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Studies on the Influence of Altitude on Abundance of Fall Armyworm (*Spodoptera Frugiperda* (Je Smith)) (Lepidoptera: Noctuidae) in Tanzania

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ABSTRACT

Fall armyworm (FAW) (*Spodoptera frugiperda*) is one of the most devastating polyphagous field crop pests in many parts of the world, including Tanzania. Influence of altitude on the abundance of *S. frugiperda* was studies by using Pheromone (Frugilure *S. frugiperda*, Chemtica international, S.A) embedded cup traps. The study was conducted along sites of Mt. Uluguru slopes including; 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 site equidistantly arranged at 100 m apart) were used. 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 *S. frugiperda* was abundantly recorded across he tested altitude albeit at varied abundance. There was significant difference ($p < 0.001$) among altitude on *S. frugiperda* abundance, whereby at low altitude, *S. frugiperda* abundance was high compared to medium and high altitude. Rainfall had positive correlation on *S. frugiperda* abundance ($r = 0.16$, $r = 0.04$) for SUA and Mlali 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 at 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 negative correlation with *S. frugiperda* abundance. Thus, appropriate and effective management practices of *S. frugiperda* should be considered throughout maize production areas and across crop production seasons regardless of the altitude.

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

INTRODUCTION

Fall Armyworm (FAW) (*Spodoptera frugiperda* JE Smith) (Lepidoptera: Noctuidae) is a devastating pest of maize which is native to America [1]. The pest was reported for the first time in the African continent in early 2016 [2]. According to Day et al.[1], 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 are imposed [3].

Weather parameters play an important role in regulating the population of *S. frugiperda* under agro-ecosystems [4]. Positive or negative correlation of weather factors with *S. frugiperda* abundance have been reported [5]. Outbreaks and resurgence of the insect pest is linked to environmental factors including elevation (Low, Medium and High altitude) weather such as temperature (high or low), abundance or scarcity of rainfall and the use of susceptible varieties in ecosystems [4]. 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 insects leading to temporal and spatial dynamics [6]. 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 [4]. Pheromone lures have long been used in monitoring, mass trapping and mating disruption of a great diversity of insect pests [7].

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 to inform decision making on pest management [8]. Once the chemical composition of naturally occurring pheromone has been determined, the similar synthetic pheromone can be manufactured and used as a lure in a trap to monitor the moth population [3]. Frugilure, the pheromone lures specific to *S. frugiperda* has been manufactured by Chemtica International S.A. and recommended by FAO for monitoring the pest. The only major challenge with pheromone traps is that some predators have evolved to detect these pheromones and may use them to locate prey [8]. Trap uses may sometimes results into undesired outcome when non target insects including natural enemies are lured [9, 8]. 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. There has been assumption that the population and abundance of *S. frugiperda* could be affected by the altitude suggesting the possibility of higher altitude to be less infested with the pest as the case would be with low to medium altitude. Data on the altitudinal influence on abundance and distribution of *S. frugiperda* are scanty. Whether the pest abundance varied through the crop growing season has not been established in Tanzania. Understanding these parameters will guide informed decision making on where maize can be grown without much worry about *S. frugiperda* and locations that requires intensive management of the pest. Timing of maize crop planting with season of low pest abundance could also help in reducing pest management costs. The objectives of the current study were; i) to determine the abundance of *S. frugiperda* across varied range of altitude, and ii) to establish the relationship between selected weather parameters and *S. frugiperda* abundance.

MATERIALS AND METHODS

Study Location

The study was conducted in Morogoro at four locations along the Uluguru maountain ranges which included; Sokoine University of Agriculture (SUA) Horticultural Unit located at 525 m above sea level (masl), Mlali located at 579 masl, Mgeta located at 1050 masl, and Nyandira located at 1691 masl. Experimental locations coordinate 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. 1). Variation in altitude (from low to high) has been clearly shown using colours with SUA site being the lowest and Nyandira the highest.

Experimental Design

The experiment was laid out in Randomized Complete Block Design (RCBD) with four locations (as blocks). Treatments were the altitude (low, medium and high) and the four traps at each site represented four replications. A commercially available *S. frugiperda* lure (Frugilure *S. frugiperda* manufactured by Chemtica international, S.A batch number P061-Lure) and moth catcher bucket traps were used for the study. Four traps embedded with pheromone lures were equidistantly set (100 m apart) at each location as per protocol [10]. 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 each of four sides (100 meters apart) of the selected maize farms at a height of 1.5 m above the ground (Fig 2).

The experimental sites were approximately about 15 km apart. Grease was applied to the pole and the strings that held the trap to the pole to prevent the catches from being preyed on by predatory arthropods such as Big-headed 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. Please note that in the study area maize crop takes three months from establishment to maturity.

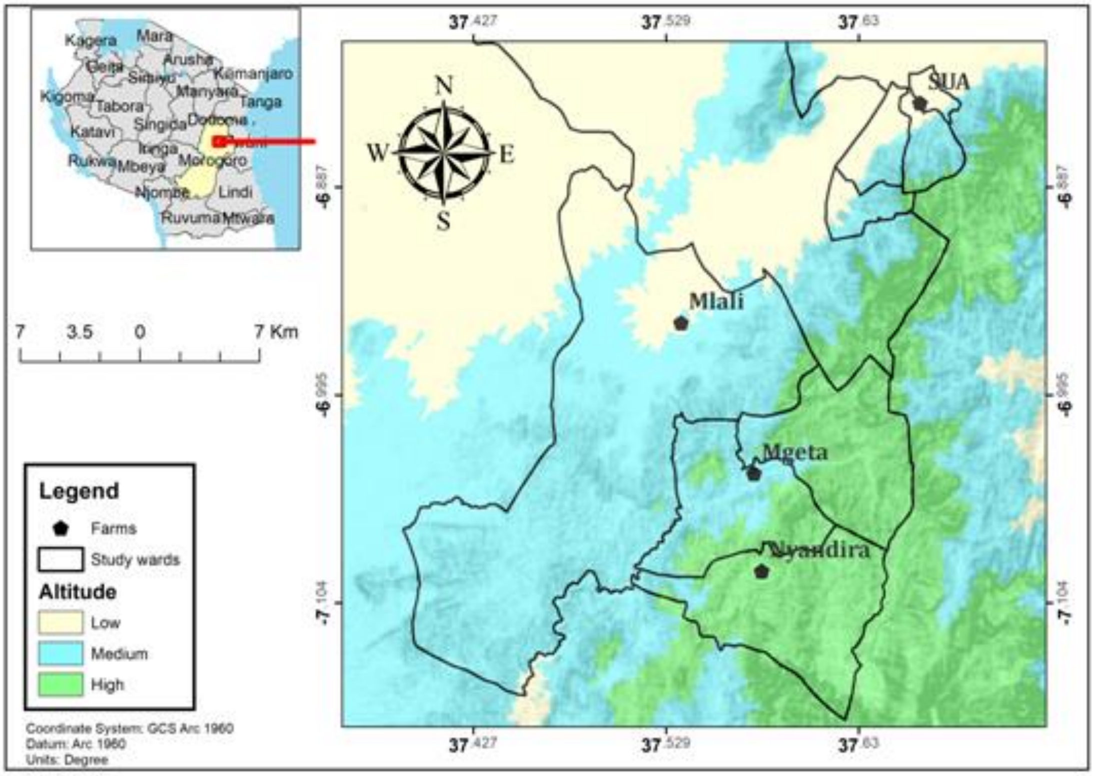

Figure 1: Study sites as extracted from Tanzanian map (Top left)

Figure 2: Trap for S. *frugiperda* monitoring; A, maize crop at V2 stage and B, maize crop at V8 stage

Data Collection

Data of trapped *S. frugiperda* moths were collected at one week interval for the duration of six months. Data collected includes, number of adult *S. frugiperda* moths trapped per trap per location. Weather parameters (Temperature, Relative humidity and Rainfall) were recorded for one week interval. Bearing on advice by the meteorological experts from the Tanzania Meteorological Agency, the weather parameters for SUA and Mlali locations were obtained from

SUA meteorological station and that of Mgeta and Nyandira collected by using a Maxim integrated i-button devices (DS 9490#, 0838C, 365060 PHIL) (Hygrocron) manufactured by maxim integrated company. Recorded weather parameters using the i-button devices were Temperature and Relative humidity. The rainfall data for Mgeta and Nyandira were collected from the SUA station at Nyandira.

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 assumptions 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 met. Data on weather parameters (Temperature and Relative humidity) recorded by Maxim integrated i-button devices (DS 9490#, 0838C, 365060 PHIL) (Hygrocron) were retrieved by one wire viewer software.

Data Analysis

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

RESULTS

Spodoptera Frugiperda Catches Across the Season

The recorded *S. frugiperda* catches suggested that the pest was present throughout the trapping period in the whole six months period. The *S. frugiperda* abundance varied significantly (F= 7.66, Df = 23, $p < 0.001$, and F= 40.03, Df = 3, $p < 0.001$) among dates and locations (Fig. 3). At SUA site the highest *S. frugiperda* catches were recorded during the 2nd week of January and the lowest was during the 2nd week of February and 4th week of March. At Mlali site the highest *S. frugiperda* catches was recorded during the 2nd week of January and the 3rd week of May and the lowest was during the 2nd week of February and 4th 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.

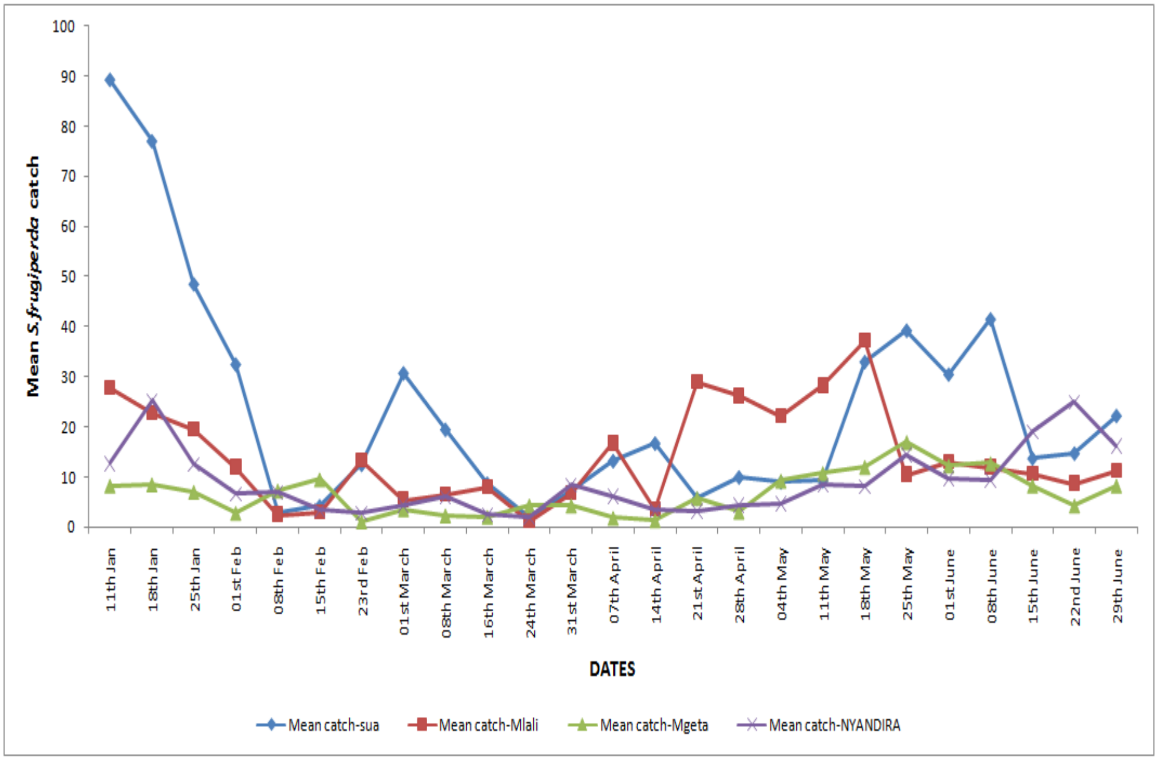

Figure 3: Weekly trend of *Spodoptera frugiperda* catches per trap for duration of six months

Spodoptera frugiperda Abundance at Different Altitude

The obtained results suggested a highly significant (F= 22.05, Df= 3, $p < 0.001$) influence of altitude on *S. frugiperda* abundance (Fig. 4). Numbers of trapped moths declined with increase in altitude. SUA site had the highest mean *S. frugiperda* catches while Nyandira had the lowest.

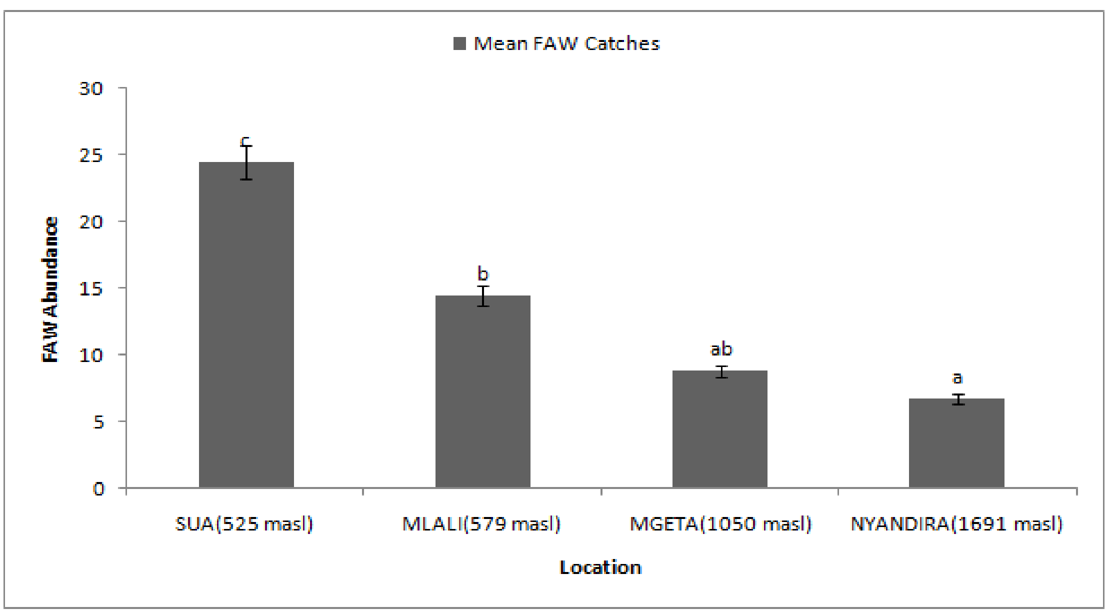

Figure 4: Mean Spodoptera *frugiperda* catches at different altitude for duration of six months

Relationship between Trap Catches and Selected Weather Variables

The obtained results showed a statistically significant ($p < 0.05$) positive association between temperature and *S. frugiperda* abundance (Table 1). Each additional unit of temperature in the habitat led to an increase in *S. frugiperda* abundance by 0.0649 (6.49 %). Thus, the higher the temperature the greater the abundance of *S. frugiperda* and vice versa. Conversely, the relative humidity and rainfall had no effect on *S. frugiperda* abundance as the collected data suggested 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 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, * significant influence

Location-Based Correlation Between Weather Parameters and *Spodoptera Frugiperda* Catches

The correlation analysis of the recorded weather parameters against *S. frugiperda* abundance at SUA (Table 2) showed that, temperature and relative humidity were negatively correlated with *S. frugiperda* abundance (r = -0.04 and r = -0.44) whereas the rainfall had a 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: Correlation analysis of weather parameters against *S. frugiperda* catches at SUA

	Mean Catches	Temperature	RH	Rainfall
Mean Catches	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 $p \leq 0.05$

The result on the correlation analysis of weather parameters against *S. frugiperda* catches at Mlali site (Table 3) suggested insignificant (P > 0.05) negative correlation between weather parameters (temperature and relative humidity) and *S. frugiperda* abundance (r = -0.36 and -0.35). Nevertheless, a positive correlation was (r = 0.04) was established between rainfall and *S. frugiperda* abundance but was likewise statistically insignificant (P > 0.05).

Table 3: Correlation analysis of weather parameters against *S. frugiperda* catches at Mlali

	Mean Catches	Temperature	RH	Rainfall
Mean Catches	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 site (1050 masl) the correlation analysis of weather parameters against *S. frugiperda* catches (Table 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 highly significant at 1% level of significance.

Table 4: Correlation analysis of weather parameters against *S. frugiperda* catches at Mgeta

	Mean Catches	Temperature	RH	Rainfall
Mean Cathes	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 correlation analysis of weather parameters against *S. frugiperda* trap catches at Nyandira (Table 5) suggested negative correlations for rainfall and relative humidity (r = -0.38 and -0.72) on *S. frugiperda* catches but a positive (r=0.21) correlation with the temperature. Both rainfall and temperature had insignificant correlation with *S. frugiperda* catches at 5% level of significance while a significant (p < 0.01) correlation was established with the relative humidity.

Table 5: Correlation analysis of weather parameters on *S. frugiperda* catches at Nyandira

	Mean Catches	Temperature	RH	Rainfall
Mean Cathes	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 $p \leq 0.01$

DISCUSSION

The current study revealed that, variation in altitude has a significant influence on the abundance of *S. frugiperda* as determined through the trap catches 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 [11]. 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. [12] indicated that increase in rainfall and decrease in temperature slows crop growth and water saturation in the soil and this may cause limited availability of 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. [13] 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 high altitude like Nyandira (1691 masl) experienced low temperature while low altitude like SUA (at low altitude) experienced high temperature matches the observed trend by Pair et al. [12]. Nyandira experienced low temperature ranging from 17°C to 22°C especially during the rainy season, and this affected the population of *S. frugiperda* [13]. 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. [14] showed that, increase in temperature to optimum level may favour the rate of photosynthesis in maize which in turn favours the continuous and abundance of food supply to *S. frugiperda*.

The weather data in all locations suggested negative correlation between relative humidity and *S. frugiperda* abundance and the trend was nearly significant in all locations. By implication, this means an increase in relative humidity results into a decrease in numbers of *S. frugiperda*. Rojas et al. [13] reported similar observation 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 until when further increase in rainfall impacts heavily on the pest number leading to a decline in catches as eggs get washed away. The positive impact of rainfall in favouring vegetative growth of maize, the *S. frugiperda* preferred host could have an indirect influence on abundance of *S. frugiperda*. Vigorous growth of host plants attracts female *S. frugiperda* to lay more eggs on the host plant which consequently contributes to rapid build-up in *S. frugiperda* population due to adequacy of the available food. Similar finding was reported by Anandhi et al. [14] that the higher the rainfall distribution the greater the influence it has on *S. frugiperda.* Likewise, Mitchel et al. [15] reported that in the tropics *S. frugiperda* population has tendency to vary with changes in rainfall. The case is different for Mgeta and Nyandira sites which indicated negative correlations between rainfall and *S. frugiperda* abundance although the trend was found to be 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) the major host crops particularly maize was grown on relatively large scale compared to the higher altitude. 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 [16], plentiful rains could have resulted in lush growth of the *S. frugiperda* preferred host plants impacting negatively on 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 were mainly planted with vegetable crops particularly tomato, cabbage, eggplants and carrots while maize was 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. [13] asserted 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 et al. [17], *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 reducing the number of moths catches over time during the growth stages [11].

Temperature difference can be another reason for the observed differences in *S. frugiperda* abundance. At low altitude high temperature was received compared with medium to high altitude. According to Schlemmer, [18] high temperature from 26^0C to 32^0C favours developmental growth of *S. frugiperda* including egg hatching, larval development, pupation, and adult emergence. Simmons & Rogers [19] reported that the required optimum temperature for the mating of *S. frugiperda* is approximately 25-35°C which is favorable 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 tandem with Schlemmer [18] that continuous low temperature, lower thermal limit tends 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 [7]. 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 [7]. This suggests the need to embrace appropriate management options for *S. frugiperda* regardless of whether the maize crop is grown at low or high-altitude areas.

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 a scanty safe window that may allow uninterrupted growth of maize crop. Therefore, intensive control measures should be imposed at low altitude areas compared to high altitude due to the high abundance of *S. frugiperda* as compared to high altitude areas.

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