Response of *Spodoptera frugiperda* Larval Instars to Commonly Used Insecticides in Tanzania

Abstract

Fall armyworm, *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera: Noctuidae), is a polyphagous migratory pest reported in Tanzania in 2017. Limited choices of officially registered insecticides for the control of the pest when it first occurred led to many farmers opting for the few available ones including those that were not registered for the pests. The current study drew from a survey conducted in 2018 that listed the insecticides commonly used by farmers against the pest. The study assessed the effectiveness of the insecticides against the different *S. frugiperda* larval instars under field condition in 2019 and 2020 growing seasons. Ten commonly used insecticides were applied on *S. frugiperda* damaged maize crop. Obtained results suggested a varied effectiveness of the tested insecticides with some inflicting significant ($p < 0.001$) mortality of *S. frugiperda* larvae while some proved ineffective. Ninja plus 5EC, Profecron 720 EC, Multi alpha plus 150 EC and Duduba 450 EC, caused highest mortality of *S. frugiperda* in all experimental plots accompanied with reduced incidences and damage severities on maize crop while Thunder 145 OD and Attakan 350 SC were the least effective. Yields obtained from the experiments 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 prove that some insecticides were effective against the pest while some were not. As such farmers' complaints on the ineffectiveness of traded insecticides could be real.

Key words: *Spodoptera frugiperda*, Fall armyworm, Insecticides, Mortality, Larval instars, Maize crop.

1.0 Introduction

Fall armyworm (FAW), *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae) is a 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 countries 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 in 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, including Maize, Sorghum, Rice, Sugar cane, Cow pea, Soybean, Groundnuts, Cotton, Round potato, Amaranthus, Grape, Orange, Papaya, Napier, Desmodium and various ornamental plants.

Due to its polyphagous and migratory nature *S. frugiperda* has become a pest of concern wherever is reported to occur (Baudron et al., 2019). 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 African countries which suggestively a major threat to food security in the continent (Day et al., 2018). On February 2017 *S. frugiperda* was first detected in Rukwa, Tanzania and thereafter reported 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 to long distances and feed on a broad host range which makes other control options less efficient and instead the use of insecticides has 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 combined 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 registering authority (The Tropical Pesticide Research Institute-TPRI) 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 (G. Rwegasira, unpublished data). 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 existed vacuum and prescribed whatever they had to unsuspecting farmers. As observed by Kumela et al. (2018) the outcome of using insecticides was disappointing and could not satisfy farmers because most of them proved ineffective against *S. frugiperda*. While farmers feared of most products being counterfeit, quick survey (unpublished data) done by researchers at Sokoine University of Agriculture (SUA) indicated that most insecticides were genuine although not all were recommended for use against *S. frugiperda.* The use of wrong insecticides coupled with poor application techniques including dosages and timing of application were visualized as possible causes for added inefficacy of the insecticides. Fernandes et al. (2019) reported that the six instar stages of *S. frugiperda* have varied responses to insecticides and the more advanced the stage the higher the chances of resistance against insecticides.

The fact that farmers in Tanzania applied a wide range of insecticides against *S. frugiperda* which variably led to inadequate effectiveness worried SUA researchers. Preliminary study led to establishment of a list of insecticides used against the pest in the country, upon which the ten common ones were identified. Although it is a well-established fact that some insecticides were not recommended against the pest, the possibility of resistance which is often tied to larval developmental stages could not be overlooked. Moreover, it is not uncommon that an insecticide registered for one pest may be extended to another pest (through label extension) after is proven effective against other pests. The objectives of the study were to; (i) determine the effectiveness of tested insecticides against *S. frugiperda* on maize crop, (ii) to determine the responses of different *S. frugiperda* larval instars to the test insecticides and (iii) establish the resultant maize yield with respect to the tested insecticides against *S. frugiperda.* The present study details the findings and shares insights on those knowledge gaps.

2.0 Materials and Methods

2.1 Study location

The study was conducted under field condition at Mikese in Morogoro, Tanzania (Fig. 1) located at 83^{0}46'S, 30^{0}38'E and 394m above sea level. The soil of the area was predominantly Sandy loam. The study was conducted during the short rainy season from November 2019 to February, 2020 and repeated during the long rainy season from March to June, 2020. The experimental field was in isolation, located at a minimum of 1 km away from other farms.

2.2 Establishment of *Spodoptera frugiperda* colony

Spodoptera frugiperda larvae and eggs were collected from maize plots at SUA campus and nearby villages around SUA Edward Moringe Campus. About 300 fourth instar *S. frugiperda* larvae were collected, preserved and kept in different containers. The larvae were reared in cages of 100 cm x 50 cm x 50 cm in dimension, these cages have well ventilation for the larvae to survive. Larvae were fed daily on tender leaves 10-15 days old obtained from a side plot established to serve as source of forage for reared colonies. 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 e-merged 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. The insects were reared as described above 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).

2.3 Experimental design and maize crop establishment

The study was laid out as factorial experiment in a split-plot design with 44 treatment combinations replicated three times. Factor A consisted of four larval developmental stages (Larval stage (1-2), (2-3), (3-4) and (4-6) and Factor B consisted of ten commonly used insecticides and a negative control making a total of 11 treatments (Table 1). The ten test insecticides used were selected among many considering the most commonly used by at least a cumulative number of ten different farmers and found in at least three regions in Tanzania. These were as detailed (Table 1). 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. 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 2.25 m x 1.5 m which gave a total area of 3.375 m^2. The distance from one replication to another was 2 m, from one plot to another was 1m and the total experiment area was 1589.5 m^2. Maize seeds of the variety DKC 90-89 was purchased from agro-dealer and planted at a spacing 75cm by 30cm. All agronomic practices including thinning, gap filling, weeding and fertilizer application were carried out in the field as per standard recommendations.

2.4 Artificial infestation

Artificial infestation of 10 *S. frugiperda* larvae (1st 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

2.5 Treatments application

Eleven treatments (Ten insecticides plus water as control) were used. The insecticides were measured into clean water as per manufacturer's recommendation and thoroughly mixed for 5-10 minutes. 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 recording the respective *S. frugiperda* injury signs on maize crop namely; window pane, circular holes, irregular holes, and extensive defoliation with production of fuss caused by (1st and 2nd instar), (2nd and 3rd instar), (3rd and 4th instar) and (4th to 6th instar) of *S. frugiperda* respectively on at least 50% of plants in the respective treatments. Insecticide spray was done twice at a 14 days interval.

2.6 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 and live larvae was recorded. Seven days after each of the insecticide applications, number of injured 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) as presented below:

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

The pest damage severity scores were recorded at seven days intervals by visual assessment using a rating scale from 1 to 5 as described by Fotso et al. (2019) (Table 2). Plant heights and leaf number were recorded at 70 days after seed emergency. After maize plant had attained maturity, maize cobs were harvested and sun dried for five days, threshed and sun dried again for three days to allow attainment of recommended moisture content for storage of maize grains at 14%. The moisture was measured by using moisture meter and the yield (kg/plot) of dry maize grain was calculated 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.

2.7 Data Analysis

Data from the first and second season were averaged, tested for normality and found not normally distributed after which were arcsine transformed using the formula: arcsine √(xi/100) whereby, xi referred to individual observation score (Gomez and Gomez, 1984). Two way ANOVA was performed using Genstat software 16th edition on the data collected and Tukey's honest test of significance was used for means separation at $p \leq 0.05$.

3.0 Results

3.1 Response of *S. frugiperda* larval instars to the tested insecticides

Obtained results (Table 3) suggested a highly significant effect (F = 1.2, Df = 30, $p \leq 0.001$) of treatment combination between larvae developmental stages and insecticides. Treatment combination of larval stage (1-2) with insecticides (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. Larval stage (1-2) with Attakan 350 SC had the lowest mortality (72.22%).

Table 3: Response of *S. frugiperda* larval instars to tested insecticides

LARVAL DEVELOPMENT STAGE-INSECTICIDE	MORTALITY (%)
Larval stage (2-3) xWater	16.67a
Larval stage (4-6) xWater	16.67a
Larval stage (3-4) xWater	16.67a
Larval stage (1-2) xWater	16.67a
Larval stage (4-6) xAttakan 350 SC	66.67b
Larval stage (4-6) xThunder 145 OD	66.67b
Larval stage (1-2) xAttakan 350 SC	72.22b
Larval stage (4-6) xNinja Plus 5 EC	77.78b
Larval stage (4-6) xBelt 480 SC	77.78b
Larval stage (4-6) xSnow xThunder 16 EC	77.78b
Larval stage (1-2) xThunder x145 OD	77.78b
Larval stage (4-6) xDudu Acelamectin 5 EC	83.33b
Larval stage (4-6) xLiberate 200 EC	83.33b
Larval stage (3-4) xNinja Plus 5 EC	83.33b
Larval stage (4-6) xSnow Thunder 16 EC	88.89b
Larval stage (2-3) xThunder 145 OD	88.89b
Larval stage (3-4) xBelt 480 SC	88.89b
Larval stage (3-4) xDudu Acelamectin 5 EC	88.89b
Larval stage (3-4) xThunder 145 OD	88.89b
Larval stage (2-3) xAttakan 350 SC	88.89b
Larval stage (2-3) xNinja Plus 5 EC	94.44b
Larval stage (4-6) xDuduba 450 EC	94.44b
Larval stage (4-6) xProfecron 720 EC	94.44b
Larval stage (1-2) xDudu xAcelamectin 5 EC	94.44b
Larval stage (1-2) xLiberate 200 EC	94.44b
Larval stage (1-2) xNinja Plus 5 EC	94.44b

Larval stage (2-3) xBelt 480 SC	94.44b
Larval stage (2-3) xDuduba 450 EC	94.44b
Larval stage (3-4) xAttakan 350 SC	94.44b
Larval stage (3-4) xDuduba 450 EC	94.44b
Larval stage (1-2) xProfecron 720 EC	100b
Larval stage (2-3) xDudu Acelamectin 5 EC	100b
Larval stage (2-3) xLiberate 200 EC	100b
Larval stage (2-3) xMulti Alpha Plus 150 EC	100b
Larval stage (2-3) xProfecron 720 EC	100b
Larval stage (2-3) xSnow Thunder 16 EC	100b
Larval stage (4-6) xMulti Alpha Plus 150 EC	100b
Larval stage (3-4) xLiberate 200 EC	100b
Larval stage (3-4) xMulti Alpha Plus 150 EC	100b
Larval stage (1-2) xBelt 480 SC	100b
Larval stage (1-2) xDuduba 450 EC	100b
Larval stage (1-2) xMulti Alpha Plus 150 EC	100b
Larval stage (1-2) xSnow Thunder 16 EC	100b
Larval stage (3-4) xProfecron 720 EC	100b
Mean	84.34
SE	5.868
Cv%	12.1
***p*-Value**	0.001

The treatment combination of larval stage (2-3) with insecticides (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 of larval stage (2-3) with Thunder 145 OD had lowest mortality (88.88%). Treatment combination of larval stage (3-4) with Multi Alpha plus had the highest mortality (100%) whereas with Snow thunder 16EC the lowest mortality (77.78%) was recorded. Treatment combination of larval stage (4-6) with Multi Alpha Plus 150 EC had the highest mortality (100%) whereas Attakan 350 SC proved to be least effective with the lowest mortality (66.67%).

3.2 Insecticides based-mortality of *S. frugiperda* larvae

Highly significant (F = 63.24, Df = 10, $p < 0.001$) differences among insecticides in causing mortality of *S. frugiperda* larvae with respect to the different larvae stages was observed (Table. 4) at five days after insecticides application. Thunder 145 OD and Attakan 350 SC exhibited lowest mortality rate whereas Multi alpha plus 150EC, Duduba 450EC, Profecron 720EC and Liberate 200 EC caused highest mortality of *S. frugiperda* larvae. Of all these, Multi alpha plus 150EC was the best performer causing total mortalities to all larval instars.

Table 4: Mortality of *S. frugiperda* larvae five days after insecticides application

Insecticide	Mortality (%)
Control (Water)	16.67a

Thunder 145 OD	80.56b
Attakan 350 SC	80.56b
Ninja Plus 5 EC	87.5bc
Belt 480 SC	90.28bc
Dudu Acelamectin 5 EC	91.67bc
Snow Thunder 16 EC	91.67bc
Liberate 200 EC	94.44c
Duduba 450 EC	95.83c
Profecron 720 EC	98.61c
Multi Alpha Plus 150 EC	100c
Mean	84.34
SE	2.934
CV%	12.1
***p*-Value**	0.001

*Mortality counts was based on number of recovered *S. frugiperda* larvae

3.3 Effect of insecticides on *S. frugiperda* incidence on maize crop

Collected data after two consecutive sprays suggested a highly significant ($p < 0.001$) difference among insecticides in the reduction of *S. frugiperda* incidence on maize leaves (Fig.2). Ninja plus 5EC had lowest incidence after the first round of spray whereas Thunder 145 OD retained highest incidences attributed to the lowest mortality of the pest. After 2nd round of spray, Duduba 450 EC exhibited lowest incidence whereas Attakan 350 SC and Liberate 200EC had highest incidence.

3.4 Effect of insecticides on damage severity score of *S. frugiperda* on maize crop

The collected data before and after two consecutive sprays of the test insecticides suggested a highly significant ($p < 0.001$) differences among insecticides in reduction of damage severity on maize crop (Fig. 3). Plants treated with Thunder 145 OD exhibited the highest damage severity while those treated with Profecron 720 EC had the lowest damage severity after 1st spray. The severity scores after the 2nd round of insecticide spray suggested that plants treated with Attakan 350 SC suffered greatest damages whereas those treated with Profecron 720 EC had the lowest damage severity score.

3.5 Plant heights and number of plant leaves under different treatments

The assessment on whether the applied insecticides imposed any effect on plant growth based on plant heights and number of leaves suggested no significant difference ($p = 0.124$) among treatments (Table 5). The results on mean plant heights suggested a significant ($p = 0.002$) difference among larval instars treatments implying that at larval instars 1-2 the plants were shorter and the heights increased as the larval instars advanced. At larval instar 1-2, the plants had shortest height (194 cm) while tallest plant height coincided with larval instars 4-6 (209.7 cm). Arguably, the *S. frugiperda* larvae developmental stages increased with plant height.

Table 5: Influence of *S. frugiperda* on number of leaves and plant height of infested maize crop

Larval instar stage	No. of leaves	Plant Height
Larval stage (1-2)	14.33a	194.0a
Larval stage (4-6)	14.47a	209.7b
Larval stage (3-4)	14.62a	202.4ab
Larval stage (2-3)	14.67a	203.6ab
Mean	14.52	202.45
SE	0.107	2.779
CV%	4.2	7.9
***p*-value**	0.124	0.002

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

3.6 Number of leaves, plant height and yield under different insecticides treatments

The impacts of treating maize crop against *S. frugiperda* using different insecticides (Table 6) suggested great differences among them. The recorded maize yield (tons/ha) differed significantly ($p < 0.001$) among the treated plots. Plots treated with Duduba 450 EC produced highest yield (4.1 tons/ha) whereas non-protected plot (water only) had the lowest yield (2.1 tons/ha).

Table 6: Effect of tested insecticides on maize yield

Insecticides (treatments)	Yield (Tons/ha)
Belt 480 SC	3.3a
Multi Alpha Plus 150 EC	3.9i

Snow Thunder 16 EC	3.5f
Dudu Acelamectin 5EC	3.2d
DUDUBA 450 EC	4.1j
Attakan 350 SC	2.9c
Profecron 720 EC	3.6h
Liberate 200 EC	2.8b
Ninja Plus 5 EC	3.6g
Thunder 145 OD	2.8b
Water	2.1a
Mean	3.254
SE	0.003
CV%	1.1
***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

Discussion

The current study revealed that all the tested synthetic insecticides were effective against *S. frugiperda* larval instars albeit at varied effectiveness in causing mortality as observed by Kumela et al. (2018). The fact that all insecticides caused a significant mortality to all larval instars particularly instars 1-2 suggest that all tested insecticides could be used to control *S. frugiperda* if timing of early stage instars is given ultimate consideration. Application of synthetic insecticides caused a significant reduction in maize leaf damage compared to the non-treated control. The reduction in leaf damage was attributed to the reduced number of *S. frugiperda* larvae due to the impact of insecticides on treated plants. Sisay (2018) reported similar findings that reduction in leaf damage was observed after insecticide application.

The varied effectiveness of different insecticides in causing mortality to *S. frugiperda* larvae observed in the current study was attributed to not only the reaction of specific larval instars to insecticides but also the chemical composition of insecticides which affects their mode of action. Idrees et al. (2022) reported similar observations whereby larval instars of *S. frugiperda* responded differently to the test insecticides due to inherent characteristics of the insecticides and the insect reaction. For instance Thunder 145 OD and Attakan 350 SC caused lowest mortality to *S. frugiperda* larvae whereas Multi alpha plus 150EC, Profecron 720 EC, Duduba 450 EC and Liberate 200 SC caused highest mortality. The insecticide Thunder 145 OD is chemically composed of Neonicotinoid and Pyrethrin implying that while Pyrethrin is meant to offer quick knock down effect the impact could have been compromised by limited persistence while the Neonicotinoid targets Nicotinic acetylcholine receptors (nAChRs) is might not cause total kill to the *S. frugiperda* due to the presence of several nAChR subtypes with different affinities for neonicotinoid insecticides (Taillebois et al., 2018). Attakan 350 SC on the other hand has been formulated for the sucking insects and bits of chewing ones but not specific for lepidopterans. Generally the current findings were somehow contrary to the report by Thumar (2020) that Flubendiamide performed better in reduction of plant damage with highest mortality to *S. frugiperda* and the lowest was chloropyrifos 50% + cypermethrin 5% followed by chloropyrifos. Percentage *S. frugiperda* incidence of on maize crop injury after two consecutive spraying of insecticides differed significantly among different insecticides. Ninja plus 5EC and Duduba 450 EC had significantly lowest *S. frugiperda* incidence at 1^{st} and 2^{nd} spray whereas Thunder 145 OD and Attakan 350 SC had significantly highest incidence at 1^{st} and 2^{nd} sprays.

In the present study application of insecticides for at least two rounds was proven an effective approach in controlling *S. frugiperda*. Suggestively, while some insecticides acts fast with immediate kill after application as for the case of Ninja Plus 5 EC, others take some time and the action gets well appreciated after repeated application as manifested by Duduba 450 EC, Profecron 720 EC and Multi Alpha plus 150EC. Technically two to three rounds of insecticide application are encouraged to take care of different developmental stages of insect pests as observed by Edde, (2022).

The crop infestation with *S. frugiperda* does not affect the plant growth in terms of number of leaves produced neither the plant heights as established during the present study unless the damage inflicted is advanced to the complete destruction of terminal leaf whorl that occur following production of fuss. Thus, the application of insecticides to control *S. frugiperda* did not wait to the attainment of complete destruction of terminal growth parts causing no significant impact. According to FAO (2018), the maize crops have ability to compensate for its foliar damage as long as early interventions are made and there is enough moisture and nutrient. Sisay (2018) observed that there were no significant difference in mean number of leaves and plant height after insecticide application but the reduction of leaf damage due mortality of *S. frugiperda* larvae. In the case of crop yield, the effect of insecticide application on infested maize was paramount as similarly reported by Kumela et al. (2018). Maize plots treated with Duduba 450 EC produced higher yield as manifested through the grain weight compared to non-treated plots (water) which had the lowest weight. Suggestively, Duduba 450 EC was very effective in controlling different larval instars of *S. frugiperda* and allowed compensatory growth of the crop (FAO, 2018). Likewise, Sisay (2019) recorded higher fresh weight and dry weight of maize on plots sprayed with insecticides compared to non-treated plots.

Conclusion

Generally all tested insecticides were effective in controlling *S. frugiperda* infestation and qualifying them as effective management options for the pest. Although some insecticide caused limited mortality to the pest, their performances were relatively higher than the control treatment. Should farmers be observant and monitor the pest infestation and developmental stages, any of the tested insecticide could be used to cause appreciable protection to the crop. In case farmers cannot monitor the pest establishment on the crop and subsequent developmental stages of larval instars, the best performing insecticides such as Multi alpha plus 150EC, Duduba 450EC, Profecron 720EC and Liberate 200 EC should be used.

Data availability

Data collected during this study shall be made available should it be required by the Journal of Applied Entomology.

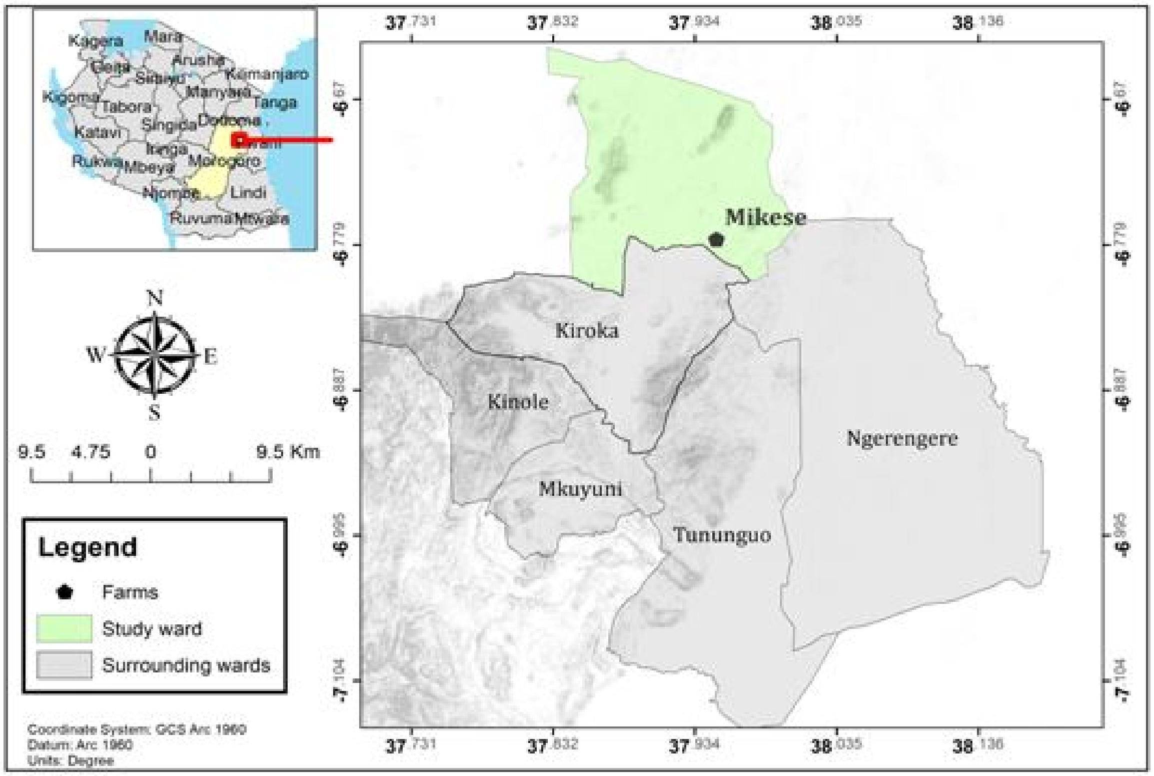

Figure 1: Study sites as extracted from Tanzanian map (Top left)

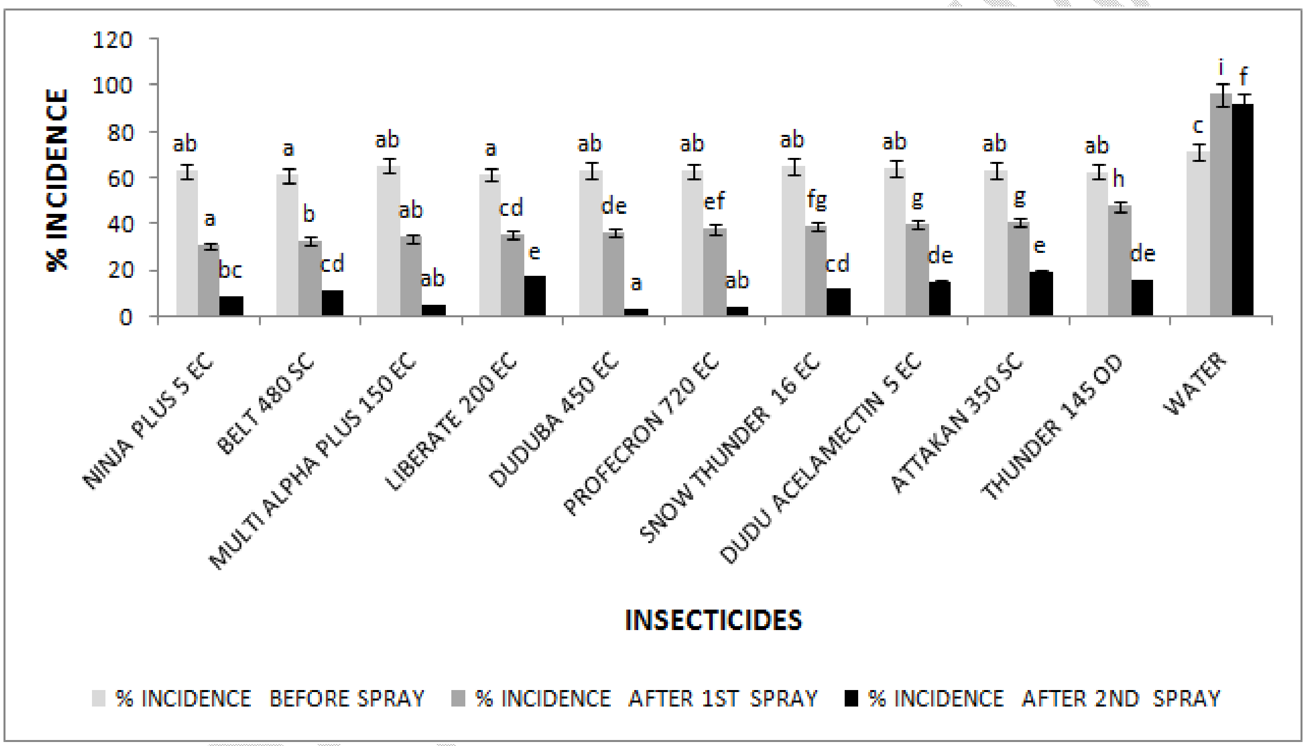

Figure 2: Influence of insecticides on *S. frugiperda* incidence on maize crop before and after insecticide sprays.

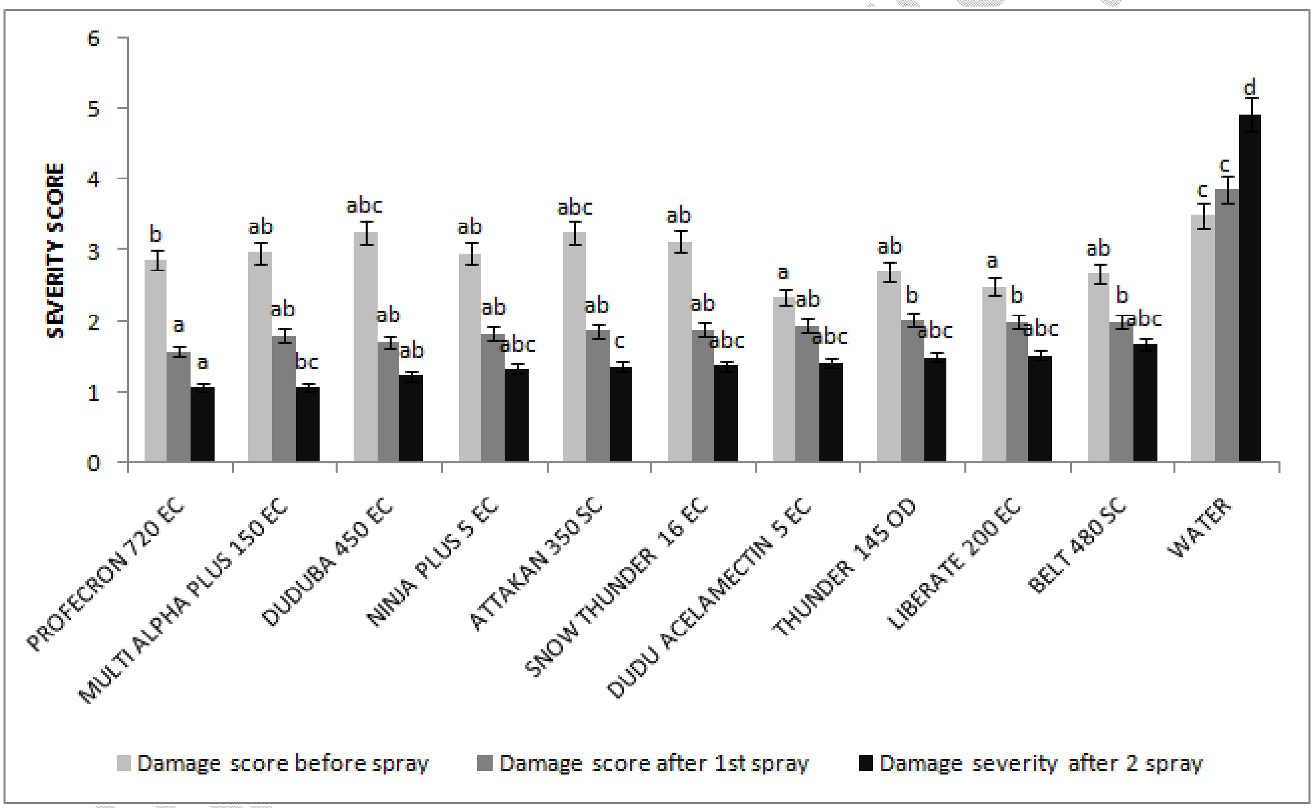

Figure 3: Damage severity score of *S. frugiperda* on maize crop before and after two consecutive sprays under field condition.

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