DYNAMICS OF FALL ARMYWORM *Spodoptera frugiperda* (Smith) (LEPIDOPTERA: NOCTUIDAE) IN MOROGORO AND PROSPECTS FOR INSECTICIDE-BASED MANAGEMENT OPTIONS

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A DISSERTATION SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN CROP SCIENCE OF SOKOINE UNIVERSITY OF AGRICULTURE MOROGORO, TANZANIA.

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EXTENDED ABSTRACT

Fall armyworm (FAW) *Spodoptera frugiperda* is one of the most devastating polyphagous field crop pests in many parts of the world, including Tanzania. This study aimed at determining the influence of altitude on the abundance of *S. frugiperda*, to assess the efficacy of insecticides that readily available and commonly used by farmers for the control of *S. frugiperda,* and to establish the reliability on injury sign observed on maize crop to determine the appropriate insecticide to apply for effective control of the pest. The study on influence of altitude showed that there was significant difference among location in FAW abundance ($p < 0.001$). At low altitude SUA, the mean FAW abundance was high (24 per trap) compared to medium (9 per trap) and high altitude (7 per trap), Mgeta and Nyandira respectively. The study on response of *S. frugiperda* larval stages to selected insecticides under the laboratory and screen house experiments showed significant variation ($p < 0.001$) in time taken to cause 50% and 100% mortality. In laboratory, Duduba 450 EC and Ninja plus 5EC caused 100% mortality at 48 hours after treatment (HAT). Thunder 145 OD was a fourth most effective with 79.05% mortality in 48HAT. In screen house varied effectiveness were significantly ($p < 0.001$) recorded among insecticides with Multi Alpha plus 150 EC causing 100% mortality to all larval instars followed by Thunder that caused 76.67% mortality 48 HAT. The field experiment conducted at Mikese to determine the right timing of insecticide application based on injury sign on maize crop suggested significant interactions ($p < 0.001$) between injury signs and larval development stages. Injury signs could be used in choosing insecticides that are effective against the respective *S. frugiperda* larvae stage. Thus, the findings from this study can be used in planning for insecticide-based management options for the control of *S. frugiperda*.

DECLARATION

I, Kiva Mbemba, do hereby declare to Senate of Sokoine University of Agriculture that this dissertation is my own original work done within the period of registration and that it has neither been submitted nor being concurrently submitted to any other institution.

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LIST OF ABREVIATIONS AND SYMBOLS

^0C	Degree Centigrade
ANOVA	Analysis of Variance
CABI	The Centre for Agriculture and Bioscience International
cm	Centimeter
DDVP	Dimethyl 2, 2-Dichloro Vinyl Phosphate
DK	Delkab
FAO	Food and Agriculture Organization
FAW	Fall armyworm
H	Hour
HSD	Honestly Significantly Difference
IPM	Integrated Pest Management
l	Litre
m	Meter
mm	Millimeter
CRD	Completely Randomized Design
RCBD	Randomized Complete Block Design
RH	Relative Humidity
SUA	Sokoine University of Agriculture
TPRI	Tropical Pesticide Research Institute
USA	United States of America

CHAPTER ONE

1.0 GENERAL INTRODUCTION

1.1 Background

Maize (*Zea mays* L.) belongs to the family Poaceae and ranks among the three most important cereal crops grown in the world (Rouf *et al*., 2016). Maize contributes to the country's economy for most of the African countries (Hailu *et al*., 2018). Maize crop is considered a food and cash crop for millions of smallholder farmers in Africa (Makirita *et al*., 2019).

In Tanzania, maize is the major cereal crop grown and consumed in almost every region (Ngurumwa, 2016; Nestory, 2016). It plays a food security role and income generation to several farming communities in the country (Nestory, 2016). Several key maize growing regions in Tanzania are Iringa, Njombe, Songwe, Mbeya, Ruvuma, Rukwa, Tanga, Kilimanjaro, Kagera, Morogoro, Manyara and Arusha (Rowhan*i et a*l., 2011; Suleiman and Kurt, 2015).

The crop is an important source of calories, contributing 33% of the total household consumption and also the major source of income and food for majority of smallholder farmers (Amar*e et* al., 2012; Suleiman and Kurt, 2015). It also serves as fodder for livestock and poultry. Maize is an essential source of carbohydrates, protein, minerals, vitamin and irons (Suleiman and Rosentrater, 2015; Day *et al*., 2017).

Despite its importance, the production of maize is constrained by both biotic and abiotic factors. These include poor yielding varieties, insect pests and diseases, weeds, poor soil fertility and drought. The most significant factor among biotic stresses is insect pests inclusive of field and storage ones. Cutworms (*Agrotis segetum*), white grubs (*Phyllophaga implicita*), elegant grasshoppers (*Zonocerus elegans*), Aphids (*Aphis gosypii*), African armyworm (*Spodoptera exempta*), locust (*Schistocera gregaria*), (*Sitophilus zeamais*), larger grain borer (*Prostephanus truncatus*), red flour beetle (*Tribolium castaneum*) and dried bean beetles (*Callosobruchus maculatus*) and Indian moths (*Plodia interpunctella*) (Suleiman and Kurt, 2015) and the recently introduced Fall Armyworm (*Spodoptera frugiperda*) are key pest known to occur in Tanzania.

Fall Armyworm (*Spodoptera frugiperda* Smith) is an insect native to tropical and subtropical regions of the Americas (Midega *et al.*, 2018). *S. frugiperda* larvae are polyphagous known to feed on more than 80 plant species many of which are important crops in Tanzania. These include maize, sorghum, rice, sugar cane, cow pea, soybean, groundnuts, cotton, round potato, amaranthus, grape, orange, papaya, napier, desmodium and various ornamental plants and may cause high yield losses if not well controlled (Prasanna *et al.,* 2018). This has made *S. frugiperda* a pest of concern wherever is reported to occur.

In Africa continent, 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). Report by Day *et al*. (2017) confirmed the presence of the pest in more than 44 countries in Africa which suggested a major threat to food security in the continent. Severe incidences of the pest usually occur during the onset of the wet season (Goergen *et al.,* 2016). In Tanzania, *S. frugiperda* was first detected in Rukwa on February 2017 and thereafter other border regions including Ruvuma and Mbeya. The extended occurrence of the pest across Africa called for immediate need of intervention strategies to minimize the crop damages and resultant economic losses.

1.2 Problem statement and justification

The production of maize in Tanzania faces a lot of challenges that significantly cause reduction in crop yield (Cairns *et al.*, 2013). Pests are among the key factors contributing to the low yield of maize (Sisay, 2018). *Spodoptera frugiperda* is an invasive and very serious pest causing substantial maize yield losses estimated at 8 to 21 million tons, leading to monetary losses of up to US$ 6.1 billion (Sisay, 2018). The pest has affected over 300 million people in Africa, who directly or indirectly depend on maize for food and well-being (Abrahams *et al.*, 2017; Sisay, 2018).

Maize crop in Tanzania is grown across a wide range of altitude from sea level to as high as about 2000m above sea level. Existing theories suggest that *S. frugiperda* might not be abundantly distributed at high altitude and thus inflicted damages could be economically insignificant. However the magnitude of *S. frugiperda* incidence and subsequent abundance based on altitude particularly in the studies locations was not well known. Understanding this would guide decision making on developing appropriate management strategy that can be taken to manage *S. frugiperda* pest based on location.

The occurrence of *S. frugiperda* is always sporadic and in high numbers which necessitate application of insecticides. Given the unprecedented outbreak of the pest in Tanzania the country was caught unprepared. By 2018 the Tropical Pesticides Research Institute (TPRI), an authority on pesticide registration banked recommend very few among the locally available insecticides to be used against *S. frugiperda.* The recommended insecticides had not been distributed throughout the country such that agro-dealers would advise farmers to make use of any available insecticides, the trap that farmers fell into out of frustrations and desire to protect their crops. A study on *S. frugiperda* management options conducted in Tanzania mainland in 2018(G. Rwegasira, unpublished data) indicated that farmers preferred insecticides compared to other management options as insecticides are quick in action and are easily available in their locality. Yet most farmers complained of inefficacy of most insecticides locally available in agro shops. Apart from suspected abuse of insecticides, the inherent enzymatic action by *S. frugiperda* whereby advanced larval instars detoxifies insecticides through microsomal oxidases (aldrin epoxidase, heptachlor epoxidase, biphenyl hydroxylase, *p*-nitroanisole *O*-demethylase, and phorate sulfoxidase) and hydrolases (helicin β-glucosidase and acetylcholinesterase) (Yu, 1991) might have contributed to insecticide ineffectiveness. Whether the ineffectiveness was born of the pest resistance or ineffectiveness of the insecticides, the data were scanty.

Counterfeit insecticides were also rumored to command their market share taking advantage of farmers' frustrations from the pest attack. It has been documented that environmental influence including weather, reaction of crop variety to insecticides and the interaction of insecticides with target pest, all affect the efficacy of insecticides (Prasanna *et al.,* 2018). In *S. frugiperda* where detoxication of insecticides through oxidative enzymes is common the timing of insecticide application should consider the larval development stage (Lwalaba *et al*., 2010). Thus, a few insecticides would work well across all six larval instars while some tend to affect only few instars at initial stages of development. Very often farmers responds to pest damage signs on crop by applying insecticide without thorough knowledge of the relationship between damage signs and the *S. frugiperda* larval development stage as well as the appropriate insecticide. Unfortunately, there has been no crop damage based guideline that would help farmers to make rational decision on when and which insecticide to apply. The current study was intended to fix these knowledge gaps by establishing the influence of altitude on *S. frugiperda* occurrence and perpetuation, identifying the most effective insecticides (among the locally available) with respect to *S. frugiperda* development stage, and developing the crop injury-based insecticide spray guide for the management of *S. frugiperda* in maize crop.

1.3 Objectives

1.3.1 Overall objective

To contribute to increased maize productivity through reduced crop losses caused by *Spodoptera frugiperda*.

1.3.2 Specific objectives

i. To determine the influence of altitude on the abundance of *Spodoptera frugiperda.*

ii. To assess the efficacy of different groups of insecticide for the control of *Spodoptera frugiperda*.

iii. To determine the right timing of insecticides application based on injury sign observed on maize crops.

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CHAPTER TWO

2.0 INFLUENCE OF ALTITUDE ON THE ABUNDANCE OF *SPODOPTERA FRUGIPERDA* JE SMITH (LEPIDOPTERA: NOCTUIDAE)

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2.1 Abstract

Fall armyworm (FAW) (*Spodoptera frugiperda)* is one of the most devastating polyphagous field pests in many parts of the world, including Tanzania. Influence of altitude on the abundance of *Spodoptera frugiperda* was determined by using Pheromone (Frugilure *S. frugiperda*, Chemtica interntional, S.A) embedded cup traps. This study was conducted at four locations with varied altitude namely SUA (525 masl), Mlali (579 masl), Mgeta (1050 masl) and Nyandira (1691 masl) located in Morogoro Region, Tanzania. A total of 16 cup traps (four at each location) were used. The four traps were arranged at 100 m apart. Weather data were recorded using Hygrocron i-button hung on a tree at equidistant from the four traps. Data on *S. frugiperda* counts and weather variables were recorded weekly for duration of six months from January to June 2020. Results showed that there was significant difference among altitude on *S. frugiperda* abundance ($p < 0.001$). At low altitude (SUA & Mlali) *S. frugiperda* abundance was high (24 adult *S. frugiperda* moths per trap per week) compared to medium, Mgeta (9 adult *S. frugiperda* moths per trap per week) and high altitude, Nyandira (7 adult *S. frugiperda* moths per trap per week). Rainfall had positive correlation on fall armyworm abundance (r = 0.16, r = 0.04) for SUA and negative correlation (r = -0.44) and (r = -0.03) for Mgeta and Nyandira.

Temperature had positive correlation (r = 0.21) on *S. frugiperda* abundance in Nyandira while SUA (r = -0.03), Mlali(r = -0.35) and Mgeta (r = -0.28) had negative correlation. Relative humidity for all four locations showed to have negative correlation with *S. frugiperda* abundance. Furthermore this study reveals that *S. frugiperda* was present in all locations for the whole period of six months hence appropriate and effective management practices should be focused from the month where major host crop (Maize) is present till near the maize flowering stage where infestation is normally low.

Keywords: *Spodoptera frugiperda*, Pheromone, Altitude, Abundance, Maize

2.2 Introduction

The Fall Armyworm (FAW) (*Spodoptera frugiperda)* is a devastating pest of maize which is native to America (Da*y et a*l., 2017). The pest was reported for the first time in the African continent in early 2016 (Prasanna *et al.*, 2018). According to Day *et al.*(2017), yield losses due to *S. frugiperda* in Africa range from 8.3 to 20.6 million metric tonnes per year in the absence of any control methods. Under farmer level, the insect can cause up to 100% yield loss if no control measures is imposed (Abraham*s et a*l., 2017).

Weather parameters play an important role in regulating the population of *S. frugiperda* under agro-ecosystems (Shahzad *et al*., 2014). Positive or negative correlation of weather factors with *S. frugiperda* abundance exists (Ali *et al.*, 2008). Outbreaks and resurgence of the insect pest is linked to weather factors such as elevations (Low, Medium and High altitude), temperature (high or low), abundance or scarcity of rainfall and the use of susceptible varieties in ecosystems (Shahzad *et al*., 2014). Altitude is inversely related to temperature given the fact that the increase of the former leads to the decrease of the later.

Weather condition affects physiological and behavioural characteristics of insect pests leading to temporal and spatial dynamics (Kingsolver, 1989). Temperature is a single most important factor controlling insects' development and hence population outbreak. Rainfall on the other hand can be the only reason for insect epidemic. Similarly, relative humidity above or below a certain limit can augment or lessen development of pests under certain conditions (Shahzad *et al*., 2014). Pheromone lures have long been used in monitoring, mass trapping and mating disruption of a great diversity of insect pests (Cruz *et al.*, 2012). Traps help to detect the invasions by novel pest species, the onset of seasonal pest activity, determine the range and intensity of pest infestation and track changes in pest populations all which help inform decision making for pest management (Spears *et al.*, 2016). The chemical composition of this has been determined, and synthetic pheromone can be used as a lure in a trap to monitor the moth population (Abrahams *et al*., 2017).

Frugilure *S. frugiperda* pheromone lures specific to *S. frugiperda* has been manufactured by Chemtica international S.A and recommended by FAO for monitoring the pest. Despite its importance pheromone traps have been experiencing challenges one among them is that some predators have evolved to detect these pheromones and may use them to identify and locate prey (Spears *et al.*, 2016). Trap uses may sometimes results into undesired outcome when non target insects including natural enemies are lured (Bhan *et al*., 2013; Spears *et al*., 2015). Thus traps and accompanying lures are expected to be as specific as possible.

Maize crop in Tanzania is grown across a wide range of altitude from sea level to as high as about 2000 m above sea level. However it is not known whether *S. frugiperda* incidence varies along the different altitude. Understanding this will guide informed decision making on where maize can be grown without much worry about *S. frugiperda* and places that requires intensive management of the pest. The objectives of the current study were; i) to determine the influence of altitude on the abundance of fall armyworm, ii) to establish the relationship between selected weather parameters and *S. frugiperda* abundance, and iii) to establish temporal abundance of *S. frugiperda* in relation to maize production season.

2.3 Materials and Methods

2.3.1 Study location

The study was conducted in Morogoro at four locations which include, Sokoine University of Agriculture (SUA) which is at 525 m above sea level, Mlali 579 m above sea level, Mgeta 1050 m above sea level and Nyandira 1691 m above sea level. Experimental locations coordinates for each location were collected using the Geographical Positioning System (GPS) and used to map the experimental sites using Google map (Arcgis software version 10.4). (Fig. 2.1).

Variation in altitude (from low to high) has been clearly shown using colours with SUA site being the lowest and Nyandira the highest.

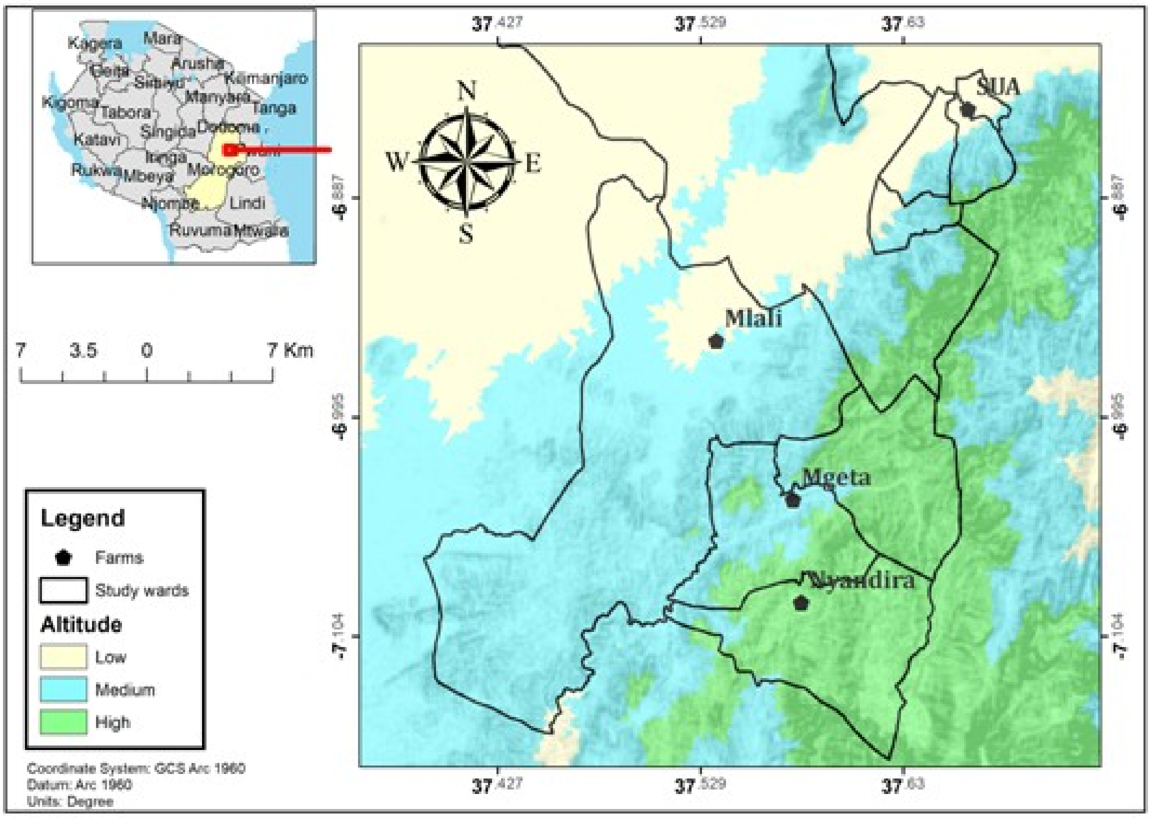

Figure 2.1: Study sites as extracted from Tanzanian map (Top left)

2.3.2 Experimental design

The experiment was laid out in Randomized Complete Block Design (RCBD) with four locations (as block). Treatments were the altitude (low, medium and high) and traps were the replications and were replicated four times. A commercially available *S. frugiperda* lure (Frugilure *S. frugiperda* manufactured by Chemtica international, S.A with batch number P061-Lure) and a moth catcher bucket trap was used for the study. Four traps embedded with pheromone lures were equidistantly set (100 m apart) at each location as per protocol (FAO and CABI, 2019). Each trap comprised of a rubber septum impregnated with *S. frugiperda* female sex pheromone hanged in a cage at the top of the moth catcher bucket and a single strip of Dimethyl 2, 2-DichloroVinyl Phosphate (DDVP) placed at the bottom of the bucket to serve as a killing agent. Male moths and other insects entering through vents on the sides of the bucket were knocked down by the DDVP into the bucket. A single trap was hanged on a pole at the centre of each of the selected maize farms at a height of 1.5 m above the ground (Plate 2.1 and 2.2). The sites were approximately about 15 km apart. Grease was applied to the thread/strings that held the trap to the pole to prevent the catches from being preyed on by predatory arthropods such as Big leaded ants, *Pheidole megacephala*. Traps were deployed in January 2020 and they remained in the field for 6 months. Trap deployment was planned to be available throughout six months regardless whether maize was available or not. This study was conducted for a total of 26 weeks. The lures and the DDVP were replaced after every two weeks. Monitoring of *S. frugiperda* dynamics was done throughout the crop establishment stage to harvesting then extended for three more months post crop maturity.

Plate 2.1: S*podoptera frugiperda* trap set in a maize field at SUA (V2 stage)

(V2 stage) = Maize with two true leaves

Plate 2.2: S*podoptera frugiperda* trap in a maize field (V8 stage)

(V8 stage) = Maize with 8 true leaves)

2.4 Data Collection

Data of trapped *S. frugiperda* moths were collected for one week interval for the duration of six months. Data collected include, number of adult *S. frugiperda* moths trapped per trap per location. Weather parameters (Temperature, Relative humidity and Rainfall) were recorded for one week interval. For SUA and Mlali location, weather data was obtained from SUA meteorological weather station and for Mgeta and Nyandira, Maxim integrated i-button devices (DS 9490#, 0838C, 365060 PHIL) (Hygrocron) manufactured by maxim integrated company were used to record weather parameters (Temperature and Relative humidity), Rainfall data for Mgeta and Nyandira was obtained from SUA station at Nyandira.

2.5 Data processing

Data collected were processed into two steps before analysis. First the data were tested for linearity, normality, multicollinearity and homogeneity assumptions, and second the data were transformed to meet the assumptions of the regression analysis. Linearity assumption were tested for each weather factor against the mean *S. frugiperda* through scatter plots, Normality of the data on the effects of temperature and humidity was verified by means of Shapiro – Wilk test and for homogeneity, Levene’s test was used. Data were neither normally distributed nor homoscedasticity and were therefore, the dependent variable (Mean *Spodoptera frugiperda* catches) were transformed by logarithm transformation to make sure all the assumptions were meet. Data on weather parameters (Temperature and Relative humidity) was recorded by Maxim integrated i-button devices (DS 9490#, 0838C, 365060 PHIL) (Hygrocron) manufactured by maxim integrated company and were retrieved by one wire viewer software.

2.6 Data Analysis

Data were subjected to Analysis of Variance (ANOVA) using GENSTAT software 16th edition. Means separation was done by using Tukey´s honest significant test ($p < 0.05$). Regression (R^2) and simple correlation (r) between weather factors and *S. frugiperda* catches were estimated using Pearson product moment correlation coefficient.

2.7 Results

2.7.1 *Spodoptera frugiperda* catches with time

The results on *S. frugiperda* catches showed that, *S. frugiperda* was present throughout all six months period. Dates and location varied significantly (F= 7.66, Df = 23, $p < 0.001$, and F= 40.03, Df = 3, $p < 0.001$) on *S. frugiperda abundance* (Fig 2.2). At SUA site the highest *S. frugiperda* catches were recorded on 2nd week of January and the lowest was on 2nd week of February and last week of March. At Mlali site the highest *S. frugiperda* catches was recorded on 2nd week of January and 3rd week of May and the lowest was 2nd week of February and last week of March. Mgeta site had the highest *S. frugiperda* catches recorded from 2nd week of February and 1st and 2nd week of May while the lowest was recorded in the 3rd week of February and 3rd week of March. At Nyandira the highest *S. frugiperda* catches were on 3rd week of January and June and the lowest was on the 3rd week of February and 2nd week of March, 2020.

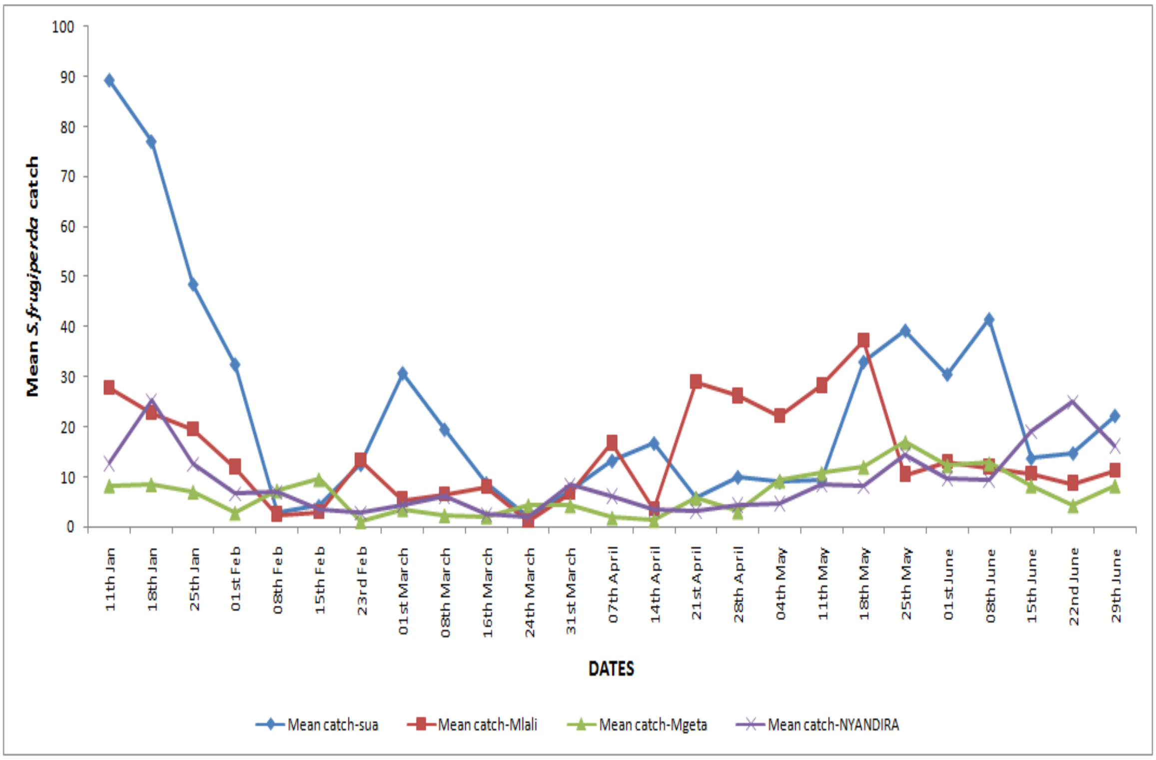

Figure 2.2: Weekly trend of *Spodoptera frugiperda* catches for duration of six months

2.7.2 *Spodoptera frugiperda* abundance at different altitude

The results showed that there was a highly significant (F= 22.05, Df= 3, $p < 0.001$) influence of altitude on fall armyworm abundance (Fig. 2.3). Numbers of trapped moths declined with increase in altitude. SUA had highest mean *S. frugiperda* catches while Nyandira had the lowest.

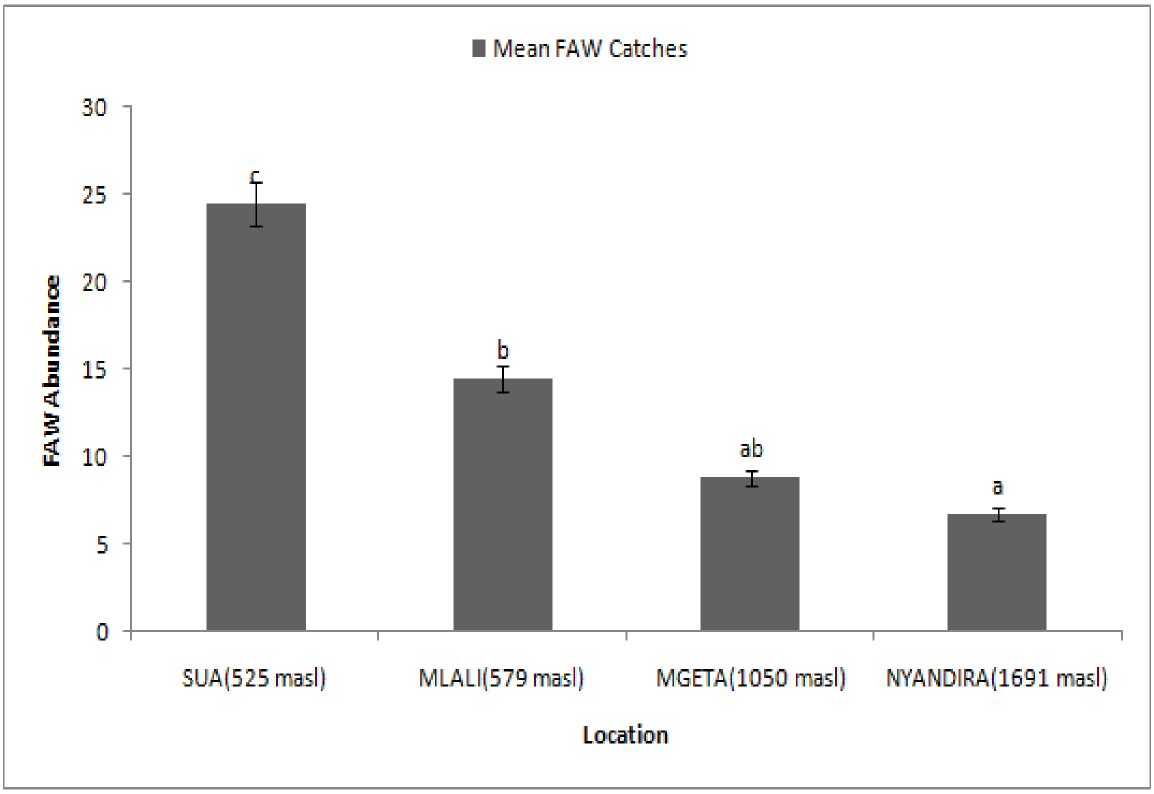

Figure 2.3: Mean Spodoptera *frugiperda* catches at different altitude for duration of six months

2.7.3 Relationship between trap catches and selected weather variables

The obtained results showed significantly ($p < 0.05$) positive association between temperature and *S. frugiperda* population abundance and the effect was statistically significant ($p < 0.05$) (Table 2.1). Each additional unit of temperature in the habitat leads to an increase in *S. frugiperda* population abundance by 0.0649 (6.49 %). Thus, the higher the temperature the greater the abundance of *S. frugiperda* and vice versa.

The relative humidity and rainfall had no effect on *S. frugiperda* abundance with statistically insignificant ($p = 0.066$ and $p = 0.2279$) values. As such, any changes in relative humidity and rainfall caused no effect on the abundance of *S. frugiperda*.

Table 2.1: Regression analysis of weather parameters against *S. frugiperda* abundance

Terms	Estimate	SE	p-value
Intercept	2.2987	0.9091	0.0131
Temperature	0.0649	0.0228	0.0055
Relative humidity	0.0186	0.0099	0.0660
Rainfall	0.0191	0.0157	0.2279
R squared	0.7452		

2.7.4 Correlation analysis of weather parameters on *Spodoptera frugiperda* abundance

The result on correlation analysis of weather parameters on *Spodoptera frugiperda* abundance at SUA (Table 2.2) showed that, temperature and relative humidity were negatively correlated with *S. frugiperda* abundance (r = -0.04 and r = -0.44) whereas Rainfall had positive correlation (r = 0.16). The correlation for both rainfall and temperature were not significant at 5% level of significance whereas the correlation for relative humidity was significant at 5% level of significance.

Table 2.2: Correlation analysis of weather parameters on *Spodoptera frugiperda* abundance at SUA

	Catches-SUA	Temperature	RH	Rainfall
Catches-SUA	1			
Temperature	-0.04	1		
Relative humidity	-0.44*	0.04	1	
Rainfall	0.16	0.25	0.19	1

N=24, df =n-2,*Significant linear correlation $p \leq 0.05$ and **Significant linear correlation $P \leq 0.01$

The result on the correlation analysis of weather parameters on *Spodoptera frugiperda* abundance at Mlali (Table 2.3) suggested that, there was negative correlation between temperature and relative humidity on fall armyworm abundance (r = -0.36 and -0.35) and the correlation was not significant at 5% level of significance. A positive correlation was (r = 0.04) was established between rainfall and *S. frugiperda* abundance but was not significant at 5% level of significance.

Table 2.3: Correlation analysis of weather parameters on *Spodoptera frugiperda* abundance at Mlali

	Catches-Mlali	Temperature	RH	Rainfall
Catches-Mlali	1			
Temperature	-0.36	1		
RH	-0.35	0.65**	1	
Rainfall	0.04	0.14	0.45*	1

N=24, df = n-2,*Significant linear correlation $p \leq 0.05$ and **Significant linear correlation ($p \leq 0.01$)

At Mgeta (1050 masl), the correlation analysis of weather parameters on *S. frugiperda* abundance (Table 2.4) suggested negative correlations between temperature, relative humidity and rainfall on *S. frugiperda* abundance (r = -0.29, -0.35 and -0.58). The influence of temperature and relative humidity was not significant at 5% level of significance, while that of rainfall was significant at 1% level of significance.

Table 2.4: Correlation analysis of weather parameters on *Spodoptera frugiperda* abundance at Mgeta.

	Catches-Mgeta	Temperature	RH	Rainfall
Catches-Mgeta	1			
Temperature	-0.29	1		
RH	-0.10	0.33	1	
Rainfall	-0.58**	0.22	0.45*	1

N=24, df =n-2,*Significant linear correlation $p \leq 0.05$ and **Significant linear correlation ($p \leq 0.01$)

The result on the correlation analysis of weather parameters on *Spodoptera frugiperda* abundance at Nyandira (Table 2.5) suggested negative correlations for rainfall and relative humidity (r = -0.38 and -0.72) on *S. frugiperda* abundance but a positive (r=0.21) correlation with the temperature. Both rainfall and temperature had insignificant correlation with *S. frugiperda* abundance at 5% level of significance while a significant at 1% correlation was established with the relative humidity.

Table 2.5: Correlation analysis of weather parameters on *Spodoptera frugiperda* abundance at Nyandira

	Catches-Nyandira	Temperature	RH	Rainfall
Catches-Nyandira	1			
Temperature	0.21	1		
RH	-0.72**	-0.31	1	
Rainfall	-0.38	0.15	0.37	1

N=24, df =n-2,*Significant linear correlation $p \leq 0.05$ and **Significant linear correlation $p \leq 0.01$

2.8 Discussion

The current study revealed that, variation in altitude has a significant influence on the abundance of *S. frugiperda* as established based on the data collected from the four study locations. Low altitude (SUA and Mlali) had higher abundance of *S. frugiperda* compared to the medium and high altitude at Mgeta and Nyandira. Nyandira area located at highest altitude (1691masl) experienced high amount of rainfall and low temperature from March to late May. This caused low *S. frugiperda* abundance due to unfavourable condition for *S. frugiperda* development. Heavy rainfall tends to wash down newly laid *S. frugiperda* eggs interfering with their development to the larval stages. Likewise, the larvae at early developmental stages (stage 1-3) are easily washed down to the soil affecting the pest's population growth (Nboyine *et al*., 2020).

At low temperatures *S. frugiperda* development rate is slowed down reducing the population growth rate. Low temperatures and excessive rain do not only affect the insect pest but also interfere with crop growth and nutrient uptake from the soil. The finding by Pair *et al*. (1986) indicated that increase in rainfall and decrease in temperature slows crop growth and water saturation in the soil and this may cause unavailability of enough food to *S. frugiperda* and unfavourable soil condition for pupation. The results on regression analysis between weather parameters and *S. frugiperda* abundance showed that, there were positive relationship between temperature and *S. frugiperda* abundance. Rojas *et al*. (2004) reported similar findings that, temperature had positive regression with *S. frugiperda* abundance. Thus, increase in temperature supports increased abundance of the pest.

Variation in altitude, whereby Nyandira (1691 masl) experienced low temperature while SUA (at low altitude) experienced high temperature matches the observed trend. Nyandira experienced low temperature ranging from 17°C to 22°C especially during the rainy season, and this affected the population of *S. frugiperda* (Rojas *et al*., 2004). Constant temperature of less than 18°C reduce *S. frugiperda* egg hatching, larval development, pupation and adult emergence as a result it caused low *S. frugiperda* population. Therefore with increase in temperature nearly to optimum levels, there was ultimate increase in *S.*

frugiperda abundance. The findings by Anandhi *et al.* (2020) showed that, increase in temperature to optimum level may favour the rate of photosynthesis of maize which in turn favours the continuous and abundance of food supply to *S. frugiperda*.

The relative humidity in all locations suggested negative correlation between relative humidity and *S. frugiperda* abundance and this correlation was nearly significant in all locations. This means that increase in relative humidity result into decrease in numbers of *S. frugiperda*. This finding is in agreement with the findings by Rojas *et al*., (2004) who reported that, relative humidity had negative correlation with *S. frugiperda* abundance. On the other hand rainfall was positively correlated with *S. frugiperda* albeit at few locations namely; SUA and Mlali. This suggests the possible influence of rainfall on *S. frugiperda* such that increase in rainfall result into increase in *S. frugiperda* abundance to some limits when the further increase in rainfall impacts heavily on the pest leading to decline in pest numbers. This could be due to the fact that, increase in rainfall favours vegetative growth of maize, the *S. frugiperda* preferred host.

Vigorous growth of host plants attracts female *S. frugiperda* to lay more eggs to the host and as a result increase in *S. frugiperda* population due to availability of enough food. This finding concurred with the report by Anandhi *et al*. (2020) that the higher the rainfall distribution the greater the influence it has on *S. frugiperda.* Similar results were reported by Mitchel *et al*. (1991) that, in the tropics *S. frugiperda* population has tendency to vary with changes in rainfall. The case is different for Mgeta and Nyandira which showed to have negative correlation between rainfall and *S. frugiperda* abundance but the trend was found statistically insignificant.

Variation in *S. frugiperda* abundance observed in this study could have been contributed not only by weather parameters but also the cropping pattern. The cropping pattern along Uluguru mountain ranges varies with altitude. At low altitude (SUA and Mlali) large areas are established with major host crops particularly maize. In addition, these areas received adequate amount of rainfall from November 2019 to May 2020 supporting the establishment and fair growth of maize throughout the season. As observed by Sparks (1979), plentiful rains could have resulted in lush growth of the *S. frugiperda* preferred host plants impacting negatively the multiplication of natural enemies and creating suitable conditions for the thriving of *S. frugiperda* population. At medium to high altitude, the area covered for production of maize crop was small as majority of farms were less than an acre. Moreover, the farms are mainly grown with vegetables particularly tomato, cabbage, eggplants and carrots and while maize is either included as edge crop or intercropped within vegetable fields with occasional plantings near homesteads. The limited availability of host crop could have contributed to low *S. frugiperda* abundance at medium and high altitude. Rojas *et al*. (2004) confirmed that the most important factor affecting trap capture of target insect pests is the availability and distribution of host plants.

Fluctuation of moths' catches in a given location has in some instances been attributed to the growth stage of the host crop. According to Murua *el at*. (2006), *S. frugiperda* infestation is plant-age dependent with the VE-V3 stages being the most preferred growth stages. Limited availability of tender leaves to support growth of neonates that will hatch from eggs tend to result in few moths visiting the maize fields for egg laying, consequently the number of moths catches over time during this growth stage is reduced (Nboyine *et al*., 2020).

Temperature difference can be another reason for the differences in *S. frugiperda* abundance. At low altitude high temperature was received compared with medium to high altitude. High temperature 26^0C to 32^0C favour developmental growth of *S. frugiperda* including egg hatching, larval development, pupation, and adult emergence (Schlemmer, 2018). According to Simmons and Rogers (1990) optimum temperature required for the mating of *S. frugiperda* is approximately 25-35°C which is favourable for transfer of nematodes during moth mating and *S. frugiperda* population build up. These reports are suggestive of the conformity in findings in the current study on high *S. frugiperda* population recorded at low altitude (SUA and Mlali) due to availability of optimum temperature. Conversely, at high altitude locations (Mgeta and Mlali) where mean temperature of about 18^0C was recorded the *S. frugiperda* developmental processes were slowed down. This finding is in agreement with Schlemmer (2018) who found out that continuous low temperature, lower thermal limit tend to slow down *S. frugiperda* development stages and may reduce population dynamics as a result of high mortality. Generally, low altitude is usually dominated by constant optimum temperature as compared to high altitude where temperature is mostly below optimum temperature.

The present study shaded insights into the population dynamics of *S. frugiperda* with season at varying altitude. As observed, the knowledge of when and where adult pests are active and abundant provides a sensitive early warning system to enable field sampling and/or control measures to be initiated at the appropriate time (Cruz *et al.*, 2012). Using pheromone traps to monitor *S. frugiperda* moths is the best means of deciding on number of the pesticide application necessary to control pest in maize (Cruz *et al.*, 2012). This implies that both farmers from low to high altitude areas needs to select effective and appropriate management options for the control of *S. frugiperda.*

2.9 Conclusion

The current study has revealed that difference in altitude has influence on the abundance of *S. frugiperda*. The variation of altitude indirectly influences temperatures that significantly affects the abundance of *S. frugiperda*. The results from trap catches have proven that *S. frugiperda* was present in all locations throughout the six months period of trapping suggesting scantly presence of the safe window that may allow uninterrupted crop growth. Thus, farmers from low to high altitude areas need to select effective and appropriate management options for the control of *S. frugiperda*. Intensive control measures should be taken more in low altitude areas compared to high altitude as in low altitude areas there is more *S. frugiperda* abundance than in high altitude areas.

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CHAPTER THREE

2.0 RESPONSE OF *SPODOPTERA FRUGIPERDA* JE SMITH (LEPIDOPTERA: NOCTUIDAE) TO SELECTED INSECTICIDES UNDER LABORATORY AND SCREEN HOUSE CONDITIONS

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3.1 Abstract

Fall armyworm (*Spodoptera frugiperda* (J. E. Smith), is a devastating insect pest which is a native to tropical and sub-tropical regions of Americas. Unexpected outbreak of the pest in Tanzania in 2017 forced the Tropical Pesticides Research Institute (TPRI), a pesticide registering authority to recommend some insecticides to be use against the pest. While some of the insecticides were hardly available to farmers, some reported to be ineffective when applied to the pest leaving farmers with limited options. In the current study, *S. frugiperda* response to selected insecticides was examined under laboratory and screen house condition at Sokoine University of Agriculture (SUA). The aim of the experiment was to assess the efficacy of the different groups of insecticides that are readily available and commonly used by farmers for the control of *S. frugiperda*. Factorial experiments were set in a Completely Randomized Design (CRD) with three replications (in laboratory bio assay and in screen house). Ten synthetic insecticides were used on different *S. frugiperda* larval stages. Results showed that these insecticides differed significantly ($p < 0.001$) in time taken to cause 50% and 100% mortality to different larval stages. In laboratory, Duduba 450 EC and Ninja plus 5 EC caused 100% mortality in 48 hours after treatment (HAT) followed by Thunder 145 OD that caused 79.05% mortality in the same duration. In screen house experiment insecticides performances were highly varied ($p < 0.001$) with Multi Alpha plus 150 EC causing 100% mortality in 48 HAT followed by Thunder 145 OD that caused 76.67% mortality in 48 HAT . Generally, the obtained results suggested significant variation in larval instars response to different insecticides. Multi alpha plus 150 EC, Profecron 720EC, Duduba 450 EC and Ninja plus 5EC caused high mortality as compared to Thunder 145OD and Attakan 350 SC in both Laboratory bioassay and Screen house experiments. These results showed great potential of synthetic insecticides as management option for the control of *S. frugiperda* in maize crop.

Key words: Insecticides, larval developmental stages, *Spodoptera frugiperda*, pest management, maize crop.

3.2 Introduction

Fall Armyworm (*Spodoptera frugiperda* (J. E. Smith), (Lepidoptera: Noctuidae) is an insect native to tropical and subtropical regions of the Americas and is now wide spread across the globe (Midega *et al.,* 2018; CABI, 2019). *Spodoptera frugiperda* larvae are polyphagous and migratory pest known to feed on more than 353 plant species many of which are important crops in Tanzania including maize, sorghum, rice, sugar cane, cow pea, soybean, groundnuts, cotton, round potato, amaranthus, grape, orange, pawpaw, napier, desmodium and various ornamental plants and may cause high yield losses if not well controlled (Prasanna *et al.,* 2018; Firake and Behere, 2020). This has made *S. frugiperda* a pest of concern wherever is reported to occur. *S. frugiperda* has six larval instar stages with body length ranging from 1.7mm to 34.2mm (Capinera, 2002; Prasanna *et al*., 2018; FAO and CABI, 2019). The pest can inflict damage to nearly all developmental stages of maize plant and their destruction differs from one instar stage to another (FAO and CABI, 2019). Response of these larval stages to insecticides differs significantly whereby the first instars (1-3) are more susceptible than the later instars (4-6) (Hardke *et al*., 2011; Fernandes *el al*., 2019).

In African continent, 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). Further, Day *et al*. (2018) reported the presence of the pest in more than 44 countries in Africa which suggested a major threat to food security in the continent. Severe incidences of the pest usually occur during the onset of the wet season (Goergen *et al.,* 2016). In Tanzania, *S. frugiperda* was first detected in Rukwa Region on February 2017 and thereafter in other border regions including Ruvuma and Mbeya. The extended occurrence of the pest across Africa called for immediate intervention strategies to minimize the crop damages and resultant economic losses.

Insecticides are used as major components of IPM in controlling the *S. frugiperda* because outbreaks are usually in high numbers and the pest has ability to migrate long distances and feed on a broad host range which makes other control options less effective (Belay *et al*., 2012). 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). Research report by Hardke *et al*. (2011) confirmed high efficiency of the used insecticides against *S. frugiperda*, although to some extent ovipositional preferences and the larvae behavior within the host plant have greatly reduced susceptibility to many insecticides (Hardke *et al.,* 2011).

TPRI in 2018 recommended several insecticides for use against *S. frugiperda* considering what was registered and available on Tanzanian markets despite the scanty information about their efficacy. Some of the recommended insecticides were either inadequately available (with limited distribution across the country) or exhibited limited effectiveness against the pest. Most farmers in Tanzania acted out of frustration and resorted to whatever was available on pesticide markets in attempt to rescue their maize crop (G. Rwegasira unpublished data). Farmers complained that, most of recommended insecticides proved ineffective against the pest prompting some to believe that they were mostly counterfeit products. Complaints were enormous necessitating the need for research on the efficacy of some of commonly used insecticides against *S. frugiperda (*G. Rwegasira unpublished data*).* Information on the response of the *S. frugiperda* larval stages to the commonly used insecticides was also lacking. The objectives of the current study were specifically to, i) To determine the efficacy of the commonly used insecticides against *S. frugiperda*, ii) to establish the response of different *S. frugiperda* larval stages to the selected insecticides, and iii) to identify the best choice of insecticides that would control the *S. frugiperda* relying on the resultant pest damage signs on maize crop. The current paper details the finding from experiments set forth to examine the stated objectives.

3.3 Materials and Methods

3.3.1 Study location

The study was conducted in the laboratory and in the screen house at Horticulture unit , Sokoine University of Agriculture (SUA), Morogoro, Tanzania. The location is at latitude $6^0$50'S, longitude of $37^0$39'E and altitude of 524 m above sea level. The temperature in the laboratory was maintained at an average of 26^{o}C and relative humidity of 75%. At screen house maximum temperature was 31^{o}C and minimum temperature was 24 ^{o}C.

3.3.2 Establishment of *Spodoptera frugiperda* colony

FAW larvae were collected from other established maize farms at SUA main campus and nearby villages. About 300 fourth instar *S. frugiperda* larvae were identified and collected.

The larvae were put in different containers and rearing cages of 100 cm x 50cm x 50cm in dimension, these cages have well ventilation for the larvae to survive. Larvae were daily fed with maize tender leaves of 10-15 days old and these leaves were changed daily. Once pre pupal stage was reached they were transferred to other containers filled with one-third of soil for pupation. Sterile cotton soaked in a honey solution was placed in a petri dish inside the oviposition cages as a food source for the emerging adults and were allowed to mate. Adults that emerged on the same day were counted and isolated into cohorts of 30 cohort 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 and they were provided with tender and fresh maize leaves (Deryck, 2017).

3.3.3 Rearing of *Spodoptera frugiperda* larvae

The insects were reared as described above until sufficient population was obtained and maintained to run the experiment. The rearing was done at room temperature 26 ^{o}C and 76% RH. Second generation (F2) larvae were used for the study (Deryck, 1979; Cruz *et al*., 2010; Hardke *et al*., 2011). Maize variety DEKALB HYBRID (DKC90-89) was sown at SUA field station on a 20 m x 20 m plot size at spacing of 75 cm x 25 cm. Two seeds were sown per hill and were thinned to one seedling per hill two weeks after emergence. Maize plots were fertilized with DAP at planting. No pesticide was applied to control pests. The leaves from these maize plants were used to feed *S. frugiperda* larvae which were reared in Entomology laboratory.

3.3.4 Preparation of insecticides

Ten different insecticides which were commonly used by farmers against *S. frugiperda* (Table 3.1) were procured from registered agro-shop in Morogoro and used in the experiments. The batch numbers of procured insecticide were cross-checked with TPRI to authenticate the registration status. Each insecticide was prepared according to the manufacturer’s recommendation including dose rates and thorough mixing with water for 5-10 minute. A hand sprayer (1000 ml) manufactured by East African seed company was used to apply the insecticides.

***Table 3.1: List of insecticides used in the experiment against* S. frugiperda**

Trade name	Active ingredient (a.i)	Insecticide group	Dosage rate(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

3.3.5 Preparation of soil for screen house experiment

Soil were prepared at ratio of 2:1:1 (top soil, compost and sand soil) and filled into the 10 liter bucket. A total of 132 buckets were filled with prepared soil media. Two maize seeds were sown per bucket. Thereafter all crop management practices were performed as recommended.

3.3.6 Experimental design and treatment allocation

3.3.6.1 Laboratory bioassay

The study was laid out as factorial experiment in completely randomized design (CRD) with 44 treatment combinations replicated three times. Factor A was four *S. frugiperda* larval instars (1^{st}-2^{nd} instar), (2^{nd} -3^{rd} instar), (3^{rd}-4^{th} instar) and (4^{th} -6^{th} instar) and factor B consisted of ten insecticides plus a control (Table 3.1). Tender leaves of maize 10-15 days old were cut into small pieces approximately 5cm length each and placed into the prepared containers for bioassay experiment. Ten *Spodoptera frugiperda* larvae grouped as described above were placed into the containers containing tender maize leaves. The 10 insecticides were applied using small (1000 ml) plastic hand sprayers. Three “shots” of fine droplets of the spray mixture were applied to each container, which provided adequate coverage of the filter paper to mimic the field spray coverage. The untreated control larvae were sprayed with an equal amount of water (used to admix with insecticides) to minimize errors due to the effect of moisture differences in the petri dishes.

3.3.6.2 Screen house experiment

The study was laid out as factorial experiment; plots were arranged in Complete Randomised Design (CRD) with 44 treatment combinations replicated three times. Factor A consisted of four maize crop injury signs (window pane, circular hole, irregular holes and extensive defoliation) and factor B consisted of ten insecticides plus control (Table 3.1).

The 10 insecticides used during laboratory bioassay were used in screen house experiment plus water as control. Each insecticide was thoroughly mixed with water following the manufacturer's recommendations. Plants treated with water were included as a control. Two weeks after maize emergency artificial infestation of *S. frugiperda* larvae (1^{st} instar) from the laboratory was done to all maize seedlings in the pots. 10 larvae were artificiall infested per plant per pot. Thereafter, The spray of insecticide was conducted based on injury signs of larvae (Window pane, Circular holes, Irregular holes and Extensive defoliation) were observed at screen house.

3.4 Data Collection

3.4.1 Laboratory bioassay

Time taken to attain 50% and 100% mortality and the percentage insect mortality was assessed at 3, 6, 12, 24, 48 hrs after treatment application. A larva was considered dead if it stood still when touched and did not move even when placed on its dorsal-ventral position.

3.4.2 Screen house experiment

Forty eight (48) hours after treatment application destructive sampling was done to maize seedlings as per maize crop injury sign (window pane, circular holes, irregular holes and extensive defoliation) were observed: number of dead larvae, number of live larvae and the total number of larvae per plant were recorded. A larva was considered dead if it could not move itself when placed on its dorsal surface.

3.5 Data Analysis

Two way analysis of variance (ANOVA) was performed for collected data to determine the efficacy of insecticides using Genstat software 16^{th} edition, Tukey's honest significance difference was used for means separation at $p \leq 0.05$.

3.6 Results

3.6.1 Time taken to 50% and 100% mortality in the laboratory bioassay

Results showed that there were significant (F = 135.23, Df = 3, $p < 0.001$ and F = 199.38, Df = 3, $p < 0.001$) difference in time taken to attain 50% and 100% mortality (Fig.3.1). Larval stages 1&2, 2&3 and 3&4 took shorter time (5.3h, 5.3h and 5.8h) to attain 50% mortality compared to larval stages 4&6 (9h). The shortest time to attain 100% mortality was observed in larval stages 1&2 and 2&3(7.1h and 6.7h) and the longest time taken was recorded in larval stages 4&6 (13h).

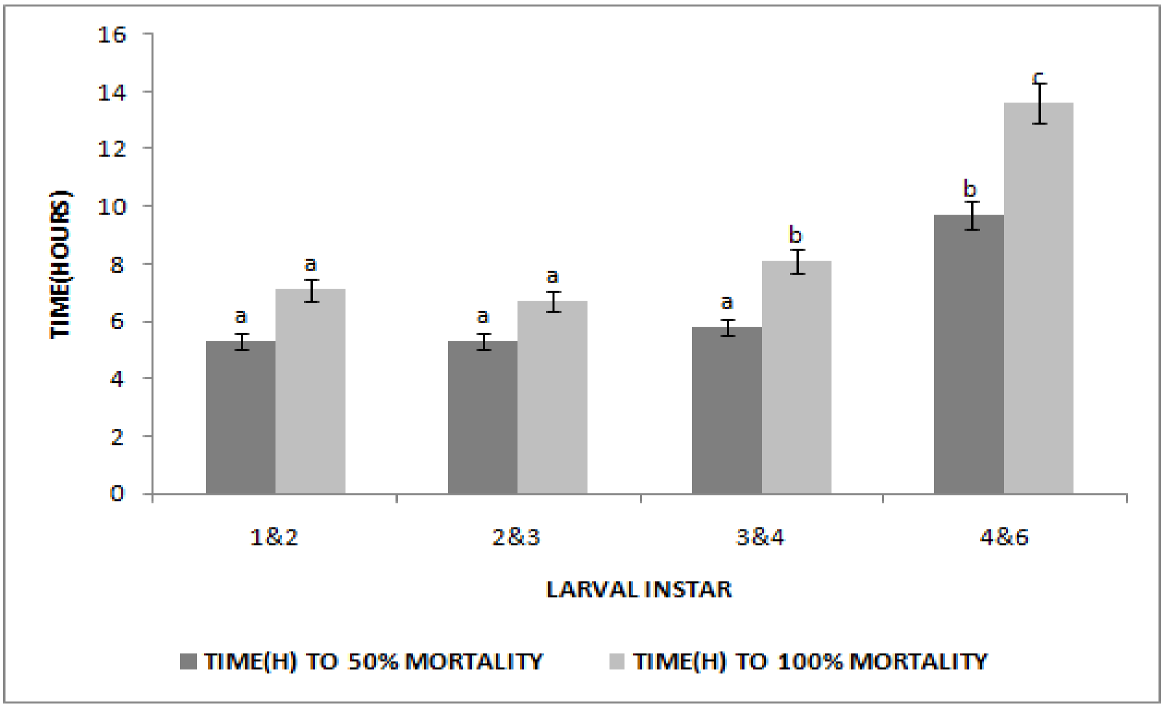

Figure 3.1: Time taken by different *S. frugiperda* larval stages to 50% and 100% mortality after treatment with selected insecticides

3.6.2 Time taken by insecticides to cause 50% and 100% mortality of *S. frugiperda* in the laboratory bioassay

Results showed that there was highly significance (F = 2894.28, Df = 10, $p < 0.001$ and F = 2657.15, Df = 10, $p < 0.001$) difference among insecticides in time taken to cause 50%

and 100% mortality (Fig. 3.2). Duduba 450 EC took shorter time to cause 50% mortality of *S. frugiperda* larvae while Thunder 145 OD took longest time to cause 50% larval mortality. Duduba 450 EC, Ninja 5 EC and Profecron 720 EC were the best performers followed by Multi Alpha plus 150 EC and Belt 480 SC in terms of time taken to cause 100% mortality. However, the differences among them were statistically insignificant ($p > 0.05$). Like on 50% mortality, Thunder 145 OD took the longest time to cause 100% mortality.

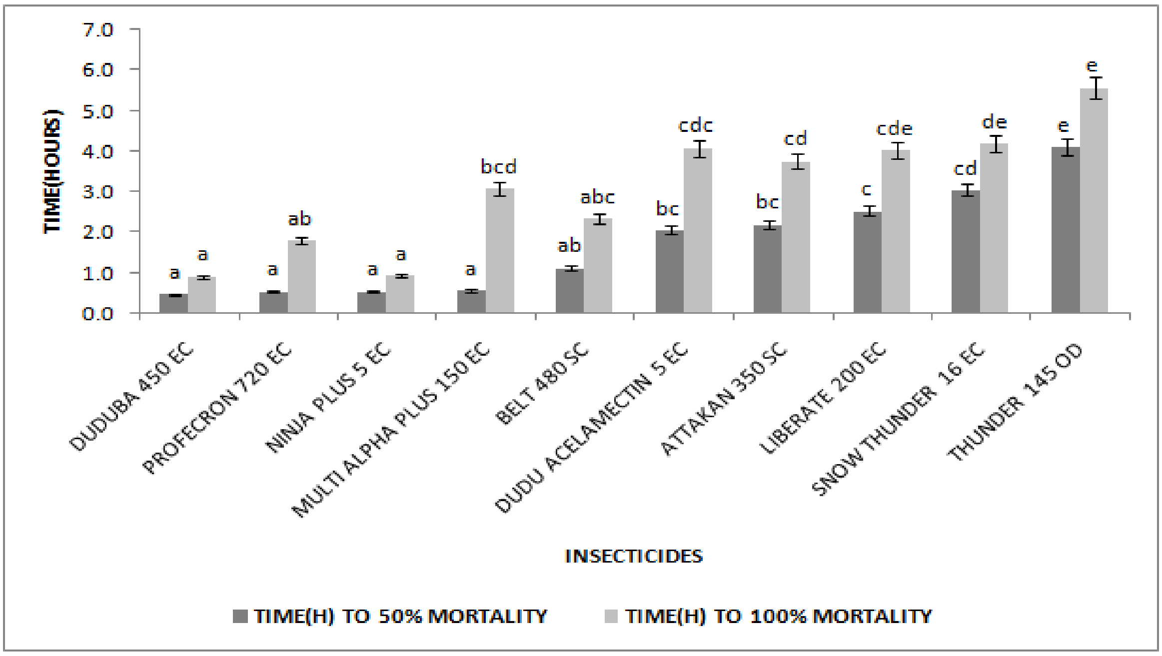

Figure 3.2: Time (Hours) taken to cause 50% and 100% mortality of *Spodoptera frugiperda* in the laboratory bioassay

3.6.3 Influence of larval instar stages and insecticides on time taken to cause 50% and 100% *Spodoptera frugiperda* mortality

Detailed interactions obtained from the combined effect of *S. frugiperda* larval developmental stages and insecticides on time taken to cause 50% and 100% mortality under laboratory condition have been shown (Table 3.2). Generally, the treatments combination of *S. frugiperda* larval instar stages and insecticides had significant (F =

12.54, Df = 10, $p < 0.001$) effect in time taken to cause 50% and 100% mortality. Treatment combination between *S. frugiperda* larval instar 1&2, 2&3 and 3&4 with all insecticides showed to have no significant difference ($p > 0.05$) in time taken to cause 50% and 100% mortality. Conversely, the treatment combination between *S. frugiperda* larval instar 4&6 with insecticides had significant difference whereas Duduba 450EC took shortest time 0.55 and 1.01 hours while Thunder 145OD took 13.5 and 17.43 hours to cause 50% and 100% mortality respectively.

Table 3.2: Influence of larval instar stages and insecticides on time taken to cause 50% and 100% *Spodoptera frugiperda* mortality

LARVAL INSTAR-INSECTICIDE	TIME (H) TAKEN TO 50% MORTALITY	100% MORTALITY
1&2x Ninja Plus 5 EC	0.26a	0.57a
1&2 xProfecron 720 EC	0.28a	0.61a
1&2 xDuduba 450 EC	0.30a	0.63a
1&2 xThunder 145 OD	0.32a	1.09ab
1&2 xBelt 480 SC	0.33a	0.73a
1&2 xSnow Thunder 16 EC	0.35a	1.29ab
2&3 xDuduba 450 EC	0.35a	0.58a
2&3 xSnow Thunder 16 EC	0.38a	0.96a
1&2 xMulti Alpha Plus 150 EC	0.40a	0.64a
2&3 xNinja Plus 5 EC	0.41a	0.62a
2&3 xProfecron 720 EC	0.44a	0.63a
2&3 xThunder 145 OD	0.48a	0.85a
2&3 xBelt 480 SC	0.52a	1.12ab
2&3 xLiberate 200 EC	0.52a	0.87a
2&3 xMulti Alpha Plus 150 EC	0.53a	0.81a
4&6 xDuduba 450 EC	0.55a	1.01a
1&2 xLiberate 200 EC	0.56a	1.66ab
4&6 xMulti Alpha Plus 150 EC	0.57a	9.25cd
2&3 xDudu Acelamectin 5 EC	0.58a	1.25ab
1&2 xAttakan 350 SC	0.61a	2.07ab
2&3 xAttakan 350 SC	0.67a	1.18a
4&6 xProfecron 720 EC	0.67a	4.43ab
4&6 xNinja Plus 5 EC	0.68a	1.01a
3&4 xDuduba 450 EC	0.72a	1.40ab
1&2 xDudu Acelamectin 5 EC	0.75a	1.5ab
3&4 xProfecron 720 EC	0.75a	1.5ab
3&4 xMulti Alpha Plus 150 EC	0.78a	1.66ab
3&4 xNinja Plus 5 EC	0.79a	1.52ab
3&4 xAttakan 350 SC	0.83a	2.07ab
3&4 xLiberate 200 EC	1.18a	2.51ab
3&4 xDudu Acelamectin 5 EC	1.24a	3,69ab
3&4 xBelt 480 SC	1.28a	2.01ab
3&4 xSnow Thunder 16 EC	2.08a	2.32ab
3&4 xThunder 145 OD	2.13a	2.91ab
4&6 xBelt 480 SC	2.37ab	2.01ab
4&6 xDudu Acelamectin 5 EC	5.65bc	9.88d
4&6 xAttakan 350 SC	6.66cd	8.85cd
4&6 xLiberate 200 EC	7.86cd	11.05d
4&6 xSnow Thunder 16 EC	9.37d	12,15d
4&6 xThunder 145 OD	13.48e	17.43e
3&4 xWater	52.67f	66.67f
2&3 xWater	31.33f	65.00f
1&2 xWater	54.66f	67.66f
4&6 x Water	58.77g	69.33f
Mean	6.04	8.79
SE	35.9	45.1
CV %	15.8	14.6
***p*-value**	0.001	0.001

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

3.6.4 Efficacy of the tested insecticides in laboratory bioassays

Different larval stages of *S. frugiperda* were exposed to insecticides for varied duration of 3, 6, 12, 24 and 48 hours. Results showed that there was highly significance difference ($p < 0.001$) among insecticides in causing mortality to *S. frugiperda* of different larval instars (Table 3.3). At 3h after treatment application, Ninja Plus 5EC and Duduba 450 EC caused higher mortality rate (100%) than Dudu acelamectin 5 EC which caused the lowest mortality (60%) of *S. frugiperda* larval instars. After 6h, Profecron 720 EC, Duduba 450 EC, Ninja plus 5EC, and Belt 480 SC had caused 100% mortality while only 75% mortality was recorded in foci treated with Thunder 145 OD. Similar relatively low mortality rate (75%) was recorded on larval instars treated with Thunder 145 OD after 12 hrs to 24 hrs while the rest of insecticides caused 100% mortality to *S. frugiperda* larvae. No deaths were recorded in water treated foci even after 12 hours except for limited mortality (4.58%) observed after 24hrs to 48hrs which are believed to have been caused by factors other than insecticides.

Table 3.3: Efficacy of tested insecticides against *S. frugiperda* in laboratory bioassays

	Mortality (%) with time lapse after treatment				
TREATMENT	**3h**	**6h**	**12h**	**24h**	**48h**
BELT 480 SC	87.5de	100d	100d	100c	100b
NINJA PLUS 5 EC	100f	100d	100d	100c	100b
DUDUBA 450 EC	100f	100d	100d	100c	100b
THUNDER 145 OD	75c	75b	75b	75b	100b
SNOW THUNDER 16 EC	77.5cd	82.5bc	87.5c	100c	100b
MULTI ALPHA PLUS 150 EC	85cd	88.33c	91.67c	100c	100b
DUDU ACELAMECTIN 5 EC	60b	82.5bc	87.5c	100c	100b
LIBERATE 200 EC	77.5cd	78.33b	87.5c	100c	100b
PROFECRON 720 EC	91.67ef	100d	100d	100c	100b
ATTAKAN 350 SC	82.5cde	87.5c	100d	100c	100b
WATER	0a	0a	0a	4.58a	4.58a
Mean	76.06	81.29	84.47	89.053	91.326
SE	2.587	1.777	1.256	0.177	0.1256
CV%	11.8	7.6	5.2	0.5	0.5
p –value	0.001	0.001	0.001	0.001	0.001

Means within a column followed by different letters are significantly different at $p < 0.05$

3.6.5 Response of different *Spodoptera frugiperda* larval instars to selected insecticides at varied time of exposure in laboratory bioassays

Results showed highly significant ($p < 0.001$) variation in responses of different *S. frugiperda* larval stages to the tested insecticides (Fig 3.3). Three hours after treatment application the lowest mortality rate was recorded on larval instars 4-6 while the highest larval mortality was recorded on larval instars 1-2 and 2-3. Similarly, at 6h, 12h and 24h after insecticides application lowest mortality rate was recorded on larval instars 4-6 and the highest larval mortality was recorded on larval instars 1-2, 2-3 and 3-4. At 48 h after treatments all larval instars succumbed to insecticides and showed no significant (P=0.39) differences in mortality rate.

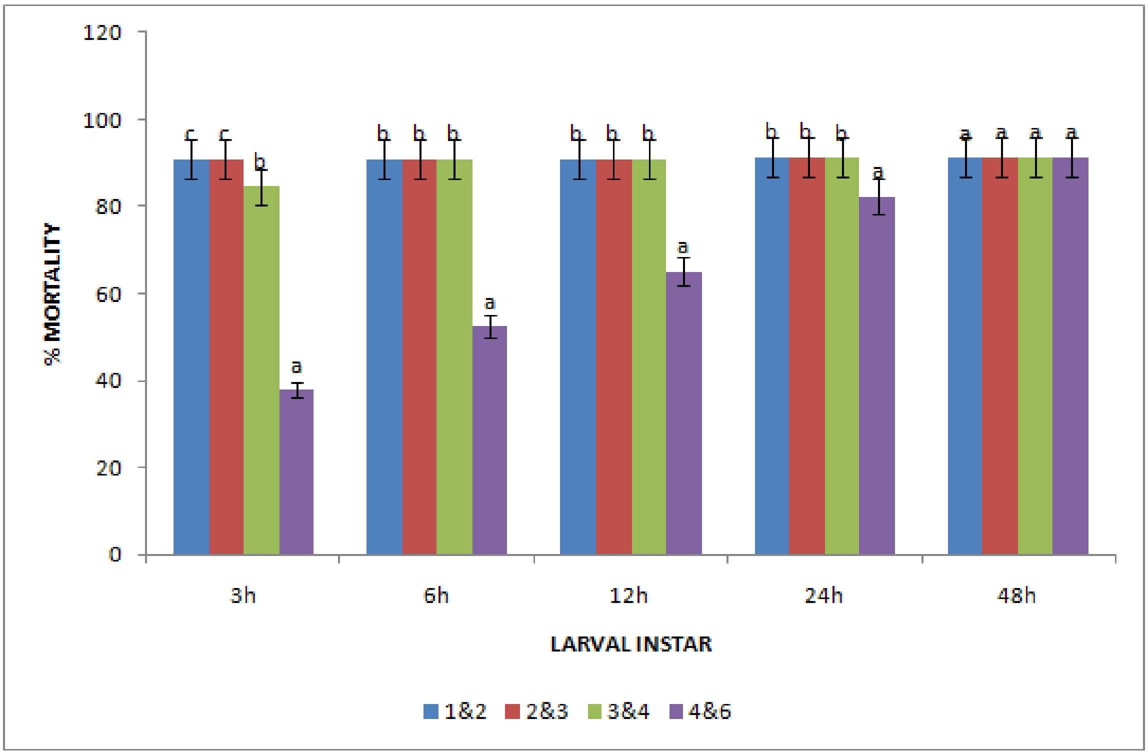

Figure 3.3: Response of different *Spodoptera frugiperda* larval instars to selected insecticides at varied time of exposure in laboratory bioassays

3.6.6 Percent mortality of *Spodoptera frugiperda* larvae instars caused by different insecticides under screen house

Results showed that there was highly significant effect ($p < 0.001$) among insecticides on causing mortality of *S. frugiperda* larvae (Fig.3.4). Thunder 145 OD showed lower mortality rate than Multi alpha plus 150EC, Duduba 450EC and Profecron 720EC which showed highest mortality rate at 48 hours after treatment application. The results on the interaction effect of crop injury sign and insecticides on mortality of *S. frugiperda* under screen house showed that the treatment combination of crop injury sign and insecticides had no significant difference statistically on mortality of *S. frugiperda* at $p = 0.293$ except for the control.

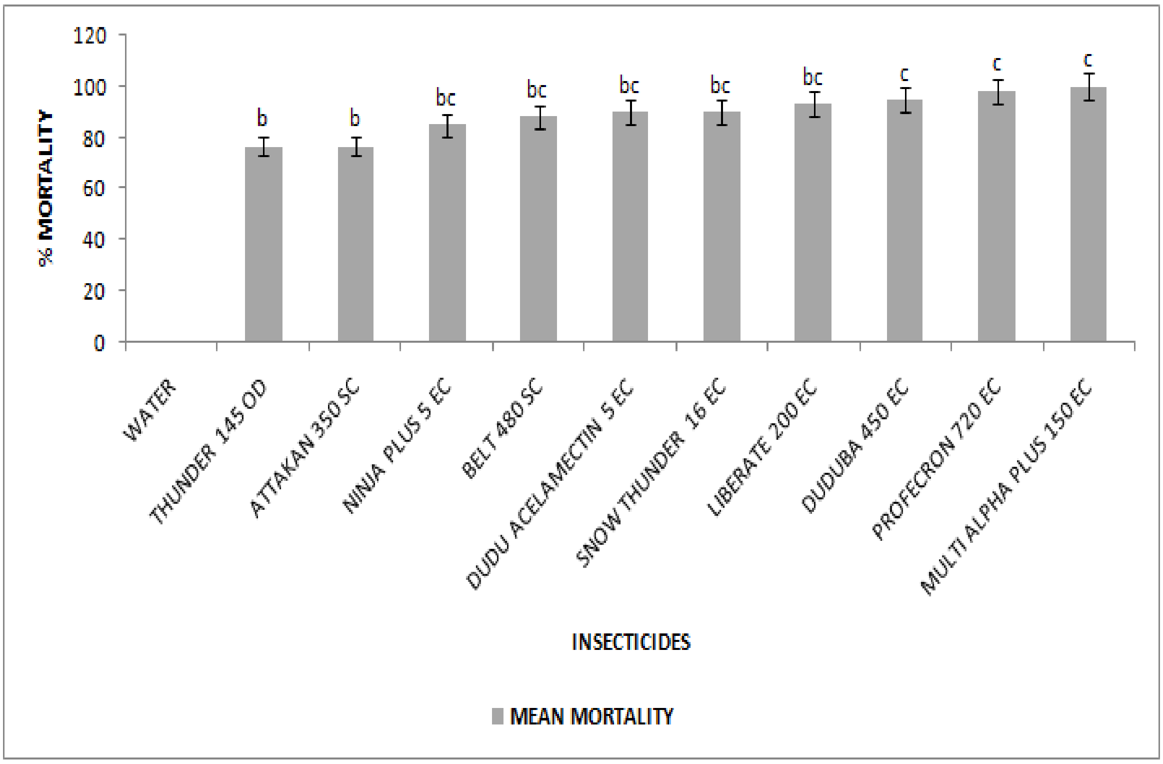

Figure 3.4: Percent mortality of *Spodoptera frugiperda* larvae instars caused by different insecticides under screen house

3.6.7 Response of *Spodoptera frugiperda* larval instars to insecticides applied based on injury signs manifested on maize crop under screen house

Results on percent Mortality of different *S. frugiperda* larval instars on maize plant under screen house showed that there were highly significant ($p < 0.001$) difference among maize crop injury signs and mortality (Fig.3.5). Insecticides applied to plants with early stage damages signs such as window pane, circular holes and irregular holes were more effective and caused highest mortality of *S. frugiperda* larvae compared to where extensive defoliation of maize plants were manifested. Limited effectiveness of insecticides manifested through lowest mortality rate was recorded.

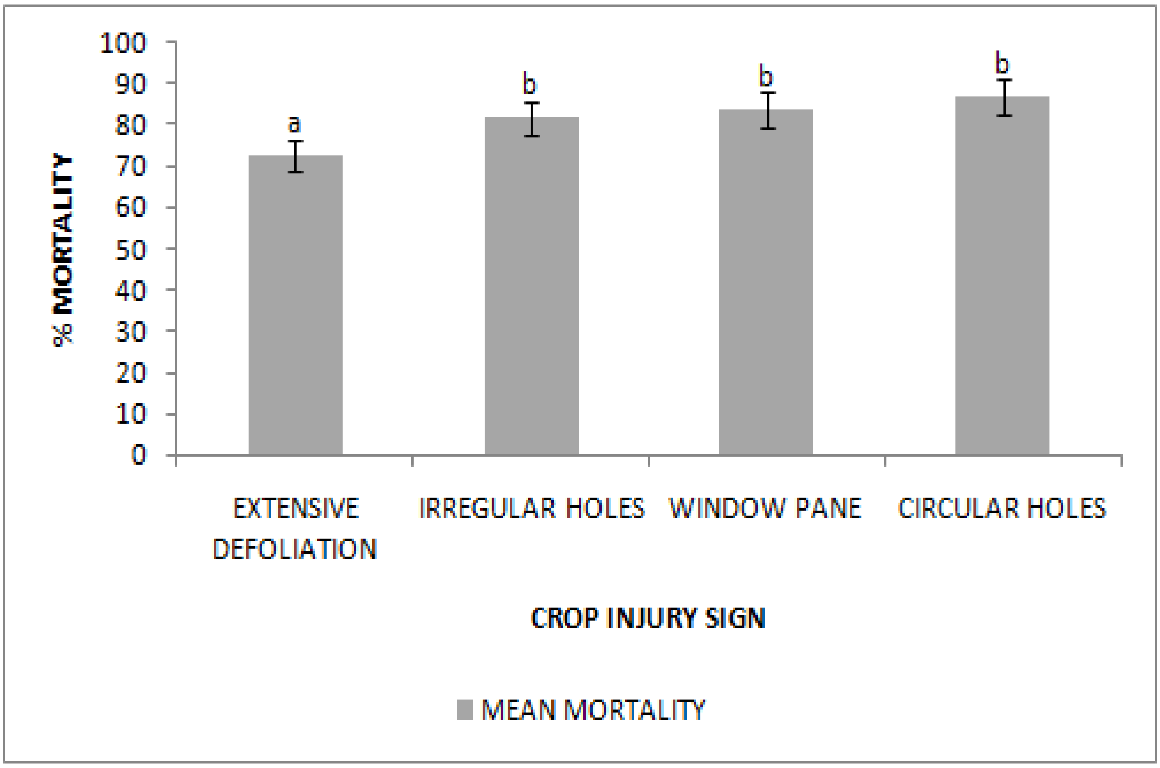

Figure 3.5: Response of *Spodoptera frugiperda* larval instars to insecticides applied based on injury signs manifested on maize crop

3.7 Discussion

The current study revealed that all the tested synthetic insecticides significantly caused mortality to different *S. frugiperda* developmental stages. The time taken to cause 50% to 100% mortality was varied among insecticides but generally Duduba 450 EC, Multi alpha Plus 150 EC, Profecron 720EC and Ninja plus 5 EC took shorter time to cause 50% and 100% mortality while Thunder 145 OD was least effective and took longer time than the rest of tested insecticides. Duduba 450EC, Ninja plus 5EC and Multi alpha plus 150EC were regarded the possible insecticides of choice due to high efficacy and quick knock down that led to early mortality of almost all *S. frugiperda* larvae. One of the active ingredients of these insecticides belong to the group of pyrethroid which has a quick knockdown effect and therefore had ability to cause rapid death to the *S. frugiperda* larvae. Belt 480 SC which belong to diamide group was found to be moderate effective in killing of *S. frugiperda* larvae. This could be due to the fact that it has no knockdown effect and therefore it took more time to cause 100% mortality.

This finding has been supported by Fernandes *et al*. (2019) who reported on the difference on efficacy between diamines group and pyrethroid group that was diamines were slow in causing mortality to *S. frugiperda* unlike pyrethroid group. Further, Guede *et al*. (2012) reported that insecticides with mode of action in the nervous system (Pyrethroid) present a marked shocked action in the different orders of insects and show high control efficiency when applied in residual pathway. The efficacy of these insecticides varied significantly as indicated by the results of both laboratory bioassay and screen house experiments. These findings are in agreement with Worku and Ebabuye (2019) that chlorpyrifos, profenophos and lambda cyhalothrin significantly caused maximum mortality to *S. frugiperda* larvae. The time taken to cause 50% and 100% mortality of *S. frugiperda* differed significantly among *S. frugiperda* larval instars whereby larval instar 1&2, 2&3 and 3&4 took shorter time to reach 50% and 100% mortality unlike larval instar 4&6. This could be attributed by small size of the larvae that made them very susceptible to many synthetic insecticides.

These results are in consistence with that of Hardke *et al.* (2011) who reported that larval instars become more tolerant to insecticides as larval age and size increases. Furthermore the results were in agreement with Adamczyk *et al*. (1999) who reported that first instars were more susceptible to insecticides compared to the later instars. Also, from the findings in both laboratory bioassay and screen house experiments, it has been shown that the percentage of larval mortality increased with increase in time. This may be due to residual toxicity of synthetic insecticides. Similar findings were reported by *Sisay et al*. (2019). In addition, the current study revealed that the used insecticides significantly caused mortality of *S. frugiperda* larvae that had inflicted different maize crop injury signs (window pane, circular hole, irregular holes and extensive defoliation). Notably, highest mortality was recorded on plants with window panes, circular holes and irregular holes compared to those with extensive defoliation.

The different larval instars development stages contributed to the phenomenon that is at early stages of *S. frugiperda* development larval instars that cause window pane to irregular holes are very susceptible to many insecticides due to their small sizes and limited cuticle development. The larvae are well exposed to applied insecticides via direct contact and the amount of product on the integument are often greater. This allows the insecticide to penetrate through the cuticle, trachea and even pores and hair interconnected to the nervous system. The insecticides eventually act on the metabolism until death which occur faster than in advanced *S. frugiperda* larval instar 4-6. These results are in line with that of Fernandes *et al*. (2019) who reported that, the new born caterpillars are easily killed by insecticides, while at their advanced developmental stages the efficiency of the insecticides decreases.

The limited number and small sized maize leaves of the potted plants in the screen house favored the insecticides' direct entry and uncompromised contacts with the *S. frugiperda* larvae which lead to high mortalities. The findings revealed that Thunder 145 OD caused lowest mortality to all maize crop injury signs in the screen house as compared to the rest of used synthetic insecticides. Multi alpha plus 150 EC, Duduba 450 EC and Profecron 720 EC caused highest mortality of *S. frugiperda* larvae irrespective of maize crop injury signs. Application of synthetic insecticides in screen house experiment showed significant reduction in leaf damage compared to the control. The control treatment recorded non to limited mortality reaffirming the effectiveness of the applied insecticides on *S. frugiperda* larvae. These findings were in agreement with that of Sisay (2018) who found that the reduction of leaf damage in screen house was the results of reduced number of *S. frugiperda* larvae due to insecticide spray. Insecticides from the group of Pyrethroid, Organophosphate or in a combination of the two such as Profecron 720EC, Ninja plus 5EC and Multi alpha plus 150EC showed to have high efficacy in causing mortality to *S. frugiperda* larvae both in the laboratory and screen house condition. Conversely, the findings in the present study contradict the report by Gutierrez-Moreno (2017) that, *S. frugiperda* larvae showed the highest resistance levels to the insecticides which belongs to the group of Pyrethroid, Carbamates and Organophosphate.

3.8 Conclusion

The laboratory bioassays and screen house potted experiments conducted in the current study suggested that *S. frugiperda*, a key maize pest can be controlled by several synthetic insecticides mainly of the Pyrethroid, Carbamates and Organophosphate groups. Damage signs on maize crop can be well related to the larval development stages and applying insecticides based in damage signs offers similar results to the bio-assays. Therefore for effective control of *S. frugiperda*, early larval instars of stages 1 through 3 are easily killed by almost any of the tested insecticide. with exception of Thunder 145 OD. Later larval instar stage 4-6 requires strong insecticide such as Multi alpha plus 150 EC, Profecron 720EC, Duduba 450EC and Snow Thunder 16EC.

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CHAPTER FOUR

4.0 CROP INJURY-BASED INSECTICIDE SPRAY GUIDE FOR THE CONTROL OF *SPODOPTERA FRUGIPERDA* ON MAIZE CROP

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4.1 Abstract

The fall armyworm (FAW), *Spodoptera frugiperda* (J. E. Smith), is a polyphagous migratory pest that attacks more than 353 plant species among which are major crops in Tanzania. The pest was reported in Tanzania in 2017. Farmers have been opting for insecticide-based control despite the lack of guidelines 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 decision to control. The objective of this study was to determine the right timing of insecticide application based on injury sign observed on maize crop. A factorial experiment was laid out in a Randomized Complete Block Design. Ten farmer-preferred insecticides were used on *S. frugiperda* damaged maize crop in the field. Obtained results suggested that injury sign based application of insecticides have 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 experimental plots accompanied with reduces incidences and damage severities on maize crop while Thunder 145 OD and Attakan 350 SC were the least effective. Yields obtained from 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). Mean number of leaves and plant height had no significant ($p > 0.05$) effect on obtained yields. 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.

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

4.2 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 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 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. 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). On 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 a 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 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 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*. While farmers feared of most products being counterfeit, quick survey (unpublished data) done by SUA researchers 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 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 guideline 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. Therefore the current study intended to develop the crop injury-based insecticide spray advisory tool for management of *S. frugiperda*.

4.3 Materials and Methods

4.3.1 Study location

The study was conducted under field condition at Mikese in Morogoro, Tanzania. The location is at latitude $83^0 46'$S, longitude of $30^0 38'$E and altitude of 394m above sea level. The soil of the area is Sandy loam.

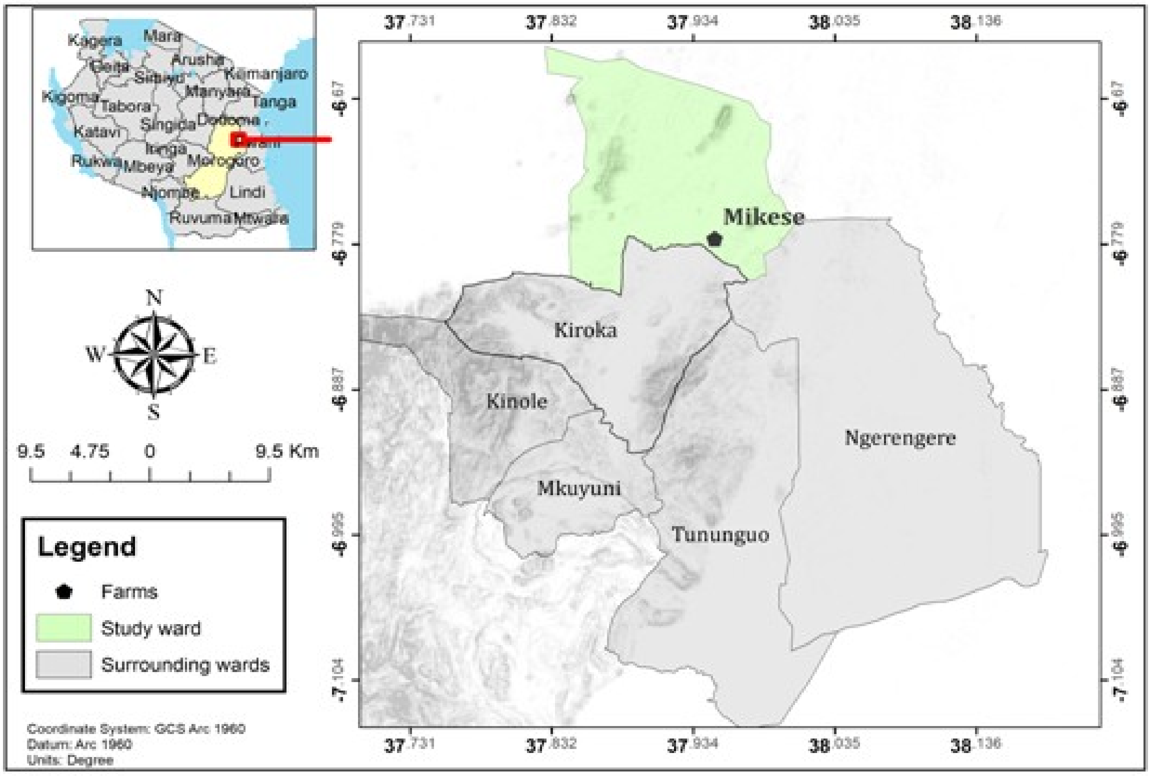

Figure 4.1: Study sites as extracted from Tanzanian map (Top left)

4.3.2 Establishment of *Spodoptera frugiperda* colony

Spodoptera frugiperda larvae and eggs were collected from maize plots at SUA campus and nearby villages around SUA 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).

4.3.3 Preparation of insecticides

Ten different insecticides were used (Table 4.1). These were: Flubendiamide (Belt 480 SC), Lamdacyhalothrin 50g/l (Ninja plus 5EC), Cypermethrin 150g/l and Chloropyrifos 300g/l (Duduba 450EC), Imidaclopride 100g/l-Betacyflurine 45g/l (Thunder 145 OD), Thiamethoxam, Emamectin- benzoate 16g/l (Snow thunder 16 EC), Emamectin Benzoate 50 g/l-Alphacypermethrin 100 g/l (Multi-Alpha plus 150EC), Alphacypermethrin, acetamiprid 100 g/l (Dudu acelamectin 5EC) Imidacloprid (Attakan 350 SC), Emamectin benzoate, Indoxacarb 140.5g/l (Liberate 200 EC) and Profenophos 720g/l (Profecron 720EC). Each insecticide was thoroughly mixed with water following the manufacturer’s recommendation for 5-10 minutes.

Table 4.1: 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

4.3.4 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 (Table 4.1). 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. 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.

4.3.5 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 4.2).

4.3.6 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 (1st and 2nd instar), (2nd and 3rd instar), (3rd and 4th instar) and (4th to 6th instar) of *S. frugiperda* was observed. Insecticide spray was done twice at a 14 days interval.

4.4 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).

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

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 4.2).

Table 4.2: 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 fall Armyworm 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 les severe.
5	> 50% leaf damage, plant stunting and funnel damaged severely.

Source: Fotso *et al*., 2019.

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.

4.5 Data Analysis

Data were for tested for normalization and found to be not normally distributed and therefore were normalized using the arcsine formula: arcsin √(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 $p \leq 0.05$.

4.6 Results

4.6.1 Effect of insecticides on mortality of *Spodoptera frugiperda* larvae under field condition 5 days after treatment application

The results showed that there were highly significant (F = 63.24, Df = 10, $p < 0.001$) differences among insecticides in causing mortality of *S. frugiperda* larvae to different maize crop injury signs (Table. 4.3). Thunder 145 OD and Attakan 350 SC showed lower mortality rate whereas Multi alpha plus 150EC, Duduba 450EC, Profecron 720EC and Liberate 200 EC caused highest mortality of *S. frugiperda* larvae.

Table 4.3: Mortality of *Spodoptera frugiperda* larvae under field condition 5 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 *Spodoptera frugiperda* larvae

4.6.2 *Spodoptera frugiperda* larvae mortality 5 days after treatments application based on crop injury signs on maize.

The results showed that there were highly significant ($p < 0.001$) difference among maize crop injury signs for percentage mortality caused by different insecticides (Table 4.4). Circular holes showed the highest mortality rate with no significance from window pane and irregular holes, and extensive defoliation had the lowest mortality rate of *S. frugiperda* larvae.

Table 4.4: ***Spodoptera frugiperda*** **larvae mortality 5 days after treatments 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 $p < 0.05$

4.6.3 Interaction effect of maize crop injury sign and insecticides on mortality of *Spodoptera frugiperda* under field condition.

The results (Table 4.5) showed 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%) 5 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 Extensive defoliation with Attakan 350 SC had the lowest mortality (66.67%).

Table 4.5: 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

4.6.4 Percentage *Spodoptera frugiperda* incidence on maize crop based on crop injury sign after two consecutive insecticide sprays under field condition

The results showed that there were significant (F = 4.31, Df = 3, $p < 0.001$) effect on maize leaf incidence among different maize crop injury sign after treatment application (Table 4.6). Window pane, circular holes and extensive defoliation plots had highest incidence level compared to irregular holes plot which had the lowest in the 1st spray. For the 2nd spray, results showed that there was a decrease in percent *S. frugiperda* incidence level compared to the 1st spray.

Table 4.6: Percentage *Spodoptera frugiperda* incidence on maize crop based on crop injury sign after two consecutive insecticide sprays under field condition

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 $p < 0.05$

4.6.5 Influence of insecticides on percent *Spodoptera frugiperda* incidence on maize plant after two consecutive spray under field condition

The results showed that there were significant ($p < 0.001$) effect among insecticides on the reduction of *S. frugiperda* incidence on maize leaves (Fig.4.2). Ninja plus 5EC had lowest incidence where as Thunder 145 OD had highest incidence after 1st spray. Duduba 450 EC showed lowest incidence to maize plants whereas Attakan 350 SC and Liberate 200EC had highest incidence after 2nd spray.

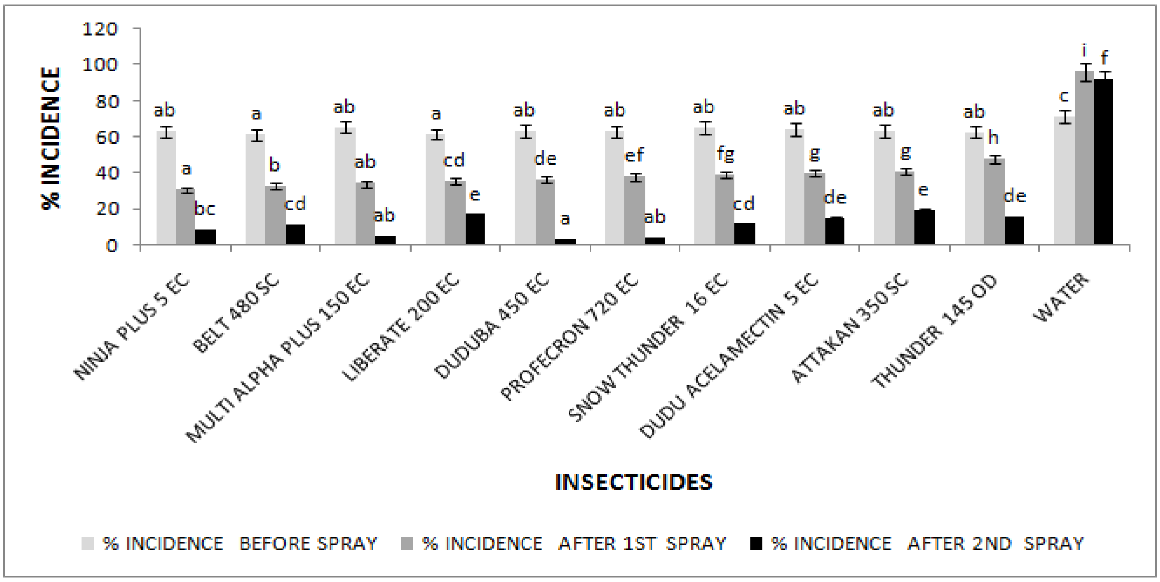

Figure 4.2: Influence of insecticides on percent *Spodoptera frugiperda* incidence on maize plant after two consecutive spray under field condition

4.6.6 Interaction effect of maize crop injury sign and insecticides on incidence after 1st and 2nd spray under field condition

The results (Table 4.7) showed that, treatment combination between maize crop injury sign and insecticides after 1st and 2nd spray had significant effect at $p < 0.001$ and $p = 0.02$. Treatment combination between window pane and insecticide showed that, Snow thunder 16EC and Thunder 145 OD showed the highest incidence 60% and 57.78% after 1st spray and belt 480 SC and Multi alpha plus 150 EC showed lowest incidence percent 37.78%. Treatment combination between circular holes. and insecticide showed that, Thunder 145 OD showed highest incidence percent 61.11% and Ninja plus 5 EC and Duduba 450 EC showed lowest incidence 31.48% after 1st spray. Treatment combination irregular holes and insecticide showed that, Liberate 200 EC showed highest incidence percent (49.21) after 1st spray and Duduba 450 EC showed the lowest incidence percent 31.75% after 1st spray. Treatment combination extensive defoliation and insecticide showed that, Thunder 145 OD showed the highest incidence percent 50% after 1st spray and Multi alpha plus 150 EC showed the lowest incidence percent 37.5% after 1st spray.

Treatment combination window pane and insecticide showed that, Attakan 350 SC showed highest incidence percent 20.83% and Duduba 450EC showed lowest incidence percent 2.78% after 2^{nd} spray. Treatment combination circular holes and insecticide showed that, Dudu acelamectin 5EC and Attakan 350 SC showed highest incidence percent 16.5% after 2^{nd} spray and Multi alpha plus 150 EC and Profecron 720 EC showed lowest incidence 2.47% after 2^{nd} spray. Treatment combination irregular holes and insecticide showed that, Attakan 350SC showed highest incidence percent 23.33% whereas Duduba 450EC and Profecron 720 EC showed lowest incidence percent after 2^{nd} spray. Treatment combination extensive defoliation and insecticide showed that, Attakan 350 SC showed highest percent of incidence 17.17% and Duduba 450 EC showed the lowest incidence percent 2.02% to extensive defoliation plots after 2^{nd} spray. The results on (Appendix Table 5) showed that, there was reduction on incidence percent on maize plants after 2^{nd} spray.

Table 4.7: Interaction effect of maize crop injury sign and insecticides on incidence after 1st and 2nd spray under field condition

Crop injury sign-Insecticides	%Incidence before spray	%Incidence after 1st spray	%Incidence after 2nd spray
Circular Holes xNinja Plus 5 EC	61.23a	31.48a	9.88a-g
Circular Holes xDuduba 450 EC	60.58a	31.48a	3.7abc
Irregular Holes xDuduba 450 EC	62.11a	31.75a	2.22a
Irregular Holes xNinja Plus 5 EC	63.21a	34.92ab	9.88a-d
Irregular Holes xMulti Alpha Plus 150 EC	64.01a	36.51abc	3.33ab
Ext Defoliation xMulti Alpha Plus 150 EC	74.30b	37.5a-d	9.09a-f
Window Pane xBelt 480 SC	61.34a	37.7a-d	8.33a-e
Window Pane xMulti Alpha Plus 150 EC	60.19a	37.7a-d	4.17abc
Irregular Holes xProfecron 720 EC	62.17a	38.1a-d	2.22a
Circular Holes xMulti Alpha Plus 150 EC	59.10a	38.8a-e	2.47ab
Extensive Defoliation xDuduba 450 EC	76.56b	38.9a-e	2.02a
Circular Holes xProfecron 720 EC	60a	38.8a-e	2.47ab
Window Pane xNinja Plus 5 EC	62.11a	40a-f	8.33a-e
Extensive Defoliation xNinja Plus 5 EC	75.11b	41.6a-f	7.07a-d
Extensive Defoliation xProfecron 720 EC	74.78b	41.6a-f	6.06a-d
Circular Holes xSnow Thunder 16 EC	61.10a	44.4b-g	11.11a-g
Window Pane xAttakan 350 SC	62a	44.4b-g	20.83efg
Window Pane xDudu Acelamectin 5 EC	61.15a	44.4b-g	18.06d-g
Window Pane xDuduba 450 EC	58.90a	44.4b-g	3.7ab
Irregular Holes xBelt 480 SC	64.13a	44.4b-g	7.78a-e
Ext Defoliation xLiberate 200 EC	76.11b	45.8b-g	13.13a-g
Ext Defoliation xAttakan 350 SC	74.34b	45.8b-g	17.17c-g
Ext Defoliation xDudu Acelamectin 5 EC	74.23b	45.8b-g	13.13a-g
Ext Defoliation xSnow Thunder 16 EC	75b	45.8b-g	13.13a-g
Circular Holes xBelt 480 SC	61.12a	46.3b-h	12.35b-g
Window Pane xLiberate 200 EC	61.25a	46.6b-h	18.06d-g
Window Pane xProfecron 720 EC	60.92a	46,6b-h	4.17abc
Extensive Defoliation xBelt 480 SC	75.59b	47,2c-h	14.14a-g
Irregular Holes xAttakan 350 SC	64.1a	47,2c-h	23.33g
Irregular Holes xDudu Acelamectin 5 EC	63.87a	47,2c-h	11.11a
Irregular Holes xSnow Thunder 16 EC	63.42a	47,2c-h	10a-g
Irregular Holes xThunder 145 OD	64.12a	47.2c-h	13.33a-g
Irregular Holes xLiberate 200 EC	62.16a	49.21d-i	22.22fg
Extensive Defoliation xThunder 145 OD	76.11b	50e-j	14.14a-g
Circular Holes xLiberate 200 EC	59.90a	51.85f-j	13.58a-g
Circular Holes xDudu Acelamectin 5 EC	60.23a	53.7g-j	16.05b-g
Circular Holes xAttakan 350 SC	59.79a	55.5g-j	16.05b-g
Window Pane xThunder 145 OD	62.11a	57.78hij	19.44d=g
Window Pane xSnow Thunder 16 EC	61.91a	60ij	11.11a-g
Circular Holes xThunder 145 OD	60.13a	61.11j	13.58a-g
Circular Holes xWater	61.22a	88.89k	96.97h
Extensive Defoliation xWater	75.11b	95.83k	96.97h
Irregular Holes xWater	63.52a	100k	86.67h
Window Pane xWater	61.21a	100k	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

4.6.7 Damage severity score of *Spodoptera frugiperda* based on crop injury sign to maize plant after two consecutive sprays under field condition

The results showed that there were significant ($p < 0.001$) differences among maize crop injury to damage severity score for both sprays (Fig. 4.3). For the 1st spray, extensive defoliation plots showed the highest damage severity score whereas window pane crop injury plots showed lowest damage severity score. For the 2nd spray, Extensive defoliation showed the highest damage severity whereas window pane showed the lowest damage severity score. Generally, results showed that there were significant reduction of damage severity score after 2nd spray compared to the 1st spray. Extensive defoliation plots showed the highest damage severity score whereas window pane plots showed the lowest damage severity score after 2nd spray.

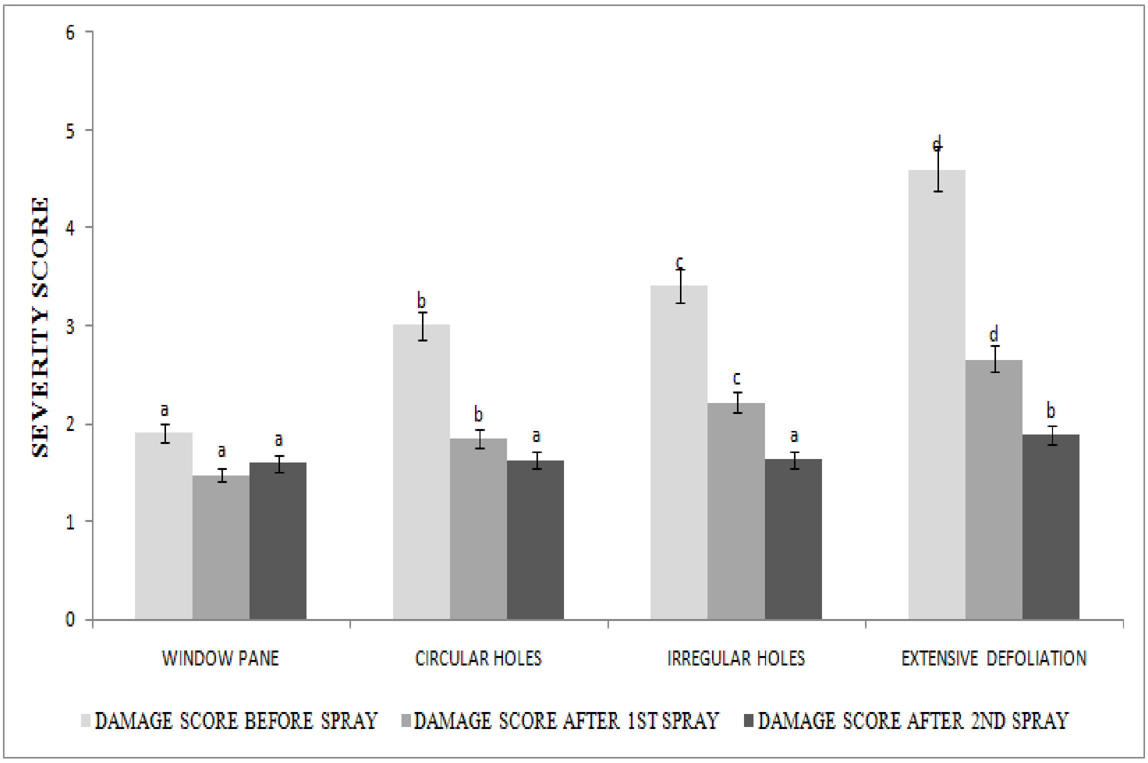

Figure 4.3: Damage severity score of *Spodoptera frugiperda* on maize plant after two consecutive spray under field condition

4.6.8 Effect of insecticides on damage severity score of *Spodoptera frugiperda* on maize plant after two consecutive sprays under field condition

The results showed there were significant ($p < 0.001$) differences among insecticides on reduction of damage severity score to maize plant after 1st and 2nd spray (Fig. 4.4). Thunder 145 OD showed the highest damage severity percent and Profecron 720 EC showed lowest damage severity after 1st spray. For the 2nd spray, Attakan 350 Sc showed highest damage severity percent whereas Profecron 720 EC showed lowest damage severity percent.

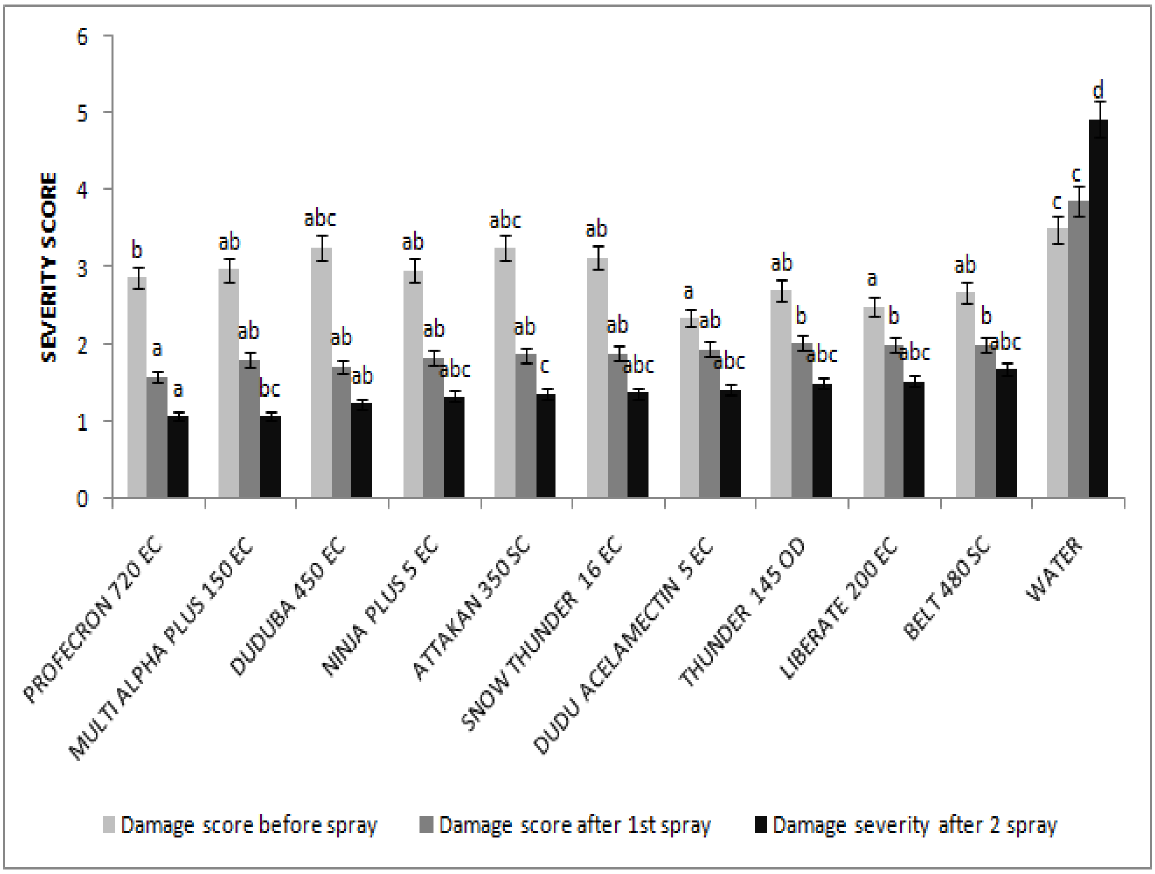

Figure 4.4: Damage severity score of *Spodoptera frugiperda* on maize plant after two consecutive spray under field condition

4.6.9 Interaction effect of maize crop injury sign and insecticides on maize damage severity score after 1st and 2nd spray application under field condition

The result (Table 4.8) showed that, treatment combination between maize crop injury sign and insecticides had significant effect in reduction of maize damage severity at $p < 0.001$. Treatment combination between window pane and insecticides showed that, Dudu acelamectin 5 EC and Attakan 350 SC showed highest damage severity score 1.7 and 1.3 after 1st and 1.2 and 1.3 after 2nd spray consecutive whereas Multi alpha plus 150 EC and Ninja plus 5 EC had lowest damage severity score (1.2) after 1st spray and Profecron 720 EC and Ninja plus had lowest damage severity 1.04 and 0.9 after 2nd spray. Treatment combination between circular holes and insecticides showed that, Thunder 145 OD and Belt 480 SC had highest damage severity score 2.98 and 2.8 after 1st spray. Profecron 720EC had lowest damage severity (1.4) after 1st spray on circular holes plots. Liberate 200 EC had highest damage severity (1.4) compared to whereas 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 4.8: Interaction between maize crop injury sign caused by *Spodoptera 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 xMulti Alpha Plus 150 EC	4.3d	2.344f-m	1.033a
Irregular holes xProfecron 720 EC	3.5c	1.674a-g	1.036ab
Circular holes xDuduba 450 EC	2.8b	1.542a-g	1.039abc
Irregular holes xMulti Alpha Plus 150 EC	3.5c	2.059a-g	1.039abc
Window Pane xProfecron 720 EC	1.8a	1.257ab	1.041bc
Extensive defoliation xProfecron 720 EC	4.7d	1.989f-n	1.1cd
Window Pane xMulti Alpha Plus 150 EC	1.9a	1.201a	1.1cd
Circular Holes xProfecron 720 EC	3.1c	1.423a-e	1.1cd
Irregular Holes xDuduba 450 EC	3.6c	1.822d-k	1.1cd
Circular Holes xMulti Alpha Plus 150 EC	2.89b	1.633b-i	1.125de
Window Pane xDuduba 450 EC	2ab	1.278abc	1.125de
Window Pane xLiberate 200 EC	2.1ab	1.388a-d	1.125de
Window Pane xThunder 145 OD	2.3ab	1.344a-d	1.167ef
Circular Holes xDudu Acelamectin 5 EC	3.51c	1.7c-j	1.167ef
Extensive Defoliation xSnow Thunder 16 EC	4.3d	2.067i-o	1.201efg
Circular Holes xNinja Plus 5 EC	3.12ab	1.611b-h	1.202efg
Irregular Holes xNinja Plus 5 EC	3.6c	2.467e-l	1.226fgh
Ext Defoliation xDudu Acelamectin 5 EC	4.10d	4.79m-p	1.227fgh
Window Pane xDudu Acelamectin 5 EC	2.2ab	1.542a-f	1.247hij
Circular Holes xAttakan 350 SC	2,5ab	2.133b-h	1.253ijk
Irregular Holes xDudu Acelamectin 5 EC	3.4c	1.634k-o	1.256ijk
Circular Holes xThunder 145 OD	2.9bc	1.267b-i	1.256jkl
Window Pane xBelt 480 SC	1.8a	1.2abc	1.212kl
Window Pane xSnow Thunder 16 EC	1.97a	1.4a-d	1.313kl
Extensive Defoliation xBelt 480 SC	4.7d	2.533opq	1.313kl
Window Pane xAttakan 350 SC	1.6a	1.364a-d	1.342lm
Irregular Holes xAttakan 350 SC	3.9cd	2.7l-o	1.4m
Irregular Holes xBelt 480 SC	3.3c	2.278nop	1.4m
Circular Holes xBelt 480 EC	2.8ab	2.311g-n	1.42mn
Circular Holes xSnow Thunder 16 EC	2.98ab	1.944h-n	1.42mn
Irregular Holes xSnow Thunder 16 EC	3.6c	1.989k-o	1.431no
Circular Holes xLiberate 200 EC	2.87bc	2.1f-n	1.433o
Extensive Defoliation xLiberate 200EC	4,9d	1.9pq	1.433o
Irregular Holes xThunder 145 OD	3.5c	2.7j-o	1.5op
Extensive Defoliation xThunder 145 OD	5.2de	2.033qr	1.5op
Extensive Defoliation xNinja Plus 5 EC	4.4d	3.078m-p	1.743p
Extensive Defoliation xAttakan 350SC	4.1cd	2.544l-p	1.8q
Extensive Defoliation xDuduba 450 EC	4.0cd	2.278k-o	1.8q
Irregular Holes xLiberate 200EC	3.3c	2.244h-n	2.533r
Window Pane xWater	2.1a	3.1r	4.722t
Extensive Defoliation xWater	3.1c	5t	5t
Circular Holes xWater	2.9ab	3.33r	5t
Irregular holes xWater	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 $p \leq 0.05$ (Tukey´s Test). CV= Coefficient of variation, SE= Standard error mean

4.6.10 Number of leaves and plant height of maize under different insecticides treatment in field condition

The results (Table 4.9), showed that there were no significant difference (p = 0.124) on the number of leaves for different maize crop injury signs (p = 0.124). The results on mean plant height showed that there were significant (p = 0.002) difference on plant height among maize crop injury plots treated with different synthetic insecticides Window pane plot had shortest plant height (194 cm) and circular holes plot had tallest plant height (203.6 cm).

Table 4.9: Number of leaves and plant height of maize based on crop injury sign **in field condition**

Crop injury sign	No. of leaves	Plant Height
Window Pane	14.33	194.0a
Extensive Defoliation	14.47	209.7b
Irregular Holes	14.62	202.4ab
Circular Holes	14.67	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

4.6.11 Number of leaves, plant height (cm) and yield (tons/ha) of maize under different insecticides sprays under field condition

The results on number of leaves of maize under different insecticides treatment (Table 4.10) showed that, there were no significant different on number of leaves p = 4.2 and also for plant height the result showed no significant different (p = 0.318). The yield of maize tons/ha from different plots showed that, there was significant difference ($p < 0.001$). Duduba 450 EC had largest yield 4.1 tons/ha and non treated plot (Water) had the smallest yield 2.1 tons/ha.

Table 4.10: Number of leaves, plant height and yield of maize (Tons/ha) under different insecticides treatment in field condition

INSECTICIDE	Number of leaves	Plant Height	Yield (Tons/ha)
Belt 480 SC	14.19	194.5	3.3a
Multi Alpha Plus 150 EC	14.33	211.8	3.9i
Snow Thunder 16 EC	14.5	205	3.5f
Dudu Acelamectin 5EC	14.5	203.2	3.2d
DUDUBA 450 EC	14.5	203	4.1j
Attakan 350 SC	14.56	201.5	2.9c
Profecron 720 EC	14.56	199.8	3.6h
Liberate 200 EC	14.64	207.6	2.8b
Ninja Plus 5 EC	14.64	202.6	3.6g
Thunder 145 OD	14.64	203.4	2.8b
Water	14.69	194.6	2.1a
Mean	14.52	202.45	3.254
SE	0.177	4.642	0.003
CV%	4.2	7.9	1.1
***p*-Value**	0.729	0.318	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

4.6.12 Crop injury-based insecticide spray guide for the management of *Spodoptera frugiperda* in maize crop

Crop injury based insecticide spray guide have been established (Table 4.11) as the output of field experiment conducted at Mikese, Morogoro region. This advisory spray guide will help farmers to manage *Spodoptera frugiperda* by making rational decision on selection of appropriate insecticides basing on the maize crop injury observed.

Table 4.11: Crop injury-based insecticide spray guide for the management of *Spodoptera frugiperda* in maize crop

Injury sign on maize	**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 once 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 highly 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 once 30% of the crop injury sign is observed and second application 14 days after first application.

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4.7 Discussion

The current study revealed that all the tested synthetic insecticides in this study were toxic to *S. frugiperda* larvae and had significant difference ability in causing mortality to *S. frugiperda* larvae on different maize crop injury sign. Application of synthetic insecticides to the maize plots showed significant reduction in leaf incidence and damage to the maize compared to the control. This reduction of leaf incidence and damage was due to the reduced number of *S. frugiperda* larvae in treated plants. These findings were in agreement with the findings by Sisay (2018) who observed reduction in leaf damage after insecticide application.

Window pane, circular holes and irregular holes plots had highest *S. frugiperda* larvae mortality rate compared to extensive defoliation plots. This may be due to the fact that window pane plots to irregular holes maize crop injury signs are caused by fall armyworm instar stage 1-4 of which are very young larvae. The young larvae are very susceptible to many insecticides compared to larval instar 4-6 which are less susceptible to insecticides. 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.

Efficacy of different insecticides in causing mortality to *S. frugiperda* larvae differs significantly. This was been supported by the results which showed that 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 to the different maize crop injury sign in the field. This finding was somehow contrary to the findings by Thumar (2020) who found out 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 1st and 2nd spray whereas Thunder 145 OD and Attakan 350 SC had significantly highest incidence at 1st and 2nd sprays.

The study also revealed that damage severity score increases from window pane to extensive defoliation plots. These results may be due the fact that at early maize crop injury sign that is window pane to irregular holes, the fall armyworm larvae instar which cause these injury are larval instar 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. These results have been also confirmed by 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. This finding is in agreement with the findings by Sisay (2019) who found that, larval mortality increased with time after insecticide application. In addition the same finding is in agreement with the findings by Belay *et al.* (2012) found that, as time increases the mortality of *S. frugiperda* larvae increases.

The results on number of leaves and plant height on different maize crop injury plots had no significant different. This findings could be caused by the proper timing and efficacy of the used insecticides towards killing of the *S. frugiperda* larvae as the results, maize crop after treatment application were able to recover from the injury which enable the crop to grow well. Report by FAO (2018), showed that maize crop have ability to compensate its foliar damage as long as there is enough moisture and nutrient. This finding support the current finding which showed that there were no significant difference in mean number of leaves due to the ability of maize crop to compensate its foliar after damage caused by *S. frugiperda*. These results are in agreement with the findings by Sisay (2018) who observed that there were no significant difference in mean number of leaves and plant height after treatment application, and found reduction of leaf damage due reduction of *S. frugiperda* larvae after insecticide application. Maize plots treated with Duduba 450 EC had largest weight compared to non-treated plot (water) which had the smallest weight. This showed that Duduba 450 EC was very effective in controlling fall armyworm larvae at different stages, therefore resulted to large production of maize. Sisay (2018), recorded higher fresh weight and dry weight of maize on the plots sprayed with insecticides compared to non-treated plots.

Effective control of *S. frugiperda* under field condition based on the observed maize crop injury, 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).

4.8 Conclusion

Generally synthetic insecticides have significant effect on controlling *S. frugiperda* infestation and hence are effective management control option. Synthetic insecticides have quick response towards insects, *S. frugiperda* being among them. In the current study insecticides effectively caused mortality up to 100%, reduced *S. frugiperda* incidences on maize crop and minimized damage severities. Different insecticides had varied efficacy in controlling different *S. frugiperda* larval instar stages. 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) were effective on window pane injury signs. Circular holes were easily taken care of by fast acting and highly effective insecticides such as Alphacypermethrin and Acetamiprid (Dudu Acelamectin 5EC), Lamdacyhalothrin (Ninja plus 5EC), Emamectin Benzoate and Indoxacarb (Liberate 200EC). Fast acting insecticide with multiple active ingredient such as Flubendiamide (Belt 480 SC), Lamdacyhalothrin (Ninja plus 5EC), Emamectin Benzoate, (Snow Thunder 16EC) were best suited to irregular holes injury signs where as extensive defoliation was best treated using fast acting and 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) are effective.

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CHAPTER FIVE

5.0 GENERAL CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The present study established that *S. frugiperda* is omnipresent wherever maize crop is grown regardless of the altitude despite the declining abundance with altitude. All tested insecticides were effective in controlling *S. frugiperda* larvae but differs significantly in their effectiveness from one larval stage to another and from one crop injury sign to the other. Early injury signs on maize crop (window pane and circular holes) tallied well with early larval development stages and were controlled by all tested insecticides. Nevertheless, advanced damage signs (extensive defoliation and production of fussy) required stronger insecticides such as Multi alpha plus 150 EC, Profecron 720EC, Duduba 450EC and Ninja plus 5EC to effectively control the damaging *S. frugiperda* larvae and reduce incidences and damage severities. *Spodoptera frugiperda* was found to be present at all altitudes (from 524 to 1961 m above sea level) albeit at varied abundance with a declining trend as altitude increased. Therefore appropriate selection of insecticides, correct timing of application and right dosage could help to reduce *S. frugiperda* incidence and damage severity.

5.2 Recommendations

The present study unveiled the dynamics of *S. frugiperda* as influence by altitude as well as the effectiveness of insecticide as vital control tool whose efficacy would be improved by using crop injury signs as clue for guided choice of insecticides and timing of application. Given the study duration and scope, the following are recommended:

i) The duration of the current study was short. Longer duration of data collection and detailed analyses could help eliminate doubts and reinforce the conclusions made.

ii) This study focused on efficacy and right timing of the insecticides application only. Future studies should focus on residual effect of these insecticides to guide appropriate choices of insecticides.

iii) The current study was conducted in one area in Morogoro region. Future research should consider involving multiple locations across different agro ecological zones in Tanzania to establish conclusive evidence over a larger area upon which country-wide recommendations can be made.

iv) Future studies should consider systems to correctly alternate insecticides from different groups in combination with non-chemical pest management strategies to avoid potential resistance from *S. frugiperda.*

APPENDICES

Appendix 1: Analysis of variance showing means number of *Spodoptera frugiperda* catches for duration of six months (January to June 2020).

S.V	D.F	S.S	M.S	F-value	P-value
Rep stratum	3	1971.3	657.1	4.32	-
Dates	23	26773.5	1164.1	7.66	<0.001
Location	3	18250.9	6083.6	22.05	<0.001
Dates.Location	69	13932.2	491.8	3.24	<0.001
Error	285	43316.7	152.0		
Total	**383**	**124244.6**			

Appendix 2: Analysis of variance showing mean percent mortality of *Spodoptera frugiperda* larvae 3, 6, 12, 24 and 48h after application of insecticides in laboratory test

3h

S.V	D.F	S.S	M.S	F-value	P-value
Larval instar	3	65036.36	21678.79	269.96	<0.001
Insecticides	10	92284.85	9228.48	114.92	<0.001
Larval instar-Insecticides	30	40963.64	1365.45	17.00	<0.001
Error	88	7066.6780.30			
Total	**131**	**205351.52**			

6h

S.V	D.F	S.S	M.S	F-value	P-value
Larval instar	3	36656.82	12218.94	322.58	<0.001
Insecticides	10	97772.73	9777.27	258.12	<0.001
Larval instar-Insecticides	30	35318.18	1177.27	31.08	<0.001
Error	88	3333.33	37.88		
Total	**131**	**173081.06**			

12h

S.V	D.F	S.S	M.S	F-value	P-value
Larval instar	3	16420.45	5473.48	289.00	<0.001
Insecticides	10	102121.21	10212.12	539.20	<0.001
Larval instar-Insecticides	30	25454.55	848.48	44.80	<0.001
Error	88	1666.67	18.94		
Total	**131**	**145662.88**			

24h

S.V	D.F	S.S	M.S	F-value	P-value
Larval instar	3	2.023E+03	6 744E+02	3561.00	<0.001
Insecticides	10	1.009E+05	1.009E+04	53293.00	<0.001
Larval instar-Insecticides	30	2.048E+04	6.828E+02	3605.00	<0.001
Error	88	1.667E+01	1.894E-01		
Total	**131**	**1.235E+05**			

48h

S.V	D.F	S.S	M.S	F-value	P-value
Larval instar	3	0.5682	0.1894	1.00	<0.397
Insecticides	10	99320.07	99320.07	52441	<0.001
Larval instar-Insecticides	30	5.6818	0.1894	1.00	<0.001
Error	88	16.6667	0.1894		
Total	**131**	**99342.9924**			

Appendix 3: Analysis of variance showing mean plant height, leaf number and weight of maize under different insecticides treatment in field condition.

Plant Height

S.V	D.F	S.S	M.S	F-value	P-value
Rep stratum	2	2916.9	1458.4	5.64	-
Crop Injury sign	3	4139.2	1379.7	5.33	0.002
Insecticides	10	3042.6	1365.45	1.18	0.318
Crop Injury signs-Insecticides	30	4778.4	304.3	0.62	0.933
Error	86	22241.8	159.3		
Total	**131**	**37118.9**	**258.6**		

Leaf number

S.V	D.F	S.S	M.S	F-value	P-value
Rep stratum	2	8.55	4.27	11.34	-
Crop Injury sign	3	2.23	0.74	1.97	0.12
Insecticides	10	2.60	0.26	0.69	0.72
Crop Injury signs-Insecticides	30	10.90	0.36	0.96	0.52
Error	86	32.41	0.37		
Total	**131**	**56.70**			

Maize weight

S.V	D.F	S.S	M.S	F-value	P-value
Rep stratum	2	0.0000515	0.0000257	0.18	-
Crop Injury signs	3	0.1039876	0.0346625	238.25	<.001
Insecticides	10	4.2835327	0.4283533	2944.28	<.001
Crop Injury sign-Insecticides	30	0.3769639	0.0125655	86.37	<.001
Error	86	0.0125119	0.0001455		
Total	**131**	**4.7770475**			