpha Plus 150 EC	100b
Circular Holes xProfecron 720 EC	100b
Circular Holes xSnow Thunder 16 EC	100b
Extensive Defoliation xMulti Alpha Plus 150 EC	100b
Irregular Holes xLiberate 200 EC	100b
Irregular Holes xMulti Alpha Plus 150 EC	100b
Window Pane xBelt 480 SC	100b
Window Pane xDuduba 450 EC	100b
Window Pane xMulti Alpha Plus 150 EC	100b
Window Pane xSnow Thunder 16 EC	100b
Irregular Holes xProfecron 720 EC	100b
Mean	84.34
SE	5.868
Cv%	12.1
p-Value	0.001

Means within a column followed by different letters are significantly different at $p \leq 0.05$ (Tukey´s Test). CV= Coefficient of variation, SE= Standard error mean

Incidence of *S. frugiperda* on Maize Crop After Two Consecutive Insecticide Sprays Based on Crop Injury Sign

Obtained results suggested a significant ($F = 4.31$, $Df = 3$, $p < 0.001$) difference in S. frugiperda incidence on maize leaf among the different maize crop injury sign after treatment application (Table 5). Window pane, circular holes and extensive defoliation plots had highest incidence level of S. frugiperda compared to irregular holes plot which had the lowest incidence after the 1st spray. For the 2nd spray, results showed that there was a decrease in percent S. frugiperda incidence levels compared to the 1st spray. Generally, the foliar incidences decreased with the two consecutive insecticide sprays despite not attaining the lowest level.

Table 5: *S. frugiperda* incidence on maize crop with respect to crop injury signs after two consecutive insecticide sprays

Crop injury sign	% Incidence before Spray	% Incidence after 1st Spray	% Incidence after 2nd Spray
Irregular holes	63.52b	40.69a	17.17a
Extensive defoliation	75.32a	42.8b	17.62a
Window pane	61.29b	43.64b	18.73b
Circular holes	60.11b	43.94b	18.81b
Mean	65	43	18.08
SE	1.2	0.3	1.487
CV	10.5	1.2	14.2
p-value	0.001	0.001	0.001

Means within a column followed by different letters are significantly different at $p < 0.05$ (Tukey´s Test). CV= Coefficient of variation, SE= Standard error mean.

Interaction between Maize Crop Injury Signs and Insecticides on S. frugiperda Incidence after 1st and 2nd Sprays

Obtained results (Table 6) suggested that, treatment combination between maize crop injury signs and insecticides after 1st and 2nd spray had significant effects at $p < 0.001$ and $p = 0.02$ respectively. Treatment combination between window pane and insecticide indicated that, Snow thunder 16EC and Thunder 145 OD had the highest incidence 60% and 57.78% after 1st spray and belt 480 SC and Multi alpha plus 150 EC had lowest incidences of about 37.8%. Treatment combination between circular holes and insecticide showed that, Thunder 145 OD had highest incidence (61.1%) and Ninja plus 5 EC and Duduba 450 EC manifested lowest incidence 31.5% after 1st spray. Treatment combination of irregular holes and insecticide showed that, liberate 200 EC had the highest incidence (49.2%) after 1st spray and Duduba 450 EC showed the lowest incidence (31.75%) after the 1st spray. Treatment combination between extensive defoliation and insecticide showed that, Thunder 145 OD had the highest incidence (50%) after 1st spray and Multi alpha plus 150 EC had the lowest incidence (37.5%) after 1st spray.

Treatment combination between window pane and insecticides suggested that, Attakan 350 SC had the highest incidence (20.83%) while Duduba 450EC had the lowest incidence (2.78%) after 2nd spray. Treatment combination between circular holes and insecticides suggested that, Dudu acelamectin 5EC and Attakan 350 SC had highest incidence (16.5%) after the 2nd spray and Multi alpha plus 150 EC and Profecron 720 EC showed lowest incidence (2.47%) after 2nd spray. Treatment combination between irregular holes and insecticides suggested that, Attakan 350SC had the highest incidence (23.33%) whereas Duduba 450EC and Profecron 720 EC manifested lowest incidence after the 2nd spray. Treatment combination between extensive defoliation and insecticides suggested that, Attakan 350 SC had the highest incidence (17.17%) while Duduba 450 EC manifested the lowest incidence (2.02%) to extensive defoliation plots after 2nd spray. Generally, there was a reduction in pest incidence on maize plants after the 2nd spray.

Damage Severity Scores of *S. frugiperda* on Maize Crop After Two Consecutive Sprays

Highly significant ($p < 0.001$) differences among maize crop injury and damage severity scores for both sprays were observed (Fig. 2). Prior to the 1st spray, extensive defoliation plots tallied with the highest damage severity score whereas the window pane plots tallied with the lowest damage severity score. Similar scenario was recorded during the 1st and the 2nd spray. The impact of insecticide spray on severity score was greater in extensively defoliated plots from 4.7 to about 2.0 compared to the window pane level which had a slight impact from the score 2.0 to about 1.7. Generally, the observed trend suggested significant reductions of damage severity scores after the 2nd spray compared to the 1st spray.

Interaction Effect of Maize Crop Injury Sign and Insecticides on Maize Damage Severity After 1st and 2nd Spray Application

The treatment combinations between maize crop injury signs and insecticides had very significant ($p < 0.001$) effects in reduction of maize damage severity (Table 7). The combination of window pane injury level and insecticides indicated that Dudu acelamectin 5 EC and Attakan 350 SC suffered highest damage severity with scores of 1.7 and 1.3 respectively after 1st and

1.2 and 1.3 respectively after 2nd spray. Conversely, the insecticides; Multi alpha plus 150EC and Ninja plus 5EC manifested the lowest damage severity score (1.2) after 1st spray and Profecron 720 EC and Ninja plus had lowest damage severity of 1.04 and 0.9 respectively after the 2nd spray. Treatment combination between circular holes and insecticides indicated Thunder 145 OD and Belt 480 SC to exhibit damage severity score of 2.98 and 2.8 respectively after the 1st spray. The application of Profecron 720EC on circular holes plots led to lowest damage severity (1.4) after the 1st spray while Liberate 200 EC had highest damage severity (1.4). Duduba 450 EC had lowest damage severity (1.0) after 2nd spray. Treatment combination between extensive defoliation and insecticides showed that, Dudu acelamectin 5EC had highest damage severity (4.7) after 1st spray whereas Profecron 720EC showed lowest damage (1.9). After the 2nd spray Attakan 350 SC showed highest damage severity (1.8) whereas Multi alpha plus showed the lowest damage severity (1.03) after second spray.

Table 6: Interactions between maize crop injury sign and insecticides on S. frugiperda incidence after 1st and 2nd spray under field condition

Crop injury sign	% Incidence before Spray	% Incidence after 1st Spray	% Incidence after 2nd Spray
Circular Holes x Ninja Plus 5 EC	61.23a	31.48a	9.88ag
Circular Holes x Duduba 450 EC	60.58a	31.48a	3.7abc
Irregular Holes x Duduba 450 EC	62.11a	31.75a	2.22a
Irregular Holes x Ninja Plus 5 EC	63.21a	34.9ab	9.88ad
Irregular Holes x Multi Alpha Plus 150 EC	64.01a	36.5abc	3.33ab
Ext Defoliation x Multi Alpha Plus 150 EC	74.30b	37.5ad	9.09af
Window Pane x Belt 480 SC	61.34a	37.7ad	8.33a-e
Window Pane x Multi Alpha Plus 150 EC	60.19a	37.7ad	4.17abc
Irregular Holes x Profecron 720 EC	62.17a	38.1ad	2.22a
Circular Holes x Multi Alpha Plus 150 EC	59.10a	38.8ae	2.47ab
Extensive Defoliation x Duduba 450 EC	76.56b	38.9ae	2.02a
Circular Holes x Profecron 720 EC	60.00a	38.8ae	2.47ab
Window Pane x Ninja Plus 5 EC	62.11a	40.0af	8.33ae
Extensive Defoliation x Ninja Plus 5 EC	75.11b	41.6af	7.07ad
Extensive Defoliation x Profecron 720 EC	74.78b	41.6af	6.06ad
Circular Holes x Snow Thunder 16 EC	61.10a	44.4bg	11.11ag
Window Pane x Attakan 350 SC	62.00a	44.4bg	20.83efg
Window Pane x Dudu Acelamectin 5 EC	61.15a	44.4bg	18.06dg
Window Pane x Duduba 450 EC	58.90a	44.4bg	3.7ab
Irregular Holes x Belt 480 SC	64.13a	44.4bg	7.78ae
Ext Defoliation x Liberate 200 EC	76.11b	45.8bg	13.13ag
Ext Defoliation x Attakan 350 SC	74.34b	45.8bg	17.17cg
Ext Defoliation x Dudu Acelamectin 5 EC	74.23b	45.8bg	13.13ag
Ext Defoliation x Snow Thunder 16 EC	75.00b	45.8bg	13.13ag
Circular Holes x Belt 480 SC	61.12a	46.3bh	12.35bg
Window Pane x Liberate 200 EC	61.25a	46.6bh	18.06dg
Window Pane x Profecron 720 EC	60.92a	46.6bh	4.17abc
Extensive Defoliation x Belt 480 SC	75.59b	47.2ch	14.14ag
Irregular Holes x Attakan 350 SC	64.10a	47.2ch	23.33g

Irregular Holes x Dudu Acelamectin 5 EC	63.87a	47.2ch	11.11a
Irregular Holes x Snow Thunder 16 EC	63.42a	47.2ch	10.0ag
Irregular Holes x Thunder 145 OD	64.12a	47.2ch	13.33ag
Irregular Holes x Liberate 200 EC	62.16a	49.21di	22.22fg
Extensive Defoliation x Thunder 145 OD	76.11b	50.0ej	14.14ag
Circular Holes x Liberate 200 EC	59.90a	51.85fj	13.58ag
Circular Holes x Dudu Acelamectin 5 EC	60.23a	53.7gj	16.05bg
Circular Holes x Attakan 350 SC	59.79a	55.5gj	16.05bg
Window Pane x Thunder 145 OD	62.11a	57.78hij	19.44dg
Window Pane x Snow Thunder 16 EC	61.91a	60.0ij	11.11ag
Circular Holes x Thunder 145 OD	60.13a	61.11j	13.58ag
Circular Holes x Water	61.22a	88.89k	96.97h
Extensive Defoliation x Water	75.11b	95.83k	96.97h
Irregular Holes x Water	63.52a	100.0k	86.67h
Window Pane x Water	61.21a	100.0k	91.67h
Mean	65.04	49.18	18.08
SE	6.763	2.1	2.62
CV%	12.25	12.8	15.4
p-Value	0.01	0.001	0.02

Means within a column followed by different letters are significantly different at $p < 0.05$ (Tukey´s Test). CV= Coefficient of variation, SE= Standard error mean

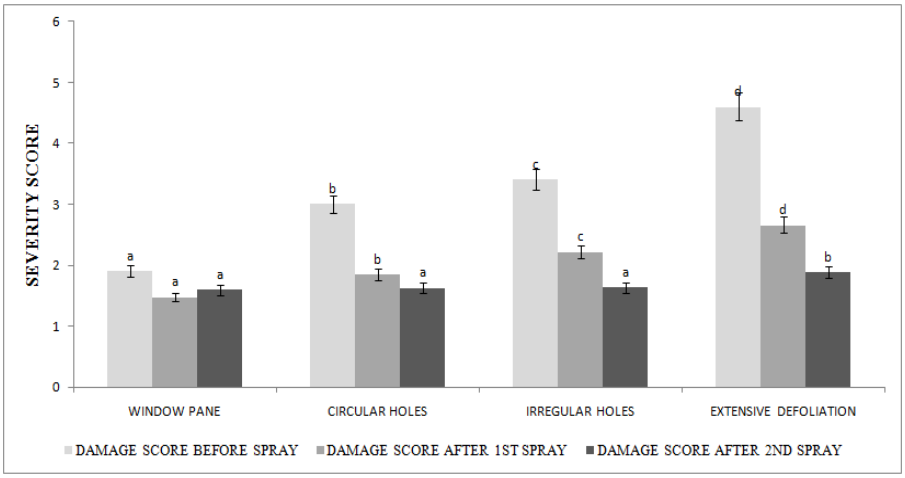


Figure 2: Damage severity score of S. frugiperda on maize plant before and after two consecutive sprays

Table 7: Interaction between maize crop injury sign caused by S. frugiperda and insecticides on maize damage severity after 1st and 2nd spray application

Crop injury sign-Insecticides	Severity score before Spray	Severity score after 1st Spray	Severity score after 2nd Spray
Window Pane x Ninja Plus 150 EC	1.9a	1.201a	0.984a
Ext defoliation x Multi Alpha Plus 150 EC	4.3d	2.344f-m	1.033a
Irregular holes x Profecron 720 EC	3.5c	1.674a-g	1.036ab
Circular holes x Duduba 450 EC	2.8b	1.542a-g	1.039abc
Irregular holes x Multi Alpha Plus 150 EC	3.5c	2.059a-g	1.039abc

Window Pane x Profecron 720 EC	1.8a	1.257ab	1.041bc
Extensive defoliation x Profecron 720 EC	4.7d	1.989f-n	1.1cd
Window Pane x Multi Alpha Plus 150 EC	1.9a	1.201a	1.1cd
Circular Holes x Profecron 720 EC	3.1c	1.423a-e	1.1cd
Irregular Holes x Duduba 450 EC	3.6c	1.822d-k	1.1cd
Circular Holes x Multi Alpha Plus 150 EC	2.89b	1.633b-i	1.125de
Window Pane x Duduba 450 EC	2ab	1.278abc	1.125de
Window Pane x Liberate 200 EC	2.1ab	1.388a-d	1.125de
Window Pane x Thunder 145 OD	2.3ab	1.344a-d	1.167ef
Circular Holes x Dudu Acelamectin 5 EC	3.51c	1.7c-j	1.167ef
Extensive Defoliation x Snow Thunder 16 EC	4.3d	2.067i-o	1.201efg
Circular Holes x Ninja Plus 5 EC	3.12ab	1.611b-h	1.202efg
Irregular Holes x Ninja Plus 5 EC	3.6c	2.467e-l	1.226fgh
Ext Defoliation x Dudu Acelamectin 5 EC	4.10d	4.79m-p	1.227fgh
Window Pane x Dudu Acelamectin 5 EC	2.2ab	1.542a-f	1.247hij
Circular Holes x Attakan 350 SC	2,5ab	2.133b-h	1.253ijk
Irregular Holes x Dudu Acelamectin 5 EC	3.4c	1.634k-o	1.256ijk
Circular Holes x Thunder 145 OD	2.9bc	1.267b-i	1.256jkl
Window Pane x Belt 480 SC	1.8a	1.2abc	1.212kl
Window Pane x Snow Thunder 16 EC	1.97a	1.4a-d	1.313kl
Extensive Defoliation x Belt 480 SC	4.7d	2.533opq	1.313kl
Window Pane x Attakan 350 SC	1.6a	1.364a-d	1.342lm
Irregular Holes x Attakan 350 SC	3.9cd	2.7l-o	1.4m
Irregular Holes x Belt 480 SC	3.3c	2.278nop	1.4m
Circular Holes x Belt 480 EC	2.8ab	2.311g-n	1.42mn
Circular Holes x Snow Thunder 16 EC	2.98ab	1.944h-n	1.42mn
Irregular Holes x Snow Thunder 16 EC	3.6c	1.989k-o	1.431no
Circular Holes x Liberate 200 EC	2.87bc	2.1f-n	1.433o
Extensive Defoliation x Liberate 200EC	4,9d	1.9pq	1.433o
Irregular Holes x Thunder 145 OD	3.5c	2.7j-o	1.5op
Extensive Defoliation x Thunder 145 OD	5.2de	2.033qr	1.5op
Extensive Defoliation x Ninja Plus 5 EC	4.4d	3.078m-p	1.743p
Extensive Defoliation x Attakan 350SC	4.1cd	2.544l-p	1.8q
Extensive Defoliation x Duduba 450 EC	4.0cd	2.278k-o	1.8q
Irregular Holes x Liberate 200EC	3.3c	2.244h-n	2.533r
Window Pane x Water	2.1a	3.1r	4.722t
Extensive Defoliation x Water	3.1c	5t	5t
Circular Holes x Water	2.9ab	3.33r	5t
Irregular holes x Water	3.76c	4s	5t
Mean	3.2	2	1.652
SE	4.632	2.8	0.262
Cv (%)	11.62	19	27.7
p-Value	0.001	0.001	0.001

Means within a column followed by different letters are significantly different at p ≤ 0.05 (Tukey´s Test). CV= Coefficient of variation, SE= Standard error mean

Maize Crop Injury-Based Insecticide Spray Guide for the Management of *S. frugiperda*

Crop injury-based insecticide spray guide have been established (Table 8) as the output of the conducted field experiment. This advisory spray guide will help farmers to manage Spodoptera frugiperda by making rational decision on selection of appropriate insecticides basing on the observed pest injury on maize crop.

Table 8: Maize crop injury-based insecticide spray guide for the management of S. frugiperda

Injury sign on maize crop	Possible larval instar stage	Advised insecticide spray and regime
Window pane	Larval instar 1-2	Use contact insecticides with single or multiple ingredient such as Lamdacyhalothrin (Ninja plus 5EC) Emamectin Benzoate and Indoxacarb (Liberate 200EC), Cypermethrin and Chloropyrifos (Duduba 450 EC). Apply twice, first application when 30% of the crop injury sign is observed and second application 14 days after first application.
Circular holes	Larval instar 2-3	Use fast acting and effective insecticides such as Alphacypermethrin and Acetamiprid (Dudu Acelamectin 5EC), Lamdacyhalothrin (Ninja plus 5EC), Emamectin Benzoate and Indoxacarb (Liberate 200EC). Apply twice, first application once 30% of the crop injury sign is observed and second application 14 days after first application.
Irregular holes	Larval instar 3-4	Use fast acting, systemic insecticide such as Flubendiamide (Belt 480 SC), Lamdacyhalothrin (Ninja plus 5EC), Emamectin Benzoate, (Snow Thunder 16EC). Apply twice, first application once 30% of the crop injury sign is observed and second application14 days after first application.
Extensive defoliation	Larval instar 4-6	Use fast acting, systemic & highly poisonous insecticide with multiple active ingredient such as Emamectin Benzoate and Alphacypermethrin (Multi Alpha Plus 150 EC), Profenofos (Profecron 720 EC), Cypermethrin and Chloropyrifos (Duduba 450 EC). Apply twice, first application when 30% of the crop injury sign is observed and second application 14 days after first application.

DISCUSSION

Window pane, circular holes and irregular holes plots had highest *S. frugiperda* larval mortality rate compared to extensively defoliated plots. This may be due to the fact that crop injury signs from window pane plots to irregular holes maize are caused by fall armyworm larval instar stages 1-4 of which are very young and easily succumbs to insecticides compared to larval instar 4-6 which are less susceptible. Similar findings were reported by Hardke et al. (2011) that larvae become more tolerant to insecticides as larval age and size increases. Furthermore, Adamczyk et al. (1999) found out that first instars are more susceptible to insecticides compared to the later instars. Cruz et al. (2012) also found out that application of insecticides to early *S. frugiperda* larvae results to high mortality as they are very susceptible to many insecticides.

The study also revealed that damage severity score increases from window pane to extensive defoliation plots. These results may be due the fact that the early maize crop injury signs from

window pane to irregular holes, the *S. frugiperda* larval instar stages which causes injury are instars 1-4. Due to their smallest in size they cause less damage to the maize plant as compared to the later stages like 4-6 instars which are large in size and consume large amount of plant leaves and therefore causing high damage severity. Similar results were reported (Adamczyk et al. 1999). Fernandez et al. (2019) reported that, the new born caterpillars are easily killed by insecticides, while at their advanced developmental stages the efficiency of the insecticides decreases. The results from this study also revealed that there is significant difference among insecticides in reducing damage severity score as it was observed that Profecron 720 EC had lowest damage severity score whereas Thunder 145 OD and Attakan 350 SC had highest damage severity percentage for both 1st and 2nd spray. The results on incidence and damage severity after treatment application showed that, as time increase the incidence and damage severity decreases and this may be due to the residual toxicity of the insecticides. Other workers (Hardke et al. 2011; Sisay, 2019) reported similar findings that larval mortality increased with time after insecticide application. In addition, Belay et al. (2012) observed that, as time increases the mortality of *S. frugiperda* larvae also increases.

Effective control of *S. frugiperda* under field condition based on the observed maize crop injury signs may be achieved by considering the following spray guide; i) For window pane**,** Use synthetic insecticide with active ingredient such as Lamdacyhalothrin (Ninja plus 5EC), Emamectin Benzoate and Indoxacarb (Liberate 200EC), Cypermethrin and Chloropyrifos (Duduba 450 EC). ii) For Circular holes, Use synthetic insecticide with active ingredient such as Alphacypermethrin and Acetamiprid (Dudu Acelamectin 5EC), Lamdacyhalothrin (Ninja plus 5EC), Emamectin Benzoate and Indoxacarb (Liberate 200EC). iii) For Irregular/rugged holes: Use synthetic insecticide with active ingredient such as Flubendiamide (Belt 480 SC), Lamdacyhalothrin (Ninja plus 5EC), and Emamectin Benzoate (Snow Thunder 16EC). iv) For Extensive defoliation and production of fuss: Use synthetic strong insecticide with contact or systemic active ingredient such as Emamectin Benzoate and Alphacypermethrin (Multi Alpha Plus 150 EC), Profenofos (Profecron 720 EC) and Cypermethrin and Chloropyrifos (Duduba 450 EC).

CONCLUSION

Different insecticides had varied effectiveness in controlling *S. frugiperda* larval instars albeit at varied developmental stages. Contact insecticides with single or multiple ingredients such as Lamdacyhalothrin (Ninja plus 5EC) could effectively control the pest at the early stages of development when window pane is a main injury sign. As the pest advances to instar stages 2 to 3 causing circular holes on maize leaves as the main injury sign, the pest could easily be taken care of by fast acting and highly effective insecticides such as Alphacypermethrin and Acetamiprid (Dudu Acelamectin 5EC) and others with similar mode of action such as Lamdacyhalothrin (Ninja plus 5EC), Emamectin Benzoate and Indoxacarb (Liberate 200EC). Fast acting insecticides with multiple active ingredients such as Flubendiamide (Belt 480 SC) and Lamdacyhalothrin (Ninja plus 5EC) were best suited to irregular holes injury signs, whereas at extensive defoliation the pest would best be treated using fast acting and highly poisonous insecticides with multiple active ingredient such as Emamectin Benzoate and Alphacypermethrin (Multi Alpha Plus 150 EC) and Profenofos (Profecron 720 EC).

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References

Abrahams, P., Bateman, M., Beale, T., Clottey, V., Cock, M., Colmenarez, Y., Corniani, N., Day, R., Early, R., Godwin, J. and Gomez, J., (2017). Fall armyworm: impacts and implications for Africa. *Evidence Note* (2). [http://www.cabi.org/faw.htm] site visited on 12/04/2020.

Adamczyk Jr, J. J., Leonard, B. R. and Graves, J. B. (1999). Toxicity of selected insecticides to fall armyworms (Lepidoptera: Noctuidae) in laboratory bioassay studies. *Florida Entomologist*, 230-236.

Belay, D. K., Huckaba, R. M. and Foster, J. E. (2012). Susceptibility of the fall armyworm, *Spodoptera frugiperda* (Lepidoptera: Noctuidae), at Santa Isabel, Puerto Rico, to different insecticides. *Florida Entomologist*, *95*(2): 476-478.

CABI (2019). Datasheet. *Spodoptera frugiperda* (fall army worm). Invasive Species Compendium http://www.cabi.org/isc/datasheet/29810 [Accessed April 2020].

Cruz, I., Figueiredo, M. D. L. C., Silva, R. B. D., Silva, I. F. D., Paula, C. D. and Foster, J. E. (2012). Using sex pheromone traps in the decision-making process for pesticide application against fall armyworm (*Spodoptera frugiperda* [Smith] [Lepidoptera: Noctuidae]) larvae in maize. *International Journal of Pest Management*, *58*(1): 83-90.

Day, R., Abrahams, P., Bateman, M., Beale, T., Clottey, V., Cock, M. and Gomez, J. (2017). Fall armyworm: impacts and implications for Africa. *Outlooks on Pest Management 28*(5): 196-201.

Deryck, P.W. (1979). Laboratory rearing of the fall armyworm. *Florida Entomological Society* 62(2): 87-91.

FAO, (2018) Integrated management of the Fall Armyworm on maize: A guide for Farmer Field School in Africa. [http://www.fao.org/faw], site visited on 14/4/2020.

FAO and CABI (2019). Community-Based Fall Armyworm (*Spodoptera frugiperda*) Monitoring, Early warning and Management, Training of Trainers Manual, First Edition. 112 pp. Licence: CC BY-NC-SA 3.0 IGO.

Fernandez, F. O., Abreu, J. A., Christ, L. M. and Rosa, A. P. (2019). Efficacy of insecticides against Spodoptera frugiperda (Smith, 1797). *Journal of Agricutural Science*, *11*, 494-503.

Firake, D. M. and Behere, G. T. (2020). Natural mortality of invasive fall armyworm, Spodoptera frugiperda (JE Smith) (Lepidoptera: Noctuidae) in maize agro ecosystems of northeast India. *Biological Control*, *148*, 104303.

Fotso Kuate, A., Hanna, R., Doumtsop Fotio, A. R., Abang, A. F., Nanga, S. N., Ngatat, S. and Fiaboe, K. K. M. (2019). Spodoptera frugiperda Smith (Lepidoptera: Noctuidae) in Cameroon: Case study on its distribution, damage, pesticide use, genetic differentiation and host plants. *PloS one*, *14*(4), e0215749.

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): e0165632.

Gomez, K. A. and Gomez, A. A (1984). Statistical Procedures for Agricultural research, 2nd edition, Singapore: John wiley and Sons.

Gutierrez-Moreno, R. A. (2017). Susceptibility of the fall armyworm, *Spodoptera frugiperda* (JE Smith) (Lepidoptera: Noctuidae) to Bacillus thuringiensis (Bt) proteins and synthetic insecticides from different corn production systems in Mexico and Puerto Rico. Dissertation for Award of PHD at Michigan State University, East Lansing, USA, 3- 17pp.

Hardke, J. T., Temple, J. H., Leonard, B. R. and Jackson, R. E. (2011). Laboratory toxicity and field efficacy of selected insecticides against fall armyworm (Lepidoptera: Noctuidae). *Florida Entomologist*, 272-278.

Kiva M. F., G. M. Tryphone and G. M. Rwegasira (2022). Response of *Spodoptera frugiperda* Larval Instars to Commonly Used Insecticides in Tanzania. Asian Plant Research Journal 10(4): 1-12, 2022. DOI: 10.9734/APRJ/2022/v10i4195.

Kiva M. F., Rwegasira, G. M., & Tryphone, G. M. (2023). Studies on the Influence of Altitude on Abundance of Fall Armyworm (*Spodoptera Frugiperda* (Je Smith)) (Lepidoptera: Noctuidae) in Tanzania. Discoveries in Agriculture and Food Sciences, 11(4). 43-54.

Midega, C. A., Pittchar, J. O., Pickett, J. A., Hailu, G. W. and Khan, Z. R. (2018). A climate-adapted push-pull system effectively controls fall armyworm, *Spodoptera frugiperda* (JE Smith), in maize in East Africa. *Crop Protection* 105: 10 - 15.

Negrisoli Jr, A.S., Garcia, M.S. and Negrisoli, C.R.B. (2010). Compatibility of entomopathogenic nematodes (Nematoda: Rhabditida) with registered insecticides for *Spodoptera frugiperda* (Smith, 1797) (Lepidoptera: Noctuidae) under laboratory conditions. *Crop protection* 29(6): 545-549.

Prasanna B.M., Joseph E.H. and Regina E, Virginia M. P, (Ed.) (2018). Fall Armyworm in Africa: A guide for integrated pest management. *Proceedings of CIMMYT Workshop, Entebbe, Uganda.16-17 September 2017*. 107pp.

Santos, A. C. V. D., Fernandes, C. C., Lopes, L. and SOUSA, A. H. D. (2016). Insecticidal oils from amazon plants in control of fall armyworm. *Revista Caatinga*, *29*(3): 642-647.

Sisay B, Simiyu J, Malusi P, Likhayo P, Mendesil E, Elibariki N, Wakgari M, Ayalew, G. and Tefera, T. (2018). First report of the fall armyworm, *Spodoptera frugiperda* (Lepidoptera: Noctuidae), natural enemies from Africa. *Journal of Applied Entomology* 142(8): 800 – 804.

Sisay, B., Tefera, T., Wakgari, M., Ayalew, G. and Mendesil, E. (2019). The Efficacy of Selected Synthetic Insecticides and Botanicals against Fall Armyworm, *Spodoptera frugiperda* in Maize. *Insects* 10(2): 45.

Sisay, B. (2018). Evaluation of Different Management options of Fall Armyworm, (JE Smith) (Lepidoptera: Noctuidae) and Assessment of its Parasitoids in Some Parts of Ethiopia. Dissertation for Award of MSc Degree at Hamaraya University, Ethiopia, 18-28pp.

Thumar, R. K., Zala, M. B., Varma, H. S., Dhobi, C. B., Patel, B. N., Patel, M. B. and Borad, P. K. (2020). Evaluation of insecticides against fall armyworm, *Spodoptera frugiperda* (JE Smith) infesting maize. *International Journal of Chemical Studies*; SP-8(4): 100-104.