FALL ARMYWORM *(Spodoptera frugiperda)* INFESTATION: FARMERS' PERCEPTION, KNOWLEDGE AND DAMAGE IN BUNGOMA AND KERICHO COUNTIES, ITS BIOLOGY AND HOST PLANT RESISTANCE

BY

JOSEPHINE NAWIRE SIMIYU

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DECLARATION

Declaration by the Candidate

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JOSEPHINE NAWIRE SIMIYU

______________________________ ____________________

AGR/PGC/010/15 **DATE**

Declaration by Supervisors

This thesis has been submitted for examination with our approval as University Supervisors.

______________________________ ____________________

PROF. LINNET GOHOLE **Date**

Associate Professor of Entomology, Department of Seed,
Crop and Horticultural Sciences
University of Eldoret, Kenya

______________________________ ____________________

PROF. TEFERA TADELE **Date**

International Centre of Insect Physiology and Ecology,
ILRI Campus Gurd Shola, Ethiopia

DEDICATION

To my beloved mum Mrs. Beatrice Simiyu, my husband Dr. Martin Wetungu and our children Ashley, Olive, Peace, Blessings and Emma.

ABSTRACT

Fall armyworm (FAW) is a new and invasive pest causing economic damage to various crops. In maize the yield loss by this pest has been estimated to be 60 %. The pest is mainly controlled using chemical insecticides which are expensive to a small holder farmer. Since the invasion of this pest in Kenya, there have been limited studies conducted on farmers' perception, knowledge, management and extent of its damage on maize. There is also limited knowledge on its biology and resistant existing Kenyan maize varieties. The objectives of this study therefore, were: to evaluate the Farmers perception and knowledge about the pest, to determine the pest's damage on maize, to determine its biology and oviposition preferences on maize, wheat and beans and to evaluate available Kenyan maize genotypes for resistance against the pest. A total of 120 farmers from Bungoma and Kericho counties were purposely selected and interviewed on knowledge and management of the pest using semi structured questionnaires. Damage was evaluated on 60 farms from the same counties that were selected using stratified random sampling technique. Leaf injury was rated using a scoring scale of 0-9. Biology and oviposition preferences were determined on maize, beans and wheat in the laboratory and greenhouse at the International Centre of Insect Physiology and Ecology (ICIPE). A total of 93 Maize genotypes (37 inbred lines, 30 hybrids and 26 OPVs) were screened for resistance against the pest at ICIPE in the green house using leaf injury rating Scale of 1-9. All the farmers interviewed had knowledge about FAW. Majority (97%) of the farmers who encountered the pest on their farms estimated crop damage of 47.3%. In controlling the pest, 48% of farmers used chemical sprays, while 40% used traditional methods like ash and sand. Damage by FAW was different among the farms in Bungoma and Kericho Counties although the variation was not statistically significant. Leaf damage ranged from 0.55 to 7.33 and percentage infested plants ranged from 16% to 100%. Kericho County had highest level of damage. FAW performed better on maize and wheat than beans. The percentage survival on maize, wheat and beans in the laboratory was 18.9%, 18.3% and 1.8% respectively. In the green house the percentage survival was 11.8% on maize, 8.3% on wheat and 0.0% on beans. The pest also preferred wheat and maize to beans for oviposition. There exists resistant (tolerant) maize genotypes (16 hybrids, 3 inbreds and 3 OPVs). The study has made contribution to knowledge that is important to various stakeholders who include farmers, researchers and government.

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LIST OF ABBREVIATIONS, ACRONYMS AND SYMBOLS

ANOVA	Analysis of Variance
CIMMYT	International Maize and Wheat Improvement Center
FAO	Food and Agricultural Organization
FAW	Fall armyworm
HPR	Host Plant Resistance
ICIPE	International Centre of Insect Physiology and Ecology
IPM	Integrated Pest Management
KALRO	Kenya Agricultural and Livestock Research Organization
OPV	Open Pollinated variety
SSG	Sorghum sudan grass

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CHAPTER ONE

INTRODUCTION

1.1 Background information

Maize (*Zea mays* L.), common bean (*Phaseolus vulgaris*) and wheat (*Tricum aestivum*) are important food crops in Kenya. Maize is the main staple food crop (Mohajan, 2014) followed by beans (Duku *et al.,* 2020), while wheat is ranked as the second most important cereal crop after maize (Kawanga *et al.,* 2016). A large proportion of maize and bean produced by small scale farmers are mostly grown as intercrops. Wheat on the other hand was originally grown by large scale farmers, although, due to land subdivision small scale farmers are also practicing it. Maize is grown in the whole country except North Eastern region (Republic of Kenya, 2015). Common bean is grown in Eastern, Western, Central and Nyanza (Wambugu & Muthama, 2009). Wheat is mostly grown in South Rift, North Rift and Central parts of Kenya (Gitau *et al*., 2010). Dry maize annual production was estimated at between 3,464,541 and 3,513,171 tons in the period 2010 - 2014 (Republic of Kenya, 2015), while wheat production is estimated to be average of 300,000 metric tons annually (Gitau *et al*., 2010). Production of common bean is estimated to be about 417,000 metric tons (Kiambi and Mugo, 2016).

Production of maize, common bean and wheat is constrained by many factors including insects. Among the insect pests that attack maize is fall armyworm (FAW) (*Spodoptera frugiperda*), which is considered a primary pest of maize (Mendes *et al.,* 2011). It has also been reported to attack wheat (Nderitu *et al.,* 2018) and common bean (Ligia *et al.,* 2016).

FAW is new in Africa but originated from southern and northern regions of America. It was first reported in Africa in late 2016 (Goergen *et al*., 2016) and Kenya in March 2017 (KALRO, 2017). FAW is polyphagus and has been reported to attack 186 plant species from 42 families (Casmuz *et al*., 2010). It causes economic losses to various crops like maize, sorghum and cotton (Day *et al*., 2017). The pest has a complete lifecycle from egg to adult, but the destructive stage is the larva, which causes damage on crops by consuming leaf tissues from the first instars through the sixth instars (Ligia *et al*., 2016). Maize yield loss by FAW has been estimated to be 60% depending on growth stage of the plants (Cruz *et al*., 2008).

Soon after FAW was detected in Kenya the Ministry of Agriculture, Livestock and Fisheries constituted a multiinstitutional technical team with experts drawn from public and private sector. The institutions represented include: KALRO, KEPHIS, CABI, PCPB, ICIPE and Plant Protection Services; State Department of Agriculture. The team mounted trainings to public and private extension service providers, seed inspectors, agrochemical dealers, spraying teams, researchers, farmers and the general public to fast track adoption of the control strategies to mitigate the threat of this new migratory pest. Among the strategies suggested by this team were; mount pheromone traps to detect the pest monitoring and scouting for signs and symptoms one week after crop germination, deep ploughing to expose the pupae to predators and solar heat and hand picking and crashing of the caterpillars. These suggested management options were just from publications from other countries. There is therefore need for a study in Kenya that will inform the management strategy that is suitable for the country on farmers' perceptions, extent of its damage, biology and existence of any resistant maize varieties. Farmers develop knowledge and management practices and have their own ideas on how to solve a problem in the practical and economical ways (Allahyari *et al*., 2017). One of the major barriers for farmers to implement a pest management program has been shown to be lack of information about farmers' perception, knowledge and management practices (Van *et al.*, 2001). Studies on farmers' perception and knowledge on different pests are very important as they help in understanding the farmers' problems caused by the existing insect pest and the challenges they face in their management practices (Midega *et al*., 2012). Furthermore, these studies will provide the foundation for the creation of learning platforms where actors are invited to collaborate and participate in developing agricultural technologies that are linked to the needs of the farmers. Midega *et al.* (2018) sought to evaluate the effectiveness of managing FAW using push and pull technology. They used desmodium as the repellant crop inside the maize plot and nappier as an attractant crop on the outside of maize plot. From their report, farmers confirmed the effectiveness of push and pull technology in mitigating Fall armyworm. Their study focused only on one technology- the push and pull. Farmers in Zambia (Kansiime *et al.*, 2019) used technologies like ash and sand application in the whorl of maize plants. Further research is therefore needed to identify other new strategies that farmers in Bungoma and Kericho counties have adopted in managing this pest which can be copied by other farmers from other regions. This research involving farmers' participation will lead to development of pest control options that are effective, adoptable and which will meet the needs of farmers.

Extent of damage of FAW on maize has been reported to vary with agro ecological zones (AEZ) and this is to do with altitude, rainfall, soils and temperature (Baudron *et al.*, 2019). Baudron *et al.* (2019) compared levels of damage in two districts of Zimbabwe representing two different zones. From their study, high level of damage (36.8 %–54.9%) was observed in the zone with low rainfall amount, high altitude, sandy loam soils and low temperature (Baudron *et al.,* 2019). The damage level in the other zone was comparatively low (26.4 %- 41.5 %) with high rainfall, lower altitude, high temperature and sand clay soils (Baudron *et al.,* 2019). Agro ecological zones in Kericho and Bungoma counties vary. Maize production in Kericho county is concentrated in Kipkelion East sub county which lies in lower highland ($LH_{2\&3}$) zones. The area receives an average rainfall of between 1125 to 1400mm annually (Jaetzold *et al*., 2012). The soils range from deep reddish brown to dark clay soils (Jaetzold *et al*., 2012). Bungoma county maize production is mainly in lower highland (LH_{1}) and upper midland ($UM_{2\ \&\ 3}$) zones which are characterized by brown to dark brown acrisols soils and red dark to red nitisols respectively (Jaetzold *et al*., 2012). The county receives an annual rainfall of up to 1800mm with temperature of 32 degrees Celsius (Jaetzold *et al*., 2012). These variations in agro ecological factors between Bungoma and Kericho counties mean variations in damage by fall armyworm as confirmed by Baudron *et al*., (2018). Since the invasion of FAW in Kenya there is limited studies on extent of damage of this pest in maize. A study therefore needs to be conducted in different AEZ being represented by Kericho and Bungoma counties. Information on extent of damage obtained from this study will be applied to other areas sharing same agro ecologies and will also improve understanding of damage by this pest and help in designing of an effective control strategy.

Several studies have been done on FAW biology in Americas and have shown that climatic conditions especially temperature (Garcia *et al.,* 2017) and host plants (Silva *et* *al*., 2017) influence distribution of FAW. America experiences four seasons (winter, spring, autumn and summer) (Belay, 2012) in a year and this affects the population of FAW. These seasons have different temperatures which impact on FAW population. For example, during summer when the population of FAW is high, the temperature averages range from a high of 27.3 degrees Celsius in Louisiana and Texas to a low of 11.3 °C in Alaska. These temperature ranges are where Bungoma and Kericho counties fall. Bungoma and Kericho experiences temperature averages of 21 degrees Celsius and 17 degrees Celsius respectively. This shows that FAW population is also likely to be high in Bungoma and Kericho. Temperature during FAW does not have the ability to diapauses (Du *et al.*, 2010) and therefore cannot withstand severe cold that is experienced during winter (Regan *et al*., 2018). These conditions in America are different from those in Africa. Africa and particularly Kenya does not experience extreme cold (winter) and therefore has the potential to host year round populations of FAW (Regan *et al*., 2018). Further research is therefore needed in Kenya to understand the insect's biology and oviposition preferences on different crops and different conditions for effective management of this pest.

The control measures for this pest have mainly been by use of chemical insecticides (Lima *et al*., 2006). This strategy has become increasingly ineffective and does not provide satisfactory control to *S. frugiperda* in field of maize (Hardke *et al*., 2015). This is because this pest after hatching, the neonates move into the whorl of the plants which makes it hard for the insecticide to reach them. This pest is also known to develop resistance to several toxicological groups of insecticides like carbaryl making it hard to control it (Morillo & Notz, 2001; Yu *et al*., 2003). The chemicals are also frequently applied without appropriate safety precautions (Kansiime *et al*., 2019) hence they pose a risk to human health. FAW has also been controlled using Integrated Pest management (IPM) strategies which include host plant resistance (HPR) (Ligia *et al*., 2016). This strategy is environment friendly and is compatible with other control methods like insecticides and natural enemies (Janini *et al*., 2011; Jesus *et al*., 2014). This strategy can also be adopted in Kenya by screening existing genotypes to identify resistant ones which will help in developing and deploying Kenyan adapted FAW-resistant elite maize hybrids/OPVs that can be planted by farmers to reduce the losses by FAW.

1.2 Statement of the problem

Fall Armyworm, is a new and invasive pest in Kenya. It originates from Southern and Northern America (Casmuz *et al*., 2010; Murua *et al*., 2006). In the absence of proper control methods, FAW can cause yield loss of 21–53 % of the annual production of maize ((Day *et al*. 2017). It has not been established from the farmers how they perceive this pest, if they have adequate knowledge about it and what management options they use to control it. Lack of this information may lead to designing a control strategy that does not meet the farmers' needs and which may not be adopted. The extent of damage of this pest in maize in different agro ecological zones has not been established and this may lead to developing a control option that is not suitable for a specific zone, and managing this pest in that zone may be a problem. This pest has majorly been found on maize although it has been reported to attack wheat (Nderitu *et al.*, 2018) and beans (Ligia *et al.*, 2016) which are also important food crops in the country (Mohajan, 2014; Duku *et al.*, 2020; Kawanga *et al.*, 2016). These three are the major staple food crops in the country and owing to the fact that many small scale farmers intercrop maize and beans, there is therefore the threat of the pest attacking beans which will cause food insecurity. The biology and ovipositional preferences of this pest on these three crops, is not known. Its behavior under different conditions has also not been established given that Kenya has diverse climatic conditions and the pest adapts differently. In Kenya there are many maize genotypes, some of which could be potentially resistant to FAW, and are currently unknown.

1.3 Justification

Studies on farmers' knowledge, perception and management of fall armyworm have been conducted in many countries (Kansiime *et al*., 2019; Baudron *et al*., 2019) but not in Kenya as the pest is new. There is therefore need to carry out this study to understand the perception and knowledge of farmers of this pest and the measures they use in controlling it. This will help in developing an adoptable and effective control option that meets farmers' needs (Munyuli *et al*., 2017). Studies on the extent of damage of FAW on maize have been reported to vary with agro ecological zones (AEZ) (Baudron *et al.*, 2019). In Kenya there are different AEZ (Jaetzold *et al*., 2012) which include high land zone, medium altitude zone, transitional zone, low land altitude zone, dryland transitional zone and dry land mid altitude zone (Schroeder *et al*., 2013). There is limited study conducted to establish the extent of damage of FAW in these zones. The study will therefore be conducted in Bungoma and Kericho counties representing different AEZ and the information on extent of damage obtained will be used as examples for areas sharing same agro ecologies and it will help to improve knowledge on damage by this pest and this will help in designing an effective control strategy. Fall Armyworm biology and ovipositional preference has previously been studied and found to be dependent on prevailing climatic conditions (temperature) and host plants (Hardke *et al*., 2015). Kenya has diverse plant species, climatic conditions and farming systems which affect the development of FAW. There is limited study on the biology of this pest on different host plant species that have been reported to be host of the pest. There is therefore need for the study to be done to evaluate the behavior of this pest on different crops specifically maize, beans and wheat which are the major staple food crops (Recha *et al*., 2018). Screening of maize genotypes for resistance against FAW in America has been done and resistant varieties have been identified (Day *et al*., 2017). Similarly, in Kenya screening of genotypes for pests like stem borers has been done and resistant varieties have been identified (Murenga *et al*., 2016). The same need to be done with FAW to identify the resistant varieties that can be used in breeding programmes as a source of resistance in order to diversify the basis of resistance to the pest. This information would inform national and regional pest risk assessment and appropriate management strategies. This information would also help raise awareness amongst farmers and developing surveillance schemes.

1.4 Research questions

- How do farmers perceive FAW, what knowledge do they have about it and what management options do they use to control it?
- Is extent of damage on maize in Bungoma and Kericho counties different, and what influences it?
- Do host plants influence the biology and ovipositional preferences of FAW?

- Are there any existing maize genotypes in Kenya that are resistant to FAW?

1.5 Objectives of the study

Main objectives

To assess farmers' perceptions and knowledge about FAW, extent of its damage, biology and resistant maize genotypes

Specific objectives

1. To determine farmers' perception, knowledge and management of FAW in Bungoma and Kericho counties of Kenya.
2. To establish the extent of damage by FAW on maize in Bungoma and Kericho counties in Kenya.
3. To determine the biology and ovipositional preferences of FAW on maize, beans and wheat under laboratory and greenhouse conditions.
4. To assess Kenyan maize genotypes for resistance to FAW.

1.6 Hypotheses

- Farmers perceive FAW as a threat, they do not have adequate knowledge about it and they use different management options to control the pest.
- The extent of damage caused by FAW in maize is different among farms in Bungoma and Kericho counties and is dependent on agro ecological zone conditions.
- Host plants influence the biology and ovipositional preferences of FAW.
- There are maize genotypes in Kenya with resistance to FAW.

CHAPTER TWO

LITERATURE REVIEW

2.1 Description and distribution of FAW

Fall armyworm (FAW) is a migratory pest, native to the tropical and subtropical regions of Americas (Pogue, 2002). It is polyphagus, feeding on almost 186 recorded plant species from 42 families (Regan *et al*., 2018; Casmuz *et al*., 2010). The pest prefers plant species from graminae family such as maize, millet, sorghum, rice, wheat, and sugar cane (Goergen *et al*., 2016). It was first reported in Africa in 2016 in Nigeria (Goergen *et al*., 2016). Since then it has spread to most parts of Africa including Kenya.

2.2 Farmers perception, knowledge and management of *S. frugiperda*

It is important to understand what farmers know about insect pests and what management options they use to control them. This is very key in designing efficient control practices that will easily be adopted and implemented by the farmers. Studies have been done on farmers' perception and knowledge of different crop pests including FAW. For instance, in Zambia, farmers reported that apart from insecticides, they also used different technologies like application of ash, soil and sand to control FAW and that this was successful to some extent (Kansiime *etal.*, 2019). These technologies, being less hazardous compared to insecticides, could be used by famers to avoid environmental risks.

Another study was conducted on Farmers perceptions and management of *S. frugiperda* in Zambia and Ghana. Among other parameters studied, the farmers were to estimate the yield losses by *S. frugiperda*. In their response in Zambia they estimated an average loss of 40% while Ghana Expected 45% loss (Day *et al.*, 2017).

From these studies it is clear that pests adapt differently to different countries because of differences in climatic conditions and farming systems. Similarly farmers also perceive and understand these pests differently and have different management options. There is therefore need for the same study to be done in Kenyan situation to understand the views of the farmers that will help in designing control strategies that will suit them in their different contexts.

2.3 Extent of damage of *S. frugiperda*

To design an effective control strategy of any pest, knowledge on extent of damage of the pest is important. The damaging stage of *S. frugiperda* is the larvae which cause severe damage in all developmental stages of the plant (Prassana *et al*., 2018). The damage is initiated by the first instar larvae which consume leaf tissue from one side leaving the opposite epidermal layer intact. When the larvae reach second or third instar, they begin to eat from the edge of the leaves while making holes (Prassana *et al*., 2018). The older larvae (fourth to sixth instar) feed extensively leaving only the ribs or stalks of corn plants. When they feed in the whorl of the plants they often produce characteristic irregular perforations in the leaves (Plate 2.1).

Plate 2.1 : FAW damaged maize (Source: Author, 2017)

Study done in Zimbabwe showed that agro ecological zones (AEZ) influences factors like soil, rainfall, temperature and altitude which influences the damage caused by FAW to crops (Baudron *et al*., 2019). These factors also influence types of crops, time of planting of the crops and even farming systems in that zone whether it is mixed farming, subsistence farming, rainfed or irrigated farming (FAO, 2017). Hatfield *et al*. (2015) in their study on the effect of temperature on plant development observed that extent of damage to plants growing in warm temperatures is low as compared to plants growing in low temperature zones. This is due to the fact that crops develop faster in warm temperature escaping the damage by *S. frugiperda* which is more serious during early growth stage of maize plants (Goergen *et al*., 2016).

Rodriguez *et al*. (2008) in Mexico studied the effect of planting date on *S. frugiperda* damage on maize. They reported that maize planted early was less infested or damaged by *S. frugiperda* as they escape late season population of pest as moths prefer young plants for oviposition. Presence of other host plants influences extent of damage by

FAW, for example nappier and desmodium crops that are used in the push pull technology have been confirmed to reduce FAW (Midega *et al*., 2018). Pumpkins intercropped with maize increases FAW damage as their wide leaves provide better shelter habitat for the moths during the day (Baudron *et al*., 2019). The presence of a variety of host plants minimizes the damage by FAW (Rodriguez *et al*., 2008). Rodriquez *et al*. (2010) studied the effect of maturity period of varieties to *S. frugiperda* damage. He also observed that early maturing variety often escapes late season population of pest, since moths prefer late maturing young crops for oviposition to enable the larvae find suitable feeding sites when they hatch (Silva *et al*., 2017)

Kenya has diverse agro ecological zones which include which include high land zone, medium altitude zone, transitional zone, low land altitude zone, dryland transitional zone and dry land mid altitude zone (Schroeder *et al*., 2013). No study on extent of damage of FAW in these zones has been conducted. This study is therefore important as it will improve the understanding of FAW damage in different zones which will help in developing management strategy for this pest based on the AEZ.

2.4 Biology and ovipositional preferences of FAW

FAW has several generations per year (Regan *et al*., 2018), with the lifecycle consisting of the egg, six to seven larval instars, pupa and adult (Hardke *et al*., 2015). The life cycle is completed in about 30 days during the summer, 60 days in the spring and autumn, and 80-90 days during the winter (Belay, 2011).

The eggs are laid in masses and are dome shaped (Plate 2.2). The total egg production per female averages about 1500 with a maximum of over 2000 (Belay, 2011). The eggs hatch within 2 to 4 days under optimal conditions (Abrahams *et al.*, 2017).

Plate 2. 2: Photo of FAW egg masses (Source: Author, 2018)

Larval stage consists of six larval instars. Young larvae are greenish in colour with a black head which turns orangish in the 2nd instar . The mature larvae have elevated dark spots occurring dorsally on the body. The face is also marked with a white inverted "Y" (Plate 2.3). The larvae tend to conceal themselves during the day but become active in the evening. The length of time for larval development ranges from 14 to 30 days depending on temperature and environmental conditions. (Capinera, 2014; Belay, 2011).

Plate 2. 3: Photo of FAW larvae (Source: MOA, 2018)

FAW pupates in the soil 2cm to 8cm (Capinera 2014; Belay, 2011). Cocoons are constructed by larvae by tying soil particles together silk. The pupa is reddish brown in colour (Plate 2.4). Duration of the pupal stage is about eight to nine days during the summer, but reaches 20 to 30 days during the winter in Florida (Capinera, 2014).

Plate 2.1: 4: photo of FAW pupa (Source: Author, 2018)

The adult stage consists of moths. Male moth has forewing shaded gray and brown with triangular white spots at the tip and near the centre of the wing (plate 2.5 a). The forewings of the female are less distinctly marked ranging from a uniform grayish brown to a fine mottling of gray and brown (plate 2.5b). Adults are nocturnal and are active during warm humid evenings.

Plate 2. 5: Photo of Male moth (left) and Female moth (right) (Source: MOA, 2018)

After the moth emerges the female undergoes a preoviposition period of three to four days, after which it deposits most of her eggs during the first four to five days of life, some oviposition occurs for up to three weeks). Adult life is estimated to average about 10 days, with a range of about seven to 21 days.

Studies have been conducted in different countries on biology of FAW and they have demonstrated that development rate and fecundity of this pest is influenced by temperature (Garcia *et al*., 2018). Developmental time of the pest decreases with increase in temperature. Fecundity also decreases with increase in temperature (Regan *et al*., 2018).

Biology of insects is also influenced by host plant nutrition (Silvia *et al.*, 2017; Golizadeh *et al*., 2009) and this depends on the chemical substances such as carbohydrates, proteins, fatty acids, amino acids, vitamins and minerals. These are required for growth, tissue maintenance, reproduction and energy. The chemical substances are usually variable between different plant species. Studies by Lee *et al*. (2007) suggested that nutrient balance, particularly protein to digestible carbohydrates (P/C) ratio is important for development of many insects. Most insects especially generalists perform better on diets with a P/C ratio greater than one than those with a P/C less than one (Lee *et al*., 2007). Many researchers have demonstrated that FAW develops faster on grasses than other crops (Lewter *et al*., 2006; Silva *et al.*, 2017; Meagher *et al.* 2004). This is because grasses have high nutritional value (their P/C ratios are high) as compared to plants from other botanical families (Baros *et al*., 2010), for example P/C ratios of maize ranges between 1.27 to 2.69 while for soybean it ranges from 0.41 to 1.57 (Silva *et al.*, 2017).

S. frugiperda has been reported to feed on many crops which include maize, beans and wheat, and these are the major staple food crops in Kenya. In most parts of Kenya especially western region, intercropping and relay cropping of maize and beans is a common practice. Although some studies have shown that beans can reduce FAW population (MOA, 2017), other studies have shown that beans are also hosts plants for FAW (Ligia *et al*., 2016). If this study confirms that beans are host plants for FAW, it will be recommended not to plant beans together with maize as this can enhance the population of this pest which will lead to food insecurity. This study on biology and ovipositional preference of FAW on maize, beans and wheat is therefore important as this will aid in developing a better control option for this pest.

2.5 Screening of maize genotypes for resistance to *S. frugiperda*

One of the important component of Integrated Pest Management is host plant resistance (HPR) (Janini *et al*., 2011; Jesus *et al*., 2014). It is environment friendly, cost effective and compatible with other control methods like insecticides and natural enemies (Smith, 2005).

Several studies have demonstrated that HPR has a potential to control FAW and other insects.

Ligia *et al*. (2016) studied the mechanisms that supported the resistance of corn against FAW using two conventional varieties and 10 transgenic varieties that were expressing Cry proteins, *B. thuringiesis*. They determined antibiosis by use of parameters like larval weight while leaf area consumed was used in determining antixenosis. From their study they identified 4 transgenic hybrids that showed antibiosis resistance (the larvae that had been fed on them had low weight compared to those that fed on other transgenic and conventional hybrids).They concluded that the pest's lower preference for transgenic varieties was due to damage of the microvilli of the pest's gut or perception of Bt protein in food by the pest. Similar study was conducted by Williams *et al*. (1990a) and in their study; they reported that morphological characteristics such as hardness of the grains and leaves are factors involved in the expression of resistance.

Xinzhi *et al*. (2014) evaluated 26 maize genotypes for resistance against FAW, for two years using leaf injury ratings and predator abundance. In their study they identified 3 germplasms which showed low leaf injury ratings but high predator abundance. They concluded that these genotypes produced some volatiles which deterred the larvae from feeding on them showing antixenosis resistance or the volatiles attracted the predators which fed on larvae ((indirect resistance) (Xinzhi *et al*., 2014).

Oliveira *et al*. (2018) also screened eleven popcorn genotypes along with one common maize variety to identify resistance mechanisms to *S. frugiperda.* They used parameters like leaf area consumed to determine antixenosis and weight of the larvae to determine antibiosis. They identified seven popcorn genotypes with antibiosis resistance (the larvae that fed on them had low weight) and the common maize variety showed antixenosis resistance (had less leaf eaten), Ligia *et al*. (2016) evaluated the types and levels of resistance of 10 common bean cultivars against FAW in the laboratory in free and no choice tests. In free choice test, the ten cultivars were placed in one container and the larvae were released to choose which cultivar to feed on (Ligia *et al*., 2016). In no choice test each cultivar was placed separately for the larvae to feed on. To evaluate antixenosis they counted the number of larvae that were attracted to each cultivar. To evaluate antibiosis they weighed the larvae and pupae and measured the developmental time for all the life stages of the pest. From their study they identified 4 genotypes with antixenosis and one cultivar with antibiosis resistance. From these studies resistant genotypes with different resistance mechanisms were identified. In Kenya there are many maize genotypes but resistant ones to FAW are not known. Similar study needs to be done on Kenyan genotypes to identify resistant ones that can be used in developing varieties that will resist this pest.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Field Survey on farmers perceptions, knowledge and management of FAW

3.1.1 Description of the study area

The study was conducted in four sub counties of Bungoma County and one sub county in Kericho County. These are the major cereal growing regions known for maize, legume and livestock production. Kericho county is located in the South Rift of Kenya and maize production is concentrated in Kipkelion East sub county which lies in lower highland ($LH_{2\ \&\ 3}$) zones. The area receives a unimodal rainfall averaging between 1125 to 1400mm annually with mean temperature of 17 ^{0} C (Jaetzold *et al*., 2012). The soils range from deep reddish brown to dark clay soils (Jaetzold *et al*., 2012). Bungoma county is located in the western of Kenya and maize production is mainly in lower highland (LH_{1}) and upper midland ($UM_{2\ \&\ 3}$) zones which are characterized by brown to dark brown acrisols soils and red dark to red nitisols respectively. Bungoma county receives a bimodial pattern of rainfall of up to 1800mm with mean temperature of 21 degrees Celsius (Jaetzold *et al*., 2012)..

3.1.2 Sampling technique and questionnaire design

The sampling sites were selected purposively basing on reports of invasion of *S. frugiperda*. Twelve respondents were randomly selected from every two wards of each sub county making a total of 120 respondents that were interviewed.

A semi-structured questionnaire (Appendix 1) was administered, with the assistance of trained agricultural enumerators after pre-testing of the questionnaire for its validity. The information that was collected included: farmers' socio-economic profiles, farm characteristics, perceptions, and knowledge and management practices of *S. frugiperda*. Individual farmers were interviewed using the national language (Kiswahili) or local language. The information on farmers' socio-economic profile, size of farm, systems of production of maize and production purposes, were addressed. Farmers were also asked to give priority pests of maize, how they perceive of *S. frugiperda*, to estimate losses due to *S. frugiperda* and the management practices undertaken by them.

3.1. 3 Data analysis

The survey data were analyzed using descriptive statistics. Means and percentages were calculated using SPSS v.20 software. The percentage of farmers who gave similar responses for each question was calculated for each sub county. Calculations did not include those who did not respond to certain questions. Where a farmer gave more than one answer to a given question, calculations on percentages were done for each group of similar responses. Analysis of variance (ANOVA) was used to analyze data on socio-economic profile, farm characteristics, perception, knowledge and management of *S. frugiperda*. Mean separation was done by Tukey's test at 0.05 level of significance.

3.2 Field Survey on extent of damage by FAW on maize in Bungoma and Kericho Counties

3.2.1 Study area and sampling technique

This study was conducted in four sub counties of Bungoma county and one sub county of Kericho County. Their climatic characteristics are as described in section 3.1.1 above.

Stratified random sampling technique was used in this experiment targeting two wards in each sub county. From each ward two villages were randomly selected and from each village three farms with maize crop at vegetative stage were randomly sampled. A total of 60 farms were sampled.

In each farm three quadrants measuring 2 m x 2 m were randomly selected. In each quadrant 20 plants were sampled at random. The parameters measured included leaf damage and percentage infested plants. Leaf damage was scored by visual observation on a rating scale of 0-9 (Davis *et al*.,1992) whereby (0 = no visible leaf damage, 1= only pin-hole damage on leaves, 2 = pin-hole and shot hole damaged to leaf, 3 = small elongated lesions (5-10 mm) on 1-3 leaves, 4 = midsized lesions (10-30 mm) on 4-7 leaves, 5 = large elongated lesions (>30 mm) or small portions eaten on 3-5 leaves, 6 = elongated lesions (>30 mm) and large portions eaten on 3-5 leaves, 7 = elongated lesions (>30 cm) and 50% of leaf eaten, 8 = elongated lesions (30 cm) and large portions eaten on 70% of leaves and 9 = most leaves with long lesions and complete defoliation was observed). Percentage FAW infestation (% IP) was calculated using the following formula by Diez, (2001).

$$\% \text{ IP} = \text{Infested plants} / \text{Total plants} \times 100.$$

Assessment was done at early stages of plant development before tasseling.

3.2.2 Data analysis

Data on leaf damage were analyzed using Kruskal - Wallis non - parametric analyses. Data on percentage FAW infestation were angular transformed (arcsine √ proportion) in order to normalize variance before being subjected to ANOVA. Mean separation was done using Tukey's multiple comparison procedures at 0.05 level of significance.The data were analysed using SPSS version 20 software.

3.3 Biology and oviposition preferences of FAW on maize, beans and wheat under laboratory and green house conditions.

3.3.1 Study site and source of specimens

This study was conducted at the International Centre of Insect Physiology and Ecology (ICIPE), Nairobi, Kenya. *Spodoptera frugiperda* larvae and adult moths were obtained from the insectary at (ICIPE).

Maize (*Zea mays*), common bean (*Phaseolus vulgaris*) and wheat (*Triticum aestivum*) were procured from an agrovet shop. The variety of maize used was H6213. This variety is one of the most commonly planted maize varieties in Kenya. It is tolerant to lodging, ear rust, grey leaf spot and leaf blight (Amudavi *et al*., 2019). It is one of the most productive hybrids on the market. The common bean evaluated was Rosecoco (GLP2). It is also one of the main bean varieties grown in Kenya. It is high yielding with wide adaptability and resistant to bean anthracnose (Amudavi *et al*., 2018). The wheat variety evaluated was Kenya Pasa, which is high yielding and resistant to lodging (Amudavi *et al*., 2018) The seeds were sown in 500 ml pots filled with soil. Three seeds each of common bean and maize and fifteen of wheat were sown per pot. After germination, maize were thinned to 2 plants/pot, 2 plants /pot for beans and 10 plants /pot for wheat. All required agronomic practices, including weeding, fertilizer application and irrigation, were performed.

3.3.2 Biology of FAW on maize, beans and wheat under laboratory and green house conditions

The host plants were transferred into screen cages (80 × 60 × 40 cm) both in the laboratory and green house 28 days after planting. The host plants were placed in screen cages with each cage holding six pots of each host plant and were replicated six times (a total of 36 pots per host plant). The experiment was done in a completely randomized design. Each pot was artificially inoculated with six neonate FAW larvae using a sterile camel hair brush.

The same experimental set up was replicated in the greenhouse**.** The temperatures in both green house and laboratory were taken using a thermo hygrometer. The measurements were taken in the morning, mid day and in the evening. The parameters that were observed in both laboratory and greenhouse set ups included larval, prepupal and pupal periods, adult longevity, percentage survival, pupal weight and reproductive potential of the pest.

Larval period

The larvae were inoculated on the host plants, and allowed to feed until the plants were completely defoliated, after which fresh new plants were introduced. The plants were checked twice daily at an interval of 12 hours to monitor when the larvae changed to pre pupae, and the number of days for larval period was recorded.

Prepupal, and pupal period

When the larvae entered the prepupal stage (when they stopped feeding and became inactive), the plants hosting last-instar larvae were uprooted, and the prepupae were transferred into 15mls vials containing moist soil. The vials were corked with cotton wool. The purpose of adding moist soil was to provide conditions similar to those in the natural habitat. The prepupae were observed twice daily to monitor when they turned into pupae, and the duration in days, of the prepupal and pupal stages was recorded. To determine the pupal weight, the pupae were weighed within 24 hrs of pupation using a microelectronic weighing scale. This was to evaluate the effect of host plants on the weight of the pupae. After weighing the pupae were carefully returned to their respective vials, and adult emergence was subsequently evaluated.

Adult longevity

When the adults emerged, they were transferred to plastic jars and covered with lids that had a plastic mesh in the middle to allow for air circulation. To feed the moths, cotton wool soaked in 10% honey solution was placed on a petri dish and put in the jars for sipping by the moths (Ligia *et al*., (2016). They were observed daily until they died, and the number of days they lived was recorded.

Reproductive potential

In the laboratory this parameter was observed on females that originated from maize and wheat only. The moths that originated from common bean were all males. In the green house this parameter was also not observed on common bean because there were no larvae that established on common bean (they all died as 3^{rd} or 4^{th} instars).

Ten single pairs of newly emerged moths 24 hr old and originating from maize and wheat were released into oviposition cages (20 × 20 × 20 cm) with maize and wheat plants as oviposition substrates. The cages had a plastic cover with a plastic mesh in the middle to allow air circulation. The female moths were examined twice daily to monitor when they commence to lay, and the duration of the pre-oviposition periods in days was recorded. When the females began to lay, the egg masses/eggs were collected daily, recorded separately placed in plastic jars to allow for hatching (evidence of mating), and the number of days taken for the eggs to hatch was recorded. The females were allowed to lay until they stopped on their own and the oviposition length in days was recorded.

Survival from the larval to adult stage

This parameter was calculated by taking the number of adult moths that originated from each of the three host plants, divided by the total initial number of larvae that were originally inoculated on each host plant multiplied by 100.

$$\% \text{ survival} = \frac{\text{No. of adult moths emerged}}{\text{Total number of larvae inoculated}} \times 100$$

3.3.3 Ovipositional preferences of S. frugiperda on maize, common bean and wheat under laboratory and green house conditions

To evaluate the ovipositional preferences of *S. frugiperda* females for maize, common bean and wheat, two experiments; free choice and no-choice tests were conducted in the laboratory and greenhouse. Maize, common bean and wheat seedlings were raised as described in section 3.3.1. Three weeks after planting the seedlings were transferred into ovipositional cages in the laboratory and greenhouse.

In the no-choice test, one cage contained a single pot of each host plant and was replicated five times (5 cages or pots for each host plant). One pair of adult moths (72 hr old) was released in each cage, and the female was allowed to oviposit freely. The experiment was arranged in a completely randomized design.

In the free choice test, one cage contained three pots of maize, three pots of wheat and three pots of bean plants that were randomly placed. The cages were replicated six times (18 pots for each host plant). Three pairs of adult moths (72 hr old) were released in each cage and allowed to oviposit freely on the provided nine host plants.

The moths were nourished on 10% honey solution presented on cotton balls according to Ligia *et al*., (2016) method. For both lab and green house tests, the plants were inspected daily to monitor if the females have laid eggs, and the egg masses/eggs on each host plant were collected, counted and recorded. The females were allowed to lay for 72 hrs according to Meager *et al.* (2011), after which the experiments were terminated.

3.3.4 Statistical analysis

Laboratory data on the duration of the larval, prepupal and pupal stages, adult longevity and pupal weight were analysed by ANOVA. Data on % larval survival were angular transformed (arcsine √ proportion) to stabilize the variance before being subjected to ANOVA. Data on ovipositional preferences were also analysed using ANOVA. Means were separated using Tukey's test. Greenhouse data on the duration of the larval, prepupal and pupal stages, adult longevity and pupal weight were collected only on maize and wheat and was analysed using t-tests, while % survival was angular transformed then analyzed using t-test. Data on preoviposition, oviposition and egg hatching periods, number of egg masses and number of eggs in both the laboratory and greenhouse experiments were also analysed using t-tests. The number of eggs per female was log transformed before being analysed. The data were analysed using SPSS v.20 programme.

3.4 Screening maize genotypes against the Fall Armyworm

3.4.1 Study site description

The study was conducted in a greenhouse at the ICIPE, Nairobi Kenya.

3.4.2 Source of maize genotypes

Thirty seven inbred lines were obtained from International Maize and Wheat Improvement Center (CIMMYT) Nairobi; thirty hybrids were obtained from KALRO and seed companies; twenty six open pollinated varieties (OPVs) were obtained from KALRO, seed companies and from local farmers.

3.4.3 Source of *S. frugiperda*

FAW specimens were obtained from insect colonies maintained at ICIPE.

3.4.4 Trial management and experimental Design

The seeds of the various maize genotypes were sown in 10-litre pots filled with potting soil. Three seeds were sown per pot. After germination thinning was done so that each pot remained with two plants. The three groups of the maize genotypes (inbred lines, hybrids and OPVs) were randomly placed in rows each of which represented one group with two replications (Plate 3.1). All the required agronomic practices including weeding, fertilizer application and irrigation were done.

Plate 3.1: Three groups of maize genotypes

3.4.5 Infesting maize genotypes with *S. frugiperda*

Forty two days after planting, each seedling was artificially infested with five 3rd instar FAW larvae in the whorl of the plants using soft forceps. Infestations with same 3rd larva instar stage were repeated at 56, 70 and 84 days after planting which coincided with vegetative, pre-flowering, flowering and maturity stages of the maize crop. Repetition of infestation was done to simulate field activity of the insect that FAW infestation is throughout maize growth stages from vegetative to maturity; it was also to ensure maximum insect pressure to avoid any escape of the susceptible genotype.

3.4.6 Data collection

Data on leaf damage was collected after every 14 days of infestation with *S. frugiperda* and this was done at 56,70, 84 and 98 days after planting. Leaf injury rating was done according to the 1 -9 rating scale developed by Tefera *et al.* (2011) (Table 3.1).

Table 3. 1: Rating scale based on foliar damage by FAW

Scale	Damage symptoms/ description	Response rating
1	No visible leaf feeding damage	Highly resistant
2	Few pin holes on older leaves	Resistant
3	Several shot-holes injury on a few leaves and small circular hole damage to leaves	Resistant
4	Several shot-hole injuries common on several leaves or small lesions Pinholes, small circular lesions and a few small elongated (rectangular shaped) lesions of up to 1.3 cm in length present on whorl and furl leaves	Moderately resistant
5	Elongated lesions (>2.5 cm long) on a few leaves a few small- to mid-sized uniform to irregular shaped holes (basement membrane consumed) eaten from the whorl and/or furl leaves	Moderately resistant
6	Several large elongated lesions present on several whorls and furl leaves and/or several large uniforms to irregular shaped holes eaten from furl and whorl leaves.	Susceptible
7	Many elongated lesions of all sizes present on several whorl and furl leaves plus several large uniform to irregular shaped holes eaten from the whorl and furl leaves.	Susceptible
8	Many elongated lesions of all sizes present on most whorl and furl leaves plus many mid-to large-sized uniform to irregular shaped holes eaten from the whorl and furl leaves.	Highly susceptible
9	Whorl and furl leaves almost totally destroyed and Plant dying as a result of foliar damage (dead heart)	Highly susceptible

Data on number of entry holes (holes resulting from larval feeding on the stem of the plants) were taken at maturity. For those plants that died prematurely number of entry holes was taken at death. Data on percentage plant survival were collected at maturity using the following formula

$$\% \text{ survival} = \frac{\text{No. of plants that survived FAW damage}}{\text{Total number of plants that were inoculated}} \times 100$$

This was done for each genotype.

3.4.7 Statistical analysis

Data on foliar damage were categorical data hence were subjected to Kruskal- Wallis non- parametric analyses. Data on percentage plant survival were angular transformed (arcsine √ proportion) in order to normalize variance. Both percentage plant survival and number of entry holes were analyzed using ANOVA. The data were analysed using SPSS v 20 software.

CHAPTER FOUR

RESULTS

4.1 Farmers Perception and Knowledge of *S. frugiperda*

4.1.1 Demographic information

Majority (56%) of the respondents in the survey were female. Farmers household size was 7 members on average. The time spent on education was 8.2 years on average. Farmers owned 4.3 hectares of land on average of which 1.7 hectares was used for maize production (Table 4.1). 65.9% of farmers interviewed planted maize for domestic puporse, 29% for both sale and own consumption while only 4. 9% for sale (Table 4.1). All (100 %) farmers in the selected sub counties in Bungoma and Kericho counties grow maize under rain fed farming system. They also reported maize as the main food crop. In Bungoma County maize was the major cash crop mentioned by most (75%) followed by sugarcane (25 %). In Kericho County maize was also mentioned as the major cash crop by 55% of farmers, followed by Irish potatoes (45 %).

Table 4. 1: Farmers demographic information, land size and use in five sub counties of Bungoma and Kericho counties

F test	Tongaren N=35	Webuye East N=45	Mt. Elgon N=8	Kabuchai N=13	Kipkelion East N=19	Mean N=120	X^2
Gender							
Male	42.9	35.6	37.5	76.9	47.4	44.2	7.257^{ns}
Female	57.1	64.4	62.5	23.1	52.6	55.8	
Family size	6	6.27	7.38	7.91	6.2	6.46	2.38^{ns}
HH education (yrs)	9.8	8.27	7.75	8.08	8.17	8.63	1.565^{ns}
Total land size (Ha)	5.34	1.6	4.31	5.88	5.03	3.88	4.032^{**}
Land for maize	2.96	0.49	1.8	1.84	1.83	1.28	1.75^{**}
Consumption (%)	48.57	74	87.5	76.9	42.39	65.9	17.506^{*}
For sale (%)	2.86	9.0	0	7.7	4.76	4.9	
Both (%)	48.57	17	12.5	15.4	52.85	29.24	
Willingness to pay for control technology							
High	35	45	8	12	19		
Based on observation	0	0	0	0	0		
Indifferent	0	0	0	0	0		

Note: Significant at *P< 0.05, **P<0.01, ***P<0.001, ns=not significant

Note: Statistically significant at *P< 0.05, **P<0.01, ***P<0.001, ns=not significant

4.1.2 Farmers knowledge and perception on FAW, source of information and stages of FAW in Bungoma and Kericho counties in 2017 cropping season

All (100 %) farmers in all the sub counties were aware of *S. frugiperda* (Table 4.2). Most of them reported to have got the information about FAW from media and extension agents (Fig 4.1)

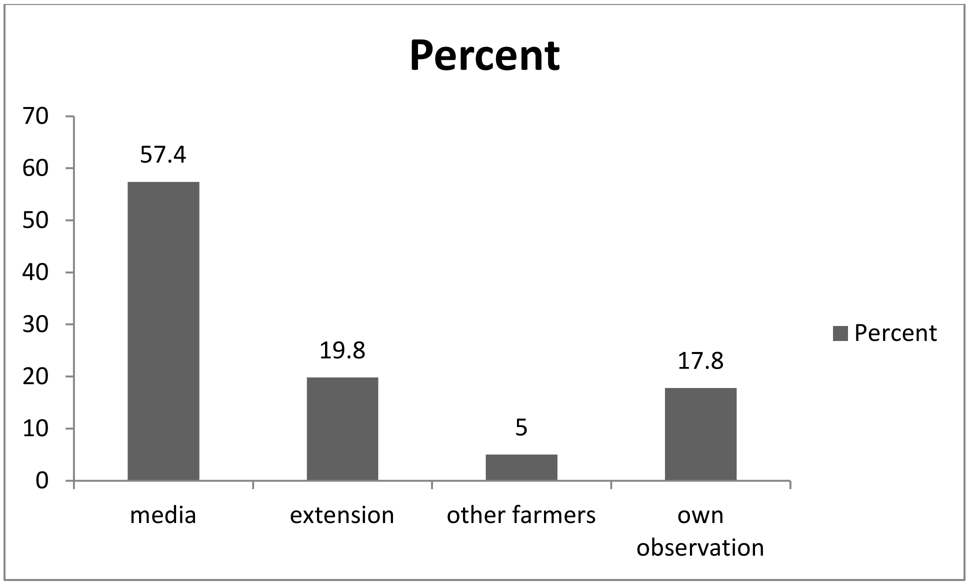

Figure 4.1 a: Main information sources of farmers regarding *S. frugiperda* in Bungoma county during 2017 cropping season

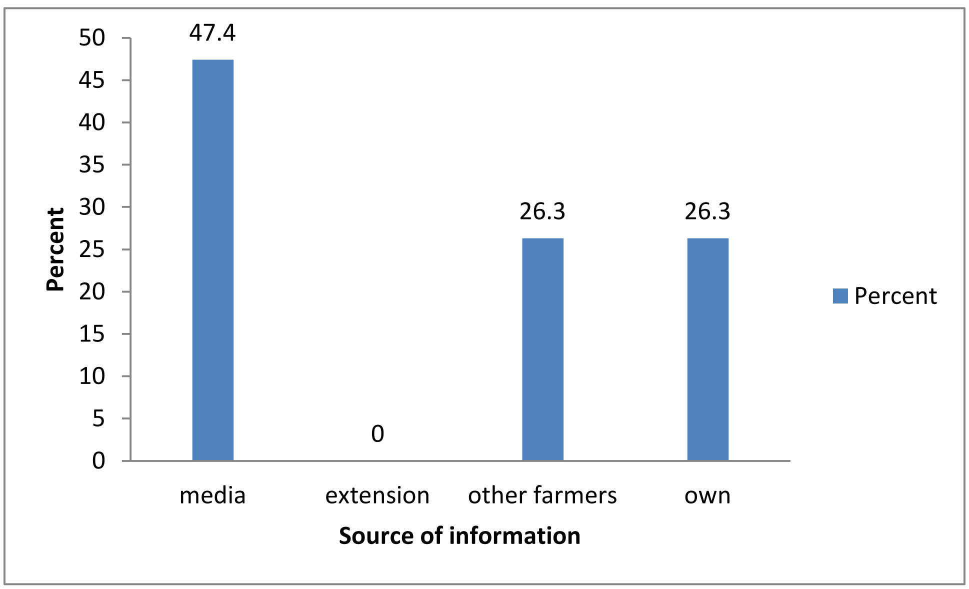

Figure 4.2b: Main information sources of farmers regarding *S. frugiperda* in Kericho county during 2017 cropping season

When farmers were asked to say when they saw the FAW pest in their farms, they reported that they had observed the pest on the maize crop when the crop was on average

53 days old after planting (Fig 4.2). All farmers reported to have encountered *S. frugiperda* in their farms. Farmers estimated FAW infestation on maize ranging between 38% and 54% (Table 4.2). Most farmers (97%) reported that the trend of spread of the *S. frugiperda* was increasing. The majority of farmers (80%) observed the larvae while few observed eggs and adult stages of the pest. Some of the farmers reported to have seen none of the stages of FAW (Fig 4.2), while all reported not to have seen pupal stage.

Table 4.2: Farmers knowledge and perception on FAW in four sub counties of Bungoma county and one sub county of Kericho county during 2017 cropping season

	Subcounty							
test	Tongaren *N=35*	Webuye East *N=45*	Mt. Elgon *N=8*	Kabuchai *N=13*	Kipkelion East *N=19*	Mean *N=120*	X^2	*F*
Know FAW (yes %)	100	100	100	100	100	100		
Time observed (weeks after Planting)	10	10	6	8	3.6	7.6		26.445***
Encountered FAW (yes %)	100	100	100	85	100	97	10.719*	
Maize plants damaged (%)	38	54	40.6	50	53.95	47.3		4.78**
Expected yield (ton/ha)								
If no damage	5.036	2.634	2.824	2.456	4.416	3.61		1.03ns
If Infested	2.335	1.074	1.581	1.227	1.406	2.229		8.39***
Trend of spread of FAW (%)								
Increasing	100	48	100	100	100	97.6		40.51***
Remain the same	0	0	0	0	0	0		
Decreasing	0	12	0	0	0	2.4		

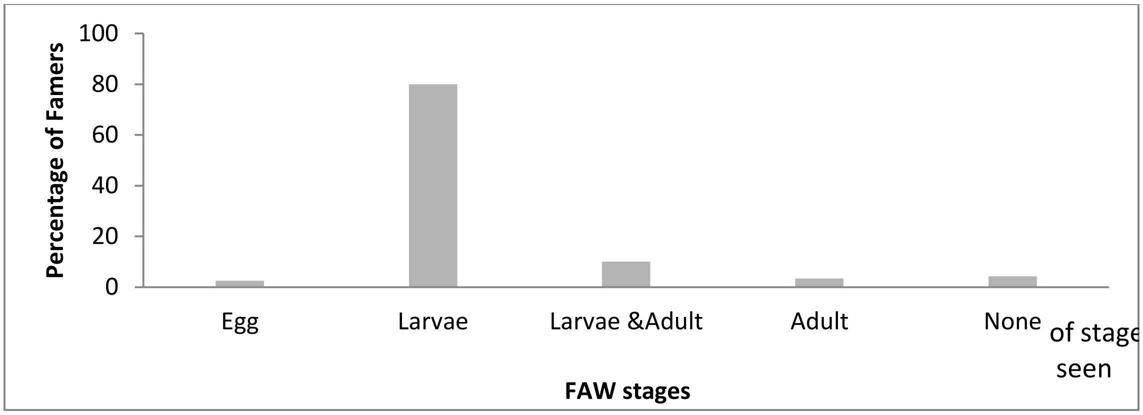

Figure 4. 3: FAW stages seen by farmers in Bungoma and Kericho counties during at 53 DAP crop stage

4.1.3 Indicators of differences and level of damage between *S. frugiperda* and stem borer on maize as perceived by farmers in sub-counties of Bungoma and Kericho counties

When asked to give the difference between *S. frugiperda* and stem borer, most farmers were able to differentiate between the two pests using colour of the larvae, their habit eating, face mark and fruss on maize leaves (Fig 4.3).

When asked to compare the level of damage between stem borer and *S. frugiperda,* most farmers perceived *S. frugiperda* to be more serious pest than stem borer with high level of damage (table 4.3).

Table 4. 3: Level of damage between *S. frugiperda* and stem borer on maize in sub-counties of Bungoma and Kericho counties as perceived by farmers in 2017 cropping season.

Sub County	Level of damage	% Response	
		FAW	Stem borer
Tongaren	High	90	0
	Medium	10	0
	Low	0	100
	No	0	0
Webuye East	High	100	0
	Medium	0	0
	Low	0	79
	No	0	21
Mt. Elgon	High	100	0
	Medium	0	10
	Low	0	85
	No	0	5
Kabuchai	High	100	0
	Medium	0	0
	Low	0	100
	No	0	0
Kipkelion East	High	100	0
	Medium	0	32
	Low	0	62
	No	0	6
X^2		4.939^{ns}	
42.296^{***}			

Note: significant at *P< 0.05, **P<0.01, ***P<0.001, ns=not significant

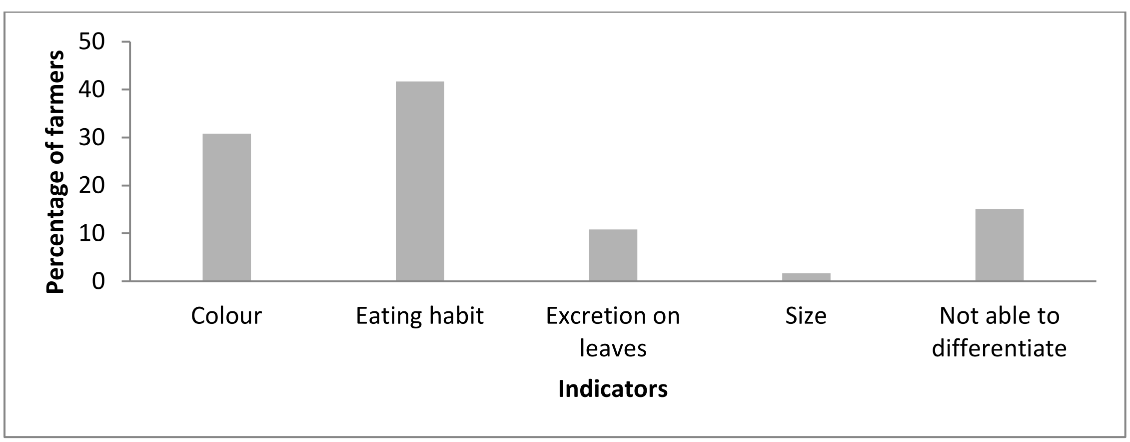

Figure 4.4: Differences between stem borer and FAW on maize as perceived by farmers in Bungoma and Kericho counties

4.1.4 *S. frugiperda* control practices in Bungoma and Kericho counties

Farmers used different practises to control the *S. frugiperda* with chemical insecticide being the main mitigating measure (48.1%) (Table 4.4). However 39.8 % of farmers used control measures like soil, ash tobacco, neem extracts and soap detergents.

Table 4.4: Methods of control of FAW in four sub counties of Bungoma and one subcounty Kericho counties

	Subcounty						
F test	Tongaren *N=35*	Webuye East *N=45*	Mt. Elgon *N=8*	Kabuchai *N=13*	Kipkelion East *N=19*	Mean *N=120*	X^2
Chemical spray 24.491***	35	74	37.5	30	63.16	48.1	
Traditional methods	58	13	37.5	69.2	21.05	39.8	
Hand picking	0	0	2.4	0	0	0.5	
No control	7	13	25	0	15.79	12.2	

Farmers used different types of insecticides but most of the farmers (43%) used Duduthrin® (Lambda cyhalothrin) to control FAW. Majority (60 %) of farmers perceived the sprayed chemicals as not effective. They reported scorching of leaves as the major drawback of chemical insecticides.

4.2 Extent of FAW damage in the sampled Sub counties

Maize leaf damage by FAW varied among the five Sub Counties and even among the sixty farms that were surveyed. Kipkelion East recorded the highest leaf damage scores while Tongaren sub county had the least leaf damage scores, but no significant differences were observed in leaf damage among the five sub counties(X^2= 6.054, df= 4, P= 0.195) (Table 4.5).

When leaf damages were compared among farms in respective sub counties, statistically significant differences were observed in Webuye East (X^2= 36.04, df= 19, P= 0.01), Tongaren($X^{2=}$ 7.95, df= 3, P= 0.05) and Kipkelion East(X^2= 21.77, df= 10, P= 0.02). However no significant differences were observed in leaf damage among the farms in Kabuchai (X^2= 20.13, df= 15, P= 0.17) and Mt. Elgon sub Counties (X^2= 12.28, df= 8, P= 0.14).

When the plants were checked for the presence of FAW larvae, Kipkelion East and Tongaren Sub Counties recorded the highest number of maize plants (expressed in percentage) that were infested by FAW compared to other sub counties although no statistical differences were observed in percentage plant FAW infestation among the five sub counties. When the percentage plant infestation was compared among the farms in individual sub counties, percentage plant infestation was same among the farms in Tongaren Sub County. In the other four sub counties significant differences were observed (Table 4.5)

Table 4.5: Extent of FAW damage in Webuye east, Tongaren, Kabuchai and Mt. Elgon and Kipkelion East sub counties

Sub county	Leaf damage			Percentage infested plants		
	(Mean ± SE)	X^2	P	(Mean ± SE)	F	P
Webuye East	3.49± 0.19	36.04	0.01	82.75± 4.14	3.504	0.002
Tongaren	3.2± 0.83	7.95	0.005	83.5± 9.69	6.8	0.14
Kabuchai	3.90± 0.3	20.13	0.17	79.58± 4.86	3.4	0.02
Mt. Elgon	3.79± 0.38	12.28	0.14	74.46± 5.79	4.34	0.005
Kipkelion East	4.80± 0.55	21.8	0.02	83.79±4.15	6.3	0.00

On percentage damaged plants original values are presented. However angular transformed values were used for the analysis.

4.3 Biology and ovipositional preferences of *S. frugiperda* on maize, wheat and common bean in laboratory and greenhouse

Development of FAW varied among the maize, wheat and common bean host plants. Variation in the development of the pest was also observed between laboratory and green house conditions

For the oviposition preference tests, FAW preferred wheat and maize for oviposition but not common bean.

4.3.1 Biology of *S. frugiperda* on maize, wheat and common bean in laboratory and greenhouse

In the laboratory developmental periods were shorter on maize and wheat but longer on common bean. Percentage survival was also low on common bean. In the green house the larvae that were inoculated on common bean did not establish themselves as they all died as 3^{rd} and 4^{th} instars. Therefore the parameters were only compared between maize and wheat, and from the results it was observed that FAW developmental times were same on maize and wheat. It was also observed that developmental periods were shorter in the green house on maize and wheat but longer in the laboratory. The number of FAW larvae that survived to adult stage was high in the laboratory but low in the green house. The parameters that were tested included larval period, prepupal and pupal period, percentage survival, pupal weight and reproductive potential (fecundity) of the pest.

Larval period

In the laboratory the larvae completed this stage on maize, wheat and common bean. On maize the period ranged from 15 to 23 days with average of 17.82 days, 16 to 26 days with an average of 19.5 days on common bean and 15 to 22 days with an average of 18.3 days on wheat. In the greenhouse however, the larvae completed this stage on maize and wheat only but not on common bean. The larvae took 13.61 days on maize and 13.63 days on wheat. The number of days for FAW larval period was significantly different among maize, wheat and common bean in the laboratory (P = 0.044, df = 2, F = 3.25) but not significantly different in the green house between maize and wheat (P = 0.941, t (72) *t* = -0.074) (Table 4.6).

Table 4. 6: Duration (days) of FAW stages on maize, beans and wheat in the laboratory and greenhouse

Host	Larval	Prepupal	Pupal	Adult longevity
Laboratory				
Maize	17.82±0.39a	3.07±0.14a	11.04±0.4a	10.14±0.32b
Beans	19.50±0.67b	3.21±0.26a	14.33±0.9b	6.33±0.80a
Wheat	18.33±0.34ab	3.41±0.22a	12.07±0.33a	12.00±0.48b
P value	0.04^{*}	0.51^{ns}	0.001^{***}	0.000***
F value	3.25	0.69	7.36	19.12
Green house				
Maize	13.61±0.16	3.66±0.21	10.93±0.44	6.71±0.37
Wheat	13.63±0.22	4.76±0.31	11.50±0.54	6.50±0.47
P value	0.941	0.003^{s}	0.416^{ns}	0.709^{ns}
t value	- 0.074	-3.051	-0. 820	0.377

For laboratory results means followed by the same letter in the column do not differ by Tukey's test (p=0.05) ^{ns} not significant.

Prepupal and Pupal period

In the laboratory prepupal duration for the prepupae that were reared on maize ranged between 2 to 5 days and 2 to 6 days for the prepupae that were reared on common bean and on wheat. In the green house the pre pupal period for the pepupae that were reared on maize was 3.6 days and 4.7days for the prepupae that were reared on wheat.

The length of pupae that were reared on maize was 11.04 days, 14.3 days for pupae reared on common bean and 12 days for the pupae that were reared on wheat in the laboratory. In the green house however the length was same (11.3 days) for both the pupae that reared on maize and those that were reared on wheat. Significant differences of FAW prepupal length were observed in the laboratory among maize, wheat and common bean (P = 0.001, df = 2, F = 7.357) and in the greenhouse between maize and wheat host plants (P= 0.003, *t* (49) = - 3.051) (Table 4.6). However no significant differences in FAW pupal length were observed among maize, wheat and common bean in the laboratory (P = 0.505, df = 2, F = 0.689) and between maize and wheat in greenhouse (P = 0.416, *t* (49) = - 0.820, F = 2.25) (Table 4.6).

Adult longevity

In the laboratory the adults whose larvae were fed on common bean lived for 6.3 days before they died. Those that originated from maize and wheat lived for 10.14 days and 12 days respectively before they died. The period was significantly different among the three host plants (P=0.000, df =2, f= 19.123). In the greenhouse the moths that emerged from the larvae that fed on maize took 6.7days before they died, while those that originated from wheat lived for 6.5 days before they died. No significant differences were observed in the number of days lived between moths that originated from maize and those that originated from wheat (P=0.709; t (27) = 0.377) (Table 4.6).

Larva to Adult survival and pupal weight

The number of the larvae that survived in laboratory (expressed in percentage) until adult eclosion was determined on maize, wheat and common bean. On maize the percentage was 18.89%, 18.33% on wheat and 1.83% on common bean. Significant differences in the percentages were observed among the three host plants (P= 0.000, df=2, F= 20.324). In the green house the percentage survival was only determined on maize and wheat host plants, on common bean no larvae survived. The percentage survival was 11.78% on maize and 8.35% on wheat. No significant differences were observed in the percentage survival between maize and wheat (P= 0.119, *t* (10) =1.704) (Table 4.7).

The weight of each pupa was taken 24 hrs after pupation. In the laboratory mean pupal weight for pupae originating from maize, wheat and beans was 0.2055 g, 0.1862 g and 0.1567 g respectively. Pupal weight differed significantly among maize, wheat and beans (P= 0.005, df= 2, F= 5.751).

In the green house because common bean didn't support any larvae, comparisons on pupal weight were only made between maize and wheat originated pupae. Pupal weight ranged between 0.120g to 0.244g on maize and 0.122g to 0.237g on wheat. No significant differences were observed (P= 0.302, *t* (72) =1.04) (Table 4.7).

Table 4. 7: Survival (%) and pupal weight (grams) of FAW on different host crops in the Laboratory and greenhouse

Host	% survival	Pupal weight (gm)
Laboratory		
Maize	18.89±2.22b	0.2055±0.008b
Beans	1.83±0.69a	0.1567±0.169a
Wheat	18.33±2.4b	0.1862±0.004b
P value	0.000*	0.005***
F value	20.324	5.751
Green house		
Maize	11.78±1.34	0.1831±0.01
Wheat	8.35±3.00	0.1758±0.01
P value	0.119	0.302
t value	1.704	1.04

For laboratory results means followed by the same letter in the column do not differ by Tukey's test (p=0.05) ns not significant. On percentage survival original values are presented. However angular transformed values were used for the analysis. For green house data no post hoc analyses were done.

Reproductive potential

The ability of the FAW females to produce young ones was established through number of egg masses/ eggs deposited. This was determined on females that originated from maize and wheat only, both in the laboratory and green house. The parameters observed included preoviposition and oviposition periods, number of egg masses/ eggs laid and the period taken for the eggs to hatch.

When the adult moths emerged the females underwent a period of pre oviposition to allow for mating before they began to lay their eggs. In the laboratory mean preoviposition length for FAW females that originated from maize and wheat was 3.8 days and 5.6 days respectively (Table 4.8). In the green house the period was 3.6 days for females that originated from maize and 3.1days for wheat originated females. Significant differences were observed in pre oviposition period between FAW females that originated from maize and those that originated from wheat in the laboratory ($P=0.004$, t $(18) = -3.35$) but not in the green house ($P = 0.248$, t $(10) = 1.226$)(Table 4.8).

After pre-oviposition period, the females began to lay their eggs. The duration taken by the females to lay their eggs is the oviposition period**.** In the laboratory mean number of days for oviposition period was 4.7 days for females that originated from maize and 5.4 days for females that originated from wheat. In the green house both females took 3.0 days to deposit their eggs. No significant differences were observed in oviposition period between FAW females that originated from maize and those that originated from wheat both in laboratory ($P = 0.119$, t $(18) = -1.625$ and greenhouse ($P = 1.00$, t $(10) = 0.00$). (Table 4.8).

In the laboratory mean number of egg masses laid by females whose larvae were reared on maize and wheat were 10.6 and 7.2 respectively. Significant differences were observed in the number of egg masses (P = 0.047, *t* (18) = 2.136). The number of eggs ranged from 360-2002 for females that originated from maize and 445- 2267 for females that originated from wheat. No significant differences were observed in the number of eggs laid (P = 0.56, *t* (18) = 0.598) between the two sets of females (those that originated from maize and those that originated from wheat) (Table 4.8).

In the green house mean number of egg masses/ female from females whose larvae were reared on maize and wheat were 8.0 and 7.0 respectively. The number of eggs ranged between 171- 1301 for females that originated from maize. For females that originated from wheat the number of eggs ranged between 230- 1338 with a mean of 736.0. No significant differences were observed in both number of egg masses (P = 0.671, *t* (10) = 0.438) and in number of eggs (P = 0.798, *t* (10) = - 0.263) between FAW females that originated from maize and those that originated from wheat. The eggs laid by female moths that originated from maize and wheat took 3.2 days and 3.1 days respectively to hatch in the laboratory, no statistical differences were observed in the hatching period between the eggs laid by females that originated from maize the eggs laid by females that originated from wheat (P = 0.773, *t* (18) = 0.293). In the green house eggs laid by females whose larvae were fed on maize took 3.4 days to hatch while those that originated from wheat took 3.1 days to hatch. No significant differences between eggs laid by females that originated from maize and those that originated from wheat were observed (P=0.585, *t* (10) = 0.564) (Table 4.8).

Table 4. 8: Preoviposition, oviposition periods, number of eggs and egg masses/ female, and number of days taken for FAW eggs to hatch (Mean±SE)

Host	Preoviposition	Oviposition	Eggmasses	Eggs	Hatchability
Laboratory					
Maize	3.8±0.2	4.7±3.0	10.6±1.34	945.9±87.5	3.2±0.25
Wheat	5.6±0.5	5.4±3.1	7.2±0.85	892.8±164.5	3.1±0.23
P value	0.004^{***}	0.119^{ns}	0.047^{s}	0.557	0.773^{ns}
t value	- 3.349	-1.635	2.136	0.598	0.293
Green house					
Maize	3.6±0.245	3.00±0.32	8.0±2.07	711.00±190.32	3.4±0.40
Wheat	3.14±0.26	3.00±0.31	7.0±1.25	736.29±140.73	3.14±0.26
P value	0.248	1.00^{ns}	0.671^{ns}	0.798	0.585^{ns}
t value	1.226	0.00	0.438	- 0.263	0.564

(P=0.05) ^{ns} not significant

4.3.2 Oviposition preferences *S. frugiperda* on maize, wheat and common bean in laboratory and greenhouse.

FAW females' ovipositional preferences were evaluated using two tests (no choice test and free choice tests) on maize, wheat and common bean to determine the host plant that is mostly preferred by FAW females for oviposition.

In no choice test FAW females preferred wheat to maize and common bean for oviposition. In the laboratory mean number of eggs laid by FAW females on wheat was 421, 335 on maize, and 155 on common bean. In the green house the average number of eggs oviposited by FAW females was 237.3 eggs on maize, 310.0 eggs on wheat and 129.7 on common bean. However no significant differences in number of eggs laid by

FAW females were observed among the three host plants both in the laboratory (P = 0.087, df = 2, F =3.25) and green house (P = 0.308, df = 2, F =1.442).

In the free choice test wheat was mostly preferred by FAW females for oviposition followed closely with maize. The females did not lay any eggs on common bean. In the laboratory mean number of eggs laid by females was 849 on wheat and 758 on maize. In the green house the females laid 743 eggs on wheat and 531 eggs on maize. Differences in FAW females ovipositional preferences were observed among maize, wheat and common in the laboratory (P=0.000, df=2, F= 1368.8) and green house (P= 0.000,df= 2, F= 1094.3)(Table 4.10).

Table 4.9: Number of egg masses and eggs (Mean ±standard error) of FAW in no choice and free choice tests on maize, beans and wheat under laboratory and green house conditions

	No choice Test		Free choice test	
Host	No. of Egg masses	No. of eggs	No. of Egg masses	No. of eggs
Laboratory				
Maize	4.25±1.93a	335±68.86a	6.00±1.18 b	758±75.33 b
Beans	3.75±1.38a	155±67.82a	0.00±0.00 a	0.00±0.00 a
Wheat	5.75±2.06a	421±95.60a	7.40±1.81b	849±121.98 b
P value	0.727^{ns}	0.087^{ns}	0.003	0.000
F value	0.330	3.25	9.948	1368.8
Green house				
Maize	2.67±0.67a	237.3±65.5a	5.00±1.16 b	531.7±71.67 b
Beans	1.00±1.00a	129.7±88.96a	0.00±0.00 a	0.00±0.00 a
Wheat	3.33±1.86a	310.0±73.3a	7.67±1.76b	743.±108.99 b
P value	0.414^{ns}	0.308^{ns}	0.012	0.000
F value	1.026	1.442	10.225	1094.3

Means followed by the same letter in the column do not differ by Tukey's test (P=0.05) ^{ns} not significant. On number of eggs original values are presented.

4.4 Resistance of maize genotypes against FAW

4.4.1 FAW Leaf damage

Inbred lines showed the most leaf damage, while hybrids had the least leaf damage score. When the leaf damage score was taken in the first infestation, all the genotypes were susceptible to FAW with the mean leaf damage score of 7.32 for inbred lines, 7.48 for hybrids and 7.85 for OPVs. In the second infestations mean leaf damage score in inbred lines was 7.6, 7.3 in hybrids and 7.5 in OPVs. In the third and fourth infestation the mean leaf damage in inbred lines increased to 8.7 and 8.8 respectively. In OPVs the damage increased to 8.4 and 8.8 respectively. In hybrid varieties the leaf damage increased to 8 in the third infestation but reduced to 7.8 in the fourth infestation.

When the final (fourth) leaf damage score was taken after the fourth infestation 34 inbred lines out of 37 had dead hearts(highly susceptible) while 3 lines were susceptible with a leaf damage score of 7 (Table 4.10). The inbred lines showed significant differences in leaf damage amongst themselves after first, second and third infestations, that is at 56 days(X^2= 73.00, df=36, P=0.0001), 70 days(X^2= 70.942, df =36, P=0.0001) and at 84 days(X^2= 71.132, df=36, P=0.000). However, there were no significant differences in leaf damage among the inbred lines at the fourth infestation (at 98 days) (X^2= 33.86, df=36, P=0.57).

Out of the 30 hybrid varieties tested, 4 showed moderate resistance (leaf damage score was 5), 9 were susceptible (leaf damage score was between 6-7) and 17 were highly susceptible (score was 8-9) (Table 4.10).). Significant differences in leaf damage among the hybrid varieties were observed at 56 days (first infestation) (X^2= 46.057, df=29, P=0.023) and fourth infestation (98 days) (X^2= 43.31, df= 29, P= 0.043). However, there were no significant differences in leaf damage at 70 days (second infestation) (X^2= 42.251, df=29, P=0.53) and 84 days (third infestation) (X^2= 37.503, df=29, P=0.134)

Out of 26 OPVs tested, 3 were susceptible (leaf damage score was 6-7) while 23 were highly susceptible (8-9) (Table 4.10). The leaf damage in OPVs was significantly different at 84 days (third infestation) (X^2= 38.610, df=25, P=0.04) and 98 days (fourth infestation) (X^2= 41.44, df= 25, P= 0.021) but not at 56 days (first infestation) (X^2= 37.553, df=25, P=0.051) and 70 days (second infestation) (X^2= 33.664, df=25, P=0.115).

Table 4. 10: Frequency distribution of 37 inbred lines, 30 hybrid varieties and 26 OPVs for resistance to *S. frugiperda* under artificial infestation

Scale	Response rating	Number of genotypes		
		Inbdred lines	**Hybrids**	**OPVs**
1	Highly resistant	0	0	0
2	Resistant	0	0	0
3	Resistant	0	0	0
4	Moderately resistant	0	0	0
5	Moderately resistant	0	4	0
6	Susceptible	0	2	0
7	Susceptible	3	7	4
8	Highly susceptible	0	4	1
9	Highly susceptible (dead hearts)	34	13	21
	TOTAL	**37**	**30**	**26**

Apart from leaf damage FAW also damaged stalks of maize plants by making holes (Fig on them making the plants to break off and die. Mean number of entry holes among the inbred lines was 1.35, 1.1 among the hybrids and 2.15 among the OPVs. The entry holes were significantly different among the lines (F=4.44, df= 36, P= 0.000) hybrids (f=11.21, df= 29, P= 0.000) and OPVs (f=3.73, df= 25, P= 0.001) (Table 4.11).

Table 4.11: FAW Leaf damage and number of entry holes (Mean ± SE) on maize genotypes at Icipe

	Mean Leaf damage (days after planting)				**Entry holes**
Genotype	56 days	70 days	84 days	98 days	
Inbred	7.32±0.2	7.6± 0.1	8.7± 0.1	8.8±0.1	1.35±0.2
Hybrids	7.48± 0.2	7.29± 0.1	8.03± 0.1	7.82±0.2	1.1±0.2
OPVs	7.85± 0.1	7.49± 0.2	8.42± 0.1	8.75±0.1	2.15±0.3

Percentage plant survival of FAW injury

Not all genotypes that showed susceptibility to FAW died. Some survived the injury by FAW and were able to regenerate by developing new leaves until they tasseled. They include three inbred lines which survived with very low percentage of 25% (Only one plant each of the three genotypes survived out of four plants that were infested), 16 hybrid varieties with mean of 50% (At least 2 plants each of the 16 hybrid varieties did not die) and 3 OPVs survived FAW injury with mean of 50.0%.

CHAPTER FIVE

DISCUSSION

5.1 Farmers Perception, knowledge and management of FAW

Farmers' perception for the management options for agricultural crop pests is directly linked to gender a difference which consequently affects agricultural productivity. In most African settings women are the ones mostly found at home working in their farms. In this study majority (56%) of farmers interviewed were female and this affected the kind of control option for FAW. In this study majority of farmers interviewed in Tongaren and Mt. Elgon sub counties were women and they mostly used traditional methods in the control of FAW. The results from this study compare favourably with the results in Zambia by Kansiime *et al*. (2019) who also reported that females are most likely to use traditional methods while males use mostly chemical insecticides in the control of fall armyworm. . This gender differences are linked primarily to ability of accessing resources, farm inputs and services (Croppenstedt *et al*. 2013). Men can easily access pesticide and utilize them, while women can easily access materials like ash and use them to control FAW. To address these differences women need to be involved in Agricultural programmes and research. Since maize is a staple food to majority (66%) of farmers in surveyed sub counties, every effort is put in to ensure that there is no threat to the crop. The farmers therefore applied more than one control measure in fighting FAW with the hope that they will eliminate it to ensure food security.

Although FAW was detected in Kenya recently (KARLO, 2017), the present study demonstrated that all farmers in the surveyed sub counties had knowledge about it. This was due to the information given by the media and the extension agents in these regions.

Farmers were concerned that a new destructive pest, fitting the description of FAW, provided by the media and extension agents, had invaded the farms and was causing a lot of damage to the maize. Farmers reported to have observed the pest 53 days on average after planting. This is the vegetative stage at which FAW pest is known to cause serious damage to maize (Georgen *et al*., 2016). Majority of the farmers could recognize the fall armyworm based on larvae attacking maize plants. Pupal stage was not reported by any farmer because the pest pupates in the soil (Belay, 2011) and therefore could not be seen easily.

Most farmers who experienced FAW in their farms estimated 47% infestation. This was in agreement with the study done in Zambia (Kansiime *et al*., 2019) where 50% infestation was reported. This high infestation intensifies small holder reliance on chemical insecticides which has negative impact on human health and environmental safety. Maize yield reduction was estimated to be between 0.77 to 1 tonnes /ha (19-25%), and this was based on perceived crop damage by the fall armyworm. Maize being a staple food in Kenya, this loss in yields threatens food security of the country which can consequently lead to malnutrion. These findings compare favorably with surveys undertaken by (Day *et al*., 2017) in different countries in Africa who estimated maize yield loss due to fall armyworm to range from 22 to 67%. In Zimbabwe reduction in yield due to FAW was estimated to be about 9% using field scouting and harvesting of quadrants (Baudron *et al*., 2019). When compared with estimates from socio-economic surveys this estimate (Baudron *et al*., 2019) is very low. In some maize genotypes, the damage by fall armyworm does not necessarily lead to severe yield losses (Kumar, 2002; Prassana *et al*., 2018). Maize plants are able to compensate for leaf damage that occured over a short period of time (Lima *et al.*, 2010). According to theses authors, severe yield losses can only occur when the whorl was destroyed. These results agree with the results of this study to some extent where farmers even though reporting 47% of their maize being affected by the fall armyworm, estimation of yield loss was less than one-third. This shows a limitation in the existing yield loss estimation methods, shown by this study as also. This calls for socio-economic models to include other variables that are directly linked to yield loss e.g. variety, cropping systems, pest management practices and presence of other abiotic and biotic stressors.

Farmers applied different methods in controlling FAW with chemical insecticides being the mostly used approach. This could be attributed to the Kenyan government initiative to distribute free pesticides to farmers for combating the spread of the pest in the five sub counties in this study. This is why the farmers have continued to use insecticides as the main control method of FAW. Fall armyworm in America is also controlled mainly by chemical sprays (Lima *et al*., 2006) and this is the case with many other insect pest species. Farmers also mixed different pesticides believing that the effect will be greater than when they used just one type of insecticide. Combined with limited adherence to safety precautions, farmers may have been exposed to health risks.

Majority of the farmers perceived that sprayed insecticides were not effective in controlling this pest. Recent studies in Africa have shown mixed results on the effectiveness of chemical use on fall armyworm (Baudron *et al*., 2019). The findings suggest the low efficacy of pesticides in controlling FAW or reducing its impacts (Prassana *et al*. 2018). This may be due to among other factors the wrong pesticides being applied or pesticides being applied at the wrong concentration and height (Baudron *et al*., 2019). Since the larvae are relatively inactive during the day and they hide in the whorl of the maize plants making it difficult for the chemical to reach them. Unless spraying is done in the morning or in the evening when the larvae are active, insecticide at this stage may not be effective (Baudron *et al*., 2019). Contact insecticides may also not be effective for older larvae as they tend to produce a lot of frass which act as a barrier for the chemical to reach them, (Goergen *et al*., 2016). Insecticides application may be repeated, for instance in Brazil on average five repetitions were done to control FAW in maize (Ribeiro *et al*., 2014), and in the south-eastern United States during the silking stage of sweet corn, spraying is often done on daily basis (Capinera, 2017). However, for our local farmers, most of whom practice subsistence farming, repeated application of the pesticide will lead to incurring additional production cost, making it an expensive endeavor which most of them will not afford. Repeated application of the same pesticide have been shown as the major cause of insecticide resistance by pest, like a case reported by Kuate *et al.* (2019) in their study on distribution, damage, pesticide use, genetic differentiation and host plants of FAW in Cameroon. To avoid occurrence of resistance to pesticide in Africa, farmers should be advised on the proper use of insecticides including rates, timing and method of application (Kuate *et al*., 2019).

Apart from insecticides, farmers reported to have also used other technologies like ash, soap detergents, tobacco, neem and sand. These non- chemical substances have shown potential for control of FAW besides providing low cost options for small holder farmers. Kansiime *et al*. (2019) also reported that application of ash/ sand showed considerable level of success in controlling FAW in Zambia.

5.2 Extent of FAW damage

Spodoptera frugiperda infestation varied considerably among the farms and sub counties surveyed. Maize in Kipkelion East Sub County had the highest mean leaf damage compared to other sub Counties in Bungoma county. Farmers in Bungoma county especially the lower zones (Webuye East and Kabuchai) normally plant their maize earlier than farmers in Kericho county. Moreover Bungoma county lies at a lower altitude (1500 -1800 m.a.s. l) and higher mean temperature (21.1^{0} C) than Kericho county which lies at an altitude of 2155 m.a.s.l. r and average annual temperature of 17^{0} C. Considering these differences in altitude and temperature, crops in Bungoma County would develop faster than those in Kericho. The rate of plant growth and development is dependent upon the temperatures surrounding the plant (Hatfield *et al*., 2015). *S. frugiperda* damage to maize is based on a pattern of continuous migration from older corn plant tissue to more succulent young plants (Murua *et al*., 2006). The FAW moth has also the capacity of flying for hundreds of kilometers (Westbrook *et al*., 2016) per night and because of this, the pest could have migrated from Bungoma where the crop was older to Kericho (Kipkelion East sub County) where the crop was still young for oviposition hence the relatively higher crop damage. Previous reports have demonstrated that maize planted early is less affected or damaged by *S. frugiperda* as compared to maize planted later (Murua *et al*., 2006). Early planting helps the crop to escape late season population of fall armyworm as moths are typically attracted to fields with young crops to lay their eggs (Rodriquez *et al*., 2010).

Precipitation and soils also have effects on larval and pupal survival (Regan *et al*., 2018). Bungoma County experiences bi modal pattern of rainfall which averages 1800mm

(Jaetzold *et al*., 2012) hence low FAW damage while Kericho experiences unimodal rainfall pattern averaging between 1125 to 1400mm ((Jaetzold *et al*., 2012) hence high FAW damage. Despite Bungoma experiencing rainfall in two seasons, the pest build up is low as compared to Kericho because maize is only planted during the long rain season while non host crops are planted during the short rain. The county also experiences warm temperatures making the crop mature faster as compared to Kericho. Kericho even though experiencing unimodal rainfall pattern the pest build up is high as crop takes long to mature due to low temperatures hence there is available of food for feeding for a longer and they can also have many generations leading to higher population . Heavy rainfall fills the maize whorl with water, in which larvae float, until it overflows and the larvae are spilled out or drown (Regan *et al*., 2018). Sims, (2008) reported that high amount of rainfall trap moths and drown them in their pupation tunnels, with the effects being stronger in more friable soils, which cause the tunnels to collapse killing the pupae.

It is important to note that a higher percentage of infested plants does not necessarily mean high leaf damage neither does high leaf damage lead to low yields (Baudron *et al.*, 2019). From these results even though maize in Kipkelion East had the highest mean leaf damage of 4.8, its percentage plant infestation was same as that of Webuye East and Tongaren which had the lowest mean leaf damage and this could be attributed to similarities in agronomic practices like intercropping, crop rotation, weeding and fertilization. This indicates that, in some genotypes, FAW damage does not lead to serious injury to the crop to the extent that yield is highly impacted (Baudron *et al.*, 2019). For instance the hybrids from CML-AG lines though suffering high FAW leaf damage produces highest yields (Kumar, 2002). Maize growth stages will also influence their susceptibility to FAW attack. During mid vegetative growth stage, FAW larvae most often defoliate the leaves within the whorl and severe losses have been reported to occur when the whorl is destroyed (Lima *et al*., 2010).

5.3 Lifecycle and ovipositional preferences of FAW on maize, beans and wheat

This study has demonstrated that FAW develops faster on maize and wheat than on beans.

Developmental time and reproductive potential of insects is influenced by host plant nutrition (Silvia *et al.*, 2017; Golizadeh *et al*., 2009) and this concerns the chemicals like carbohydrates, proteins, fatty acids, amino acids, vitamins and minerals that are required for its growth, tissue maintenance, reproduction and energy. These chemical substances are usually variable among different plant species. Studies by Lee *et al*. (2007) have suggested that nutrient balance, particularly protein to digestible carbohydrates (P/C) ratio is important for development of many insects. Most insects especially generalists perform better on diets with a P/C greater than one than those with a P/C less than one (Lee *et al*., 2007). Grasses have high nutritional value (their P/C ratios are higher) as compared to plants from other botanical families (Barros *et al*., 2010), for example P/C ratios of maize and bean range between1.27 to 2.69 (Silva *et al*., 2017) and 0.41 to 1.57 (Koute *et al*., 2018) respectively. In this respect, high level of nitrogen in maize and wheat as demonstrated by Silva *et al*. (2017), help in conversion of ingested food, making the insects to grow faster, have shorter developmental durations and high reproductive potential as reported by Chen *et al*. (2009).

Similar results were reported by other researchers. For instance Lewter *et al*. (2006) observed that FAW develops faster on grasses like maize, rye, sorghum and Bermuda grass which are C_4 plants as compared to other plants like soya bean or cotton which are C_3 plants. C_4 plants have higher photosynthetic efficiency therefore making them adequate for insect foraging compared to C_3 plants (Chuanli *et al*., 2012). Silva *et al.* (2017) in their study on biology and nutrition of *S. frugiperda* also demonstrated that larval- adult period was shorter on maize and wheat which have high nutritional quality as compared to soya bean and cotton which have low nutritional quality in terms of P/C ratio as discussed above and this explains why bean being a C3 crop has comparatively low nutritional value. Meagher *et al.* (2004) in their study on larval development of FAW on different cover crop plants observed that larvae feeding on cowpeas and sun hemp took longer to develop than those fed on corn and Sorghum- Sudan grass (SSG) and had low survival rate. According to these authors composition and nutritional adequacy of corn and SSG plants is higher compared to cowpeas and sunhemp with the consequence that ultimately, insect foraging is an exercise in acquiring the best blend and balance of suite nutrients, including amino acids, carbohydrates, sterols, phospholipids, fatty acids, vitamins, minerals, trace elements and water (Behmer, 2009).

Variations in development and reproductive potential of FAW was also observed between laboratory and green house conditions and this could have been attributed to variations in temperature under these two conditions. In the laboratory average temperature was 25 degrees Celsius while in the green house the temperature ranged from 23^0 C- 45^0 C with an average temperature of 35 degrees Celsius.

Insects are poikilothermic animals that are largely affected by temperature. Previous studies found evidence that temperature influences various biological characteristics of insects such as sex ratio, adult longevity, survival and reproductivity (Infante, 2000).

In the green house larval, prepupal, pupal and adult longevity periods were shorter compared to laboratory. This pest survived better in the laboratory than in the greenhouse in fact in the green house there were no larvae that established on common bean as they all died at larval stage presumably due to high temperatures. As discussed already, survival rate of FAW on beans is very low even under optimal conditions. The high temperatures in the green house reduces the survival rate even more as the pest apart from starving due to food inadequacy, is also undergoing dehydration due to the high temperatures. According to Regan *et al*. (2018), Busato *et al*. (2005), Elderd and Reilly. (2014), FAW developmental periods decrease with increasing temperature. Hardke *et al*. (2015) also reported that length of time for FAW larval development varies based on temperature and Survival of these stages is greatest around 25 °C, and 35 °C appears to be an upper limit for the pest to survive (Barfield and Busato *et al*., 2005). Pupal weight was also low for those pupae that were raised in the green house and most did not emerge (for those pupae that emerged as adult moths, they had deformed wings). Similar findings were reported by Sims, (2008) that pupae emerging near upper developmental threshold (35°C) exhibited some physical deformity. FAW pupation takes place in the soil (Capinera, 2001), high temperature increases the rate at which water evaporates from the soil, hence the pest is deprived of water and it dies of desiccation. More so when the soil is dry -high temperatures would lead to loss of water from the soil quickly making the soil hard- for the pest to emerge, hence the pest forces itself out of the soil, ending up with deformed wings (Capinera, 2008)

Reproduction potential was high in the laboratory than green house. More eggs were laid by FAW females that were raised in the laboratory compared to those FAW females that were raised in the green house and this was due to high temperatures experienced in the green house. These results are consistent with the findings of Simmons, (1993) that FAW fecundity decreases with increase in temperature. High temperature suppresses mating behavior and sperm transfer which must have led to decline in laying of eggs. Mating often serves not only as a stimulant for oviposition, but male contributions can provide additional nutrient resources for egg formation and development (Park *et al*., 1998). According to Ju *et al* (2010) high temperatures might cause temporary or permanent sterility or may lead to stagnancy of ovaries resulting in a reduced fertility.

Variation in the ovipositional preferences by FAW on different hosts was observed. In the free choice test *S. frugiperda* oviposited more on wheat followed closely by maize. No egg was oviposited on common bean. However in no choice test the moths oviposited on all hosts with more eggs masses found on wheat but fewer eggs found on common bean. *S. frugiperda* females oviposition preference for certain hosts is commonly associated with larval preference (Singer *et al*., 1994). Grasses and specifically wheat in this study, was most preferred for oviposition so that the larvae may establish a feeding site for survival soon after hatching (Zalucki *et al*., 2002). This was demonstrated by Silvia *et al*. (2017) who in their study on larval feeding preference, found large number of first instar larvae on wheat than maize while large number of 3rd instar larvae was found on maize than wheat. In their study on oviposition preference on maize, wheat, oat, cotton and soya bean, these authors also found wheat to be the most preferred host for oviposition in both free and no choice tests. According to these authors, FAW females ovipositional preference for certain hosts -wheat in their context- was for the larvae to establish a feeding site for survival soon after hatching as previously explained. FAW preference for grasses is also due to an ecological factor. Grasses and more specifically maize certainly offer FAW larvae better shelter in that when they reach 3rd instar they move into the whorl of the maize a site that makes it more difficult for predation and chemical control (Prowel *et al*,. 2004) and this enhances survival which will help to increase the population of the pest. In the absence of preferred host FAW females will oviposit on any available substrate as was observed in this study whereby the females only oviposited on common bean in no choice tests but not in free choice tests where wheat and maize were available. Egg masses were also found under the top surface of the cages during the study, although they were not counted. Since oviposition can induce plant based mechanism that can attract insect parasitoids (Hilker, 2006; Fatouros *et al*., 2008), FAW females will tend to place eggs in locations (like on cages surfaces which is not a plant) that will provide protection against parasitization. Furthermore they will place eggs at higher elevations than host plant (in this case under top surface of cages) to facilitate dispersal of neonates (Ching'oma and Pitre, 1999). This behavior was also reported by Prowell *et al*. (2004), Sadek *et al.* (2010) and Ladner and Altizer, (2005) who observed FAW females ovipositing on non host structures or poor host plants in the field in the absence of preferred hosts.

5.4 Screening of maize genotypes

Plants show several mechanisms potential for resistance to FAW (Baudron *et al*., 2019) which include antibiosis, antixenosis and tolerance (Tadele *et al*., 2011). Leaf damage, number of entry holes and percentage plant survival were the parameters used in this study to demonstrate different levels of resistance/susceptibility among the Kenyan maize genotypes that were screened. Leaf damage reduces the photosynthetic area which consequently affects the yield. Entry holes may cause weakened stems which may result in susceptible genotypes to lodging and other plant deformities. From the study, there are differences in resistance levels among the existing Kenyan maize genotypes with respect to leaf damage. These differences in the susceptibility indicate the inherent ability of a particular genotype to resist FAW.

In this study all the three groups of genotypes showed susceptibility to FAW attack at first- though with varying degrees. Hybrids varied from moderate resistance to highly susceptible while both inbreds and OPVs varied from susceptible to highly susceptible. In the subsequent infestations some genotypes recovered from the injury by FAW through compensatory growth showing that they exhibited some tolerance mechanism of resistance. Percentage plant survival remained the most important parameter to use to discriminate among the 93 genotypes screened for resistance. Most of the genotypes that survived the FAW injury were hybrids. From the results, apart from leaf damage, the OPVs mostly suffered stem lodging as a result of entry holes made by the FAW larvae making the plants vulnerable to stem fall. The inbred lines suffered dead hearts hence they could not survive. The hybrid varieties that survived the FAW injury had strong stalks which gave the plants good standing ability to avoid lodging. Vigorous growth was also observed more in hybrids than in OPVs and the inbred lines, before and after the infestations. These attributes gave the hybrids ability to survive the FAW injury.

These variations in susceptibility/ tolerance observed in this study is due to variations in genetic composition of these maize plant genotypes. Tolerance mechanisms in response to chewing herbivory are more frequently described by over- compensation via the production of new tissues, changes in plant architecture, and the allocation of resources to less vulnerable locations (Stowe *et al*., 2000; Tiffin, 2000; Zhou *et al*., 2015; Krimmel and Pearse, 2016). Photosynthesis and growth trait could be the tolerance mechanism exhibited by the genotypes that survived the FAW damage in this study. Defoliation that occurred during the first FAW larvae infestation triggered increased photosynthetic rate in the plant tissues that were remaining and that is why from the results the damage scores reduced in the subsequent infestations.

According to Horgan and Crisol, 2013, hybrid varieties develop faster and are superior in preemption of resources making strong plants hence they attain greater tolerance than inbred varieties through faster regrowth after FAW injury. Bueno and Lafarge (2009) also confirmed that growth rates were higher for the hybrid than for the inbred varieties at each phonological stage of plant development and this helps the hybrids to escape the mid whorl stage which is the most sensitive stage for FAW injury.

The relatively high tolerance of hybrids to herbivores may also be as a result of heterosis (Sogawa *et al.*, 2003; Cohen *et al.*, 2003; Horgan &Crisol, 2013). This can be manifested across several traits including biomass accumulation, defence and yield (Birchler *et al.*, 2006). Similarly while the OPVs are developed under conditions of low and more dispersed nutrient concentrations with less fertile soils (Duvick *et al.*, 2004; Gudu *et al.*, 2005; Denning *et al*., 2009 and Macharia *et al*., 2010), hybrids are developed under high nitrogen levels and fertile and are therefore expected to utilize nutrients more luxuriously and hence strong plants which can withstand pest injury (Muza *et al*., 2004).

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Farmers in the surveyed sub counties were aware of fall armyworm and they could correctly identify it by its morphology or feeding behaviour. Farmers identified the larval stage more than other stages of FAW as it was the damaging stage. Management of this pest was mainly by use of chemical insecticides which was partly motivated by the initial free supply that came from the government in response to its outbreak. These chemical insecticides were expensive but not very effective. The farmers also employed a range of traditional practices like use of pouring ash and sand in the whorl of the plants and drenching of tobacco, neem and soap detergents some of which had considerable levels of success. Farmers attributed the expected maize yield loss primarily to fall armyworm. The majority of farmers had access to an external source of information, including extension officers, radio/TV or an informed neighbor or family member.

Extent of damage by FAW on maize among the farms surveyed in Bungoma and Kericho counties was varied. Damage was relatively high in Kericho county (Kipkelion East Sub County) than in sub counties in Bungoma county. These variations were attributed to the differences in agro climatic factor (temperature, soil and precipitation). Same varieties also showed varied damage attributed to time of planting and differences in agronomic practices. The FAW females prefer young plants for ovipositing eggs than old plants.

FAW development, survival and reproduction is dependent on host plants with which the pest is exposed to. Grasses support FAW better than hosts from other botanical families like beans. FAW also preferred grasses (wheat and maize in this study) for oviposition than other hosts but in the absence of the preferred oviposition hosts the pest oviposited on any available substrate which includes poor host plants or non-plant hosts.

There was a lot of variation in the level of leaf damage among the maize genotypes screened. Hybrids survived the damage by FAW more than the inbreds and OPVs due to their ability to regenerate faster after the injury by FAW.

6.2 Recommendations

Farmers deployed different traditional management strategies to fight FAW some which showed some level of success. Most of these options are cheap, easily accessible and user friendly. The researchers should test and validate these options and package these technologies as one of the management option for FAW and be disseminated to other farmers who may not be aware and be encouraged to use them to reduce the cost on control of FAW.

The study on extent of FAW damage showed a lot of variation in the leaf damage among the farms in Bungoma and Kericho counties. As observed in the study farmers in Kericho County plant their maize late after those in Bungoma county hence the high leaf damage observed. Timely planting is therefore recommended to help the crop to escape late season population of fall armyworm as moths are typically attracted to fields with young crops to lay their eggs.

Intercropping beans and maize has been a common practice for smallholder farmers. Since the invasion of FAW there has been some worry that bean could also be a host crop for the pest which could increase its distribution on maize crop hence more food insecurity. From the study common bean is a poor host for FAW and the farmers should comfortably continue to intercrop it with the maize without any fear.

From the study the genotypes that tolerated the FAW injury can be used to identify the mechanism of resistance that may be present and may be used in development of maize hybrids that are resistant to this pest which can be grown by farmers to reduce losses due to FAW.

6.3 Recommendations for further Research

- Further research is needed to evaluate the efficacy of the traditional methods of FAW controlled that were applied by the farmers.
- This study focused on foliar, further research is needed on extent of damage on reproductive parts of maize crop which mostly impacts the yield.
- Further research is recommended on biology under natural (field) conditions.

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APPENDICES

Appendix I: Questionnaire for farmers perception and knowledge about FAW

1.**GENERAL INFORMATION**

1.1. Name of famer: __________________ Number of households member: ________

1.2. Gender: __________ Age: __________ Education level: __________________

1.3. District: ________________ Village: _________________

1.4. GPS reading: N: _________________ E: _______________ Alt (m.): ___________

1.5. Total land owned area : ________ Maize farm area: _______

1.6. Name of enumerator:____________________ Phone no ____________________

2. Farm practice

2.1. Which are the major crops you produce? (*List in order of importance*)

Food crops	**Cash crops**
1. _____________	1. _________________
2. _____________	2. _________________
3. _____________	3. _________________
4. _____________	4. _________________
5. _____________	5. _________________

2.2. Which type of farming system do you practice for maize;

1: With rain, 2: Wetland (*Bone*), 3: Irrigation, 4: Both (main and off-season)

2.3. If you produce maize with off-season for what purpose you use mainly?

1: Home consumption in fresh', 2: For sale (fresh) 3: For seed 4: Other

2.4. Once you harvest the off-season maize what do you plant in the rain time on that plot?

1: Maize 2: Beans 3: Left fallow 4: Other (mention)

____

2.6. Major pre-harvest insect pest on cereal crops in your area?

Name of insect	**Level of crop damage**			
	High	Medium	Low	No
Stemborer				
Fall Armyworm				

3. Main household income

3.1. Crops

Harvested crops	**Annual average yields** (kg)	**Average price** (kshs/ kg)
Maize		
Sorghum		
Beans		
Coffee		

Are the cereal crops you harvest enough to feed your family for the whole year?

1= Yes, 2= No

3.2. Livestock

Livestock owned by the hh	**Number**	**Average price** (kshs.)
Mature cows		
Mature bulls		
Heifers		
Calves		

Sheep		
Goats		
Chicken		
Donkeys		

3.3. What other asset do you have as sources of income (mill, vehicle, shop etc . . .)

On average, how much money (kshs.) do you get from non-agricultural sources of income:___

4. Perception on fall armyworm (FAW)

4.1. Do you know what fall armyworm is? 1. Yes, 2. No

[Enumerators take time to explain to the farmer and show the photos of FAW and then ask the following questions}

4.2. If you know when you see for the first time?

4.3. Known local name of the Fall army worm? ___________________________

4.4. Your main sources of information regarding FAW?

1. Media (Radio/TV), 2. Extension agents 3. Farmers, 4.Other (mention)

4.5. Can you differentiate stemborer with FAW? 1. Yes, 2. No

4.6. If you can differentiate what are the indicators? _________________________

4.7. Have you ever encountered such a pest on your crops? 1 = Yes, 2 = No

4.8. At what stage you observed the insect (circle)? 1. Egg, 2. Larva, 3. Adult

5. Level of crop damage

5.1. If yes, how much of your maize plant damaged by the pest (%)?

5.2. Which crop it destroys? 1. Maize, 2. Sorghum, 3. Grasses, 4. Other (mention)

5.3. How much maize yield you expect for this season, if no FAW damage? ______

5.4. How much maize yield you expect for this season, with damage FAW? ______

5.5. Your willingness to pay for improved technologies in controlling army worm (FAW)

1. High, 2. Based on observation and effectiveness, 3. Indifferent, 4. No

5.6. At which growth stage of maize damage by FAW is serious?

5.7. At which soil type damage of FAW is serious?.

1. High fertile, 2. Low, 3. No difference

5.8. Trends of damage from the date of your observation?

1. Extremely increasing, 2. Increasing, 3. Remain the same, 4. Decreasing

6. FAW control methods

6.1. What do you think the cause for outbreak of FAW?

____

6.2. Which methods are you using currently using to control FAW on your farms?

1. Chemical spray, 2. Hand picking, 3. Other (______________________)

6.3. If you spray chemical, mention the type: ____________

6.4. From where do you get chemical?

1. Agricultural office for free, 2. NGOs 3. Purchase, 4. Other(_________)

6.5. How do you evaluate effectiveness of the method (________) you practiced?

1. Very effective, 2. Effective, 3. Faire, 4. Not effective

6.6. Have you observed any drawback of chemical spray? (if yes what?)

6.7. What do you think for sustainable control of the pest?

6.8. Who/which institutions are supporting you in controlling/reducing damage of FAW?

1. Agricultural office, 2. Research, 3. NGOs, 4. Other (__________________)

6. Comments (If any): ______________________, _______________________

THANK YOU FOR YOUR TIME AND INFORMATION

Appendix II: List of inbred lines

Mean ± SE for Leaf damage and number of entry holes of inbred lines at Icipe.

	Leaf damage (days after planting				Entry holes
Genotype	56 days	70 days	84 days	98 days	
CKLT 10344	7.0± 0.0	8.0± 0.0	7.0± 0.0	9.0± 0.0	4.0± 1.0
CML 488	5.0± 0.0	6.0± 0.0	7.0± 0.0	7.5±1.5	0.0± 0.0
WMA 2001	8.0± 0.0	8.0± 0.0	9.0± 0.0	9.0± 0.0	0.0± 0.0
CKDHL164288	7.0± 0.0	7.5± 0.0	9.0± 0.0	9.0± 0.0	2.0± 1.0
CML567	8.0± 0.0	7.0± 0.0	9.0± 0.0	9.0± 0.0	1± 0.00
KS23-6-B	7.0± 0.0	8.0± 0.0	8.0± 0.0	9.0± 0.0	0.0±0.0
CKLMARS10183	8.0± 0.0	7.5± 0.0	9.0± 0.0	9.0± 0.0	0.0± 0.0
CKDHL166068	8.0± 0.0	7.5± 0.0	9.0± 0.0	9.0± 0.0	0.0± 0.0
CKDHL121288	5.0± 0.0	7.0± 0.0	9.0± 0.0	9.0± 0.0	0.0± 0.0
CKDHL120566	8.0± 0.0	8.0± 0.0	9.0± 0.0	9.0± 0.0	1.0± 1.0
CKDHL164271	8.0± 0.0	8.0± 0.0	9.0± 0.0	9.0± 0.0	0.0± 0.0
CKDHL164290	7.0± 0.0	6.0± 0.0	9.0± 0.0	9.0± 0.0	4.0± 1.0
CKDHL0089	8.0± 0.0	7.5± 0.0	9.0± 0.0	9.0± 0.0	5.0± 2.0
CKDHL120348	8.0± 0.0	9.0± 0.0	9.0± 0.0	9.0± 0.0	0.0± 0.0
CKDHL120668	6.0± 0.0	7.5± 0.0	9.0± 0.0	9.0± 0.0	0.0± 0.0
CKDHL121320	8.0± 0.0	7.0± 0.0	7.5± 0.0	9.0± 0.0	0.0± 0.0
CKLMLN140377	8.0± 0.0	9.0± 0.0	9.0± 0.0	9.0± 0.0	0.0± 0.0
CKLMLN140538	8.0± 0.0	9.0± 0.0	9.0± 0.0	9.0± 0.0	3.0± 1.0
CLMRCY039	8.0± 0.0	9.0± 0.0	9.0± 0.0	9.0± 0.0	0.0± 0.0
CML494	8.0± 0.0	7.5± 0.0	9.0± 0.0	9.0± 0.0	0.0± 0.0
CML247	5.0± 0.0	7.0± 0.0	9.0± 0.0	9.0± 0.0	5.0± 1.0
CML 464	7.0± 0.0	6.0± 0.0	8.0± 0.0	7.5± 1.5	1.0± 0.0
CML444	7.0± 0.0	7.0± 0.0	9.0± 0.0	9.0± 0.0	2.0± 1.0

CML395	7.0± 0.0	7.5± 0.0	7.5± 0.0	7.0± 2.0	5.0± 2.0
CML442	6.0± 0.0	7.5± 0.0	8.0± 0.0	9.0± 0.0	2.0± 0.0
CML543	7.0± 0.0	6.0± 0.0	8.0± 0.0	9.0± 0.0	0.0± 0.0
CML560	7.0± 0.0	7.5± 0.0	7.5± 0.0	7.0± 2.0	1.0± 0.0
CML559	8.0± 0.0	7.5± 0.0	8.5± 0.0	9.0± 0.0	3.0± 0.0
CKLT10139	8.0± 0.0	8.25± 0.25	9.0± 0.0	9.0± 0.0	0.0± 0.0
CML312SBR	6.0± 0.0	7.5±0.5	8.5±0.5	9.0±1.0	2.0± 2.0
CML333W	8.0± 0.0	7.75±.25	9.0± 0.0	9.0± 0.0	5.0± 0.0
MLN004	7.0± 0.0	8.5± 0.0	9.0± 0.0	9.0± 0.0	0.0± 0.0
MLN002	8.0± 0.0	8.0± 0.0	9.0± 0.0	9.0± 0.0	0.0± 0.0
CML451	8.0± 0.0	6.0± 0.0	9.0± 0.0	9.0± 0.0	3.0± 1.0
CKDHL120671	8.0± 0.0	9.0± 0.0	9.0± 0.0	9.0± 0.0	0.0± 0.0
MLN019	8.0± 0.0	7.0± 0.0	9.0± 0.0	9.0± 0.0	1.0± 0.0
CKDHL166091	8.0± 0.0	7.5± 0.0	9.0± 0.0	9.0± 0.0	0.0± 0.0
Mean	**7.32±0.15**	**7.6±0.14**	**8.7± 0.1**	**8.8±0.1**	**1.35±0.22**

Percentage plant survival among the inbred lines was 25 %. Only 3genotypes survived with percentage of 25% with mean of 25.00±0.00.

Appendix III: List of Hybrid varieties

Mean±SE for Leaf damage and number of entry holes of hybrids varieties at Icipe.

	Leaf damage				Entry holes
Genotype	56 days	70 days	84 days	98 days	
H517	8.0± 0.0	8.75 ±2.25	8.75 ±0.25	9.0± 0.0	2.0± 0.0
H614	8.0± 0.0	7. 0±1.0	7.75± 0.25	7.75±0.75	0.0± 0.0
SC DUMA 43	8.0± 0.0	8.0 ±0.5	8.25 ±0.25	5.0± 0.0	2.0± 1.0
DK777	7.5 ±0.5	7.0± 0.0	8.5 ±0.0	8.0± 0.0	0.0± 0.0
WH 501	7.0± 1.0	7.5± 0.5	8.5± 0.5	9.0± 0.0	0.0± 0.0
WE5140	6.5± 0.0	6.5 ±0.5	7.25 ±0.25	9.0± 0.0	7.0± 1.0
WH507	7.0± 1.0	7.0± 0.0	8.0 ±0.5	6.0± 0.0	0.0± 0.0
H626	6.5 ±0.5	7.0± 0.0	7.75± 0.75	7.25± 0.25	0.0± 0.0
H628	7.5 ±0.5	6.5± 0.5	8.5 ±0.5	7.0± 2.0	0.0± 0.0
SC TWIGA 81	8.0± 0.0	8.0± 0.0	7.0± 0.0	9.0± 0.0	0.0± 0.0
KH600-23A	8.0± 0.0	7.75 ±0.75	8.75 ±0.25	9.0± 0.0	5.0± 1.0
H629	8.0± 0.0	6.5± 0.5	7.5 ±1.5	9.0± 0.0	2.0± 1.0
WH509	8.0± 0.0	7.0± 1.0	8.5 ±0.5	8.25± 0.25	3.0± 0.0
OLERAI	8.0± 0.0	7.75 ±0.25	8.25 ±0.75	9.0± 0.0	0.0± 0.0
H625	6.0± 0.0	6.0± 0.0	9.0± 0.0	9.0± 0.0	1.0± 1.0
PAN4M19	7.0± 0.0	6.5 ±0.5	8.5 ±0.5	9.0± 0.0	1.0± 0.0
DK8031	7.5± 0.5	7.0 ±1.0	7.5 ±0.5	7.0± 2.0	1.0± 0.0
DH04	8.0± 0.0	7.5 ±0.5	7.5± 0.5	6.75± 1.75	2.0± 1.0
WH505	8.0± 0.0	7.0± 0.0	6.5 ±0.0	5.25± 0.25	0.0± 0.0
H6218	8.0± 0.0	8.25, 0.25	8.75 ±0.25	9.0± 0.0	4.0± 0.0

SC TEMBO 73	3.0± 0.0	7.0± 0.0	7.0± 0.0	9.0± 0.0	0.0± 0.0
WH401	8.0± 0.0	7.5 ±0.5	7.5 ±0.5	7.25± 0.35	0.0± 0.0
H6213	8.0± 0.0	6.5, 0.5	7.25 ±0.25	7.25± 1.75	0.0± 0.0
WE5135	7.0± 0.0	7.0± 0.0	8.25± 0.25	8.5± 0.5	2.0± 1.0
WE2015-2	7.5 ±0.5	7.5 ±0.5	8.0± 0.5	5.5± 0.5	0.0± 0.0
PH2859	8.0± 0.0	8.0± 0.0	8.25 ±0.75	8.25± 0.75	0.0± 0.0
PH30G19	8.0± 0.0	7.25 ±0.25	7.5 ±1.0	5.5± 0.5	0.0± 0.0
WH2015-4	8.0± 0.0	9.0± 0.0	9.0± 0.0	9.0± 0.0	0.0± 0.0
AHADI	8.0± 0.0	8.0± 0.0	9.0± 0.0	9.0± 0.0	0.0± 0.0
TENGO	8.0± 0.0	5.0± 0.0	8.0± 0.0	7.0± 2.0	1.0± 1.0
Mean±SE	**7.48± 0.18**	**7.29± 0.15**	**8.03± 0.12**	**7.82± 0.20**	**1.1±0.23**

Percentage plant survival among the hybrids ranged between 25 to 75 %. 16 survived the damage**.**

Appendix IV: List of OPVs

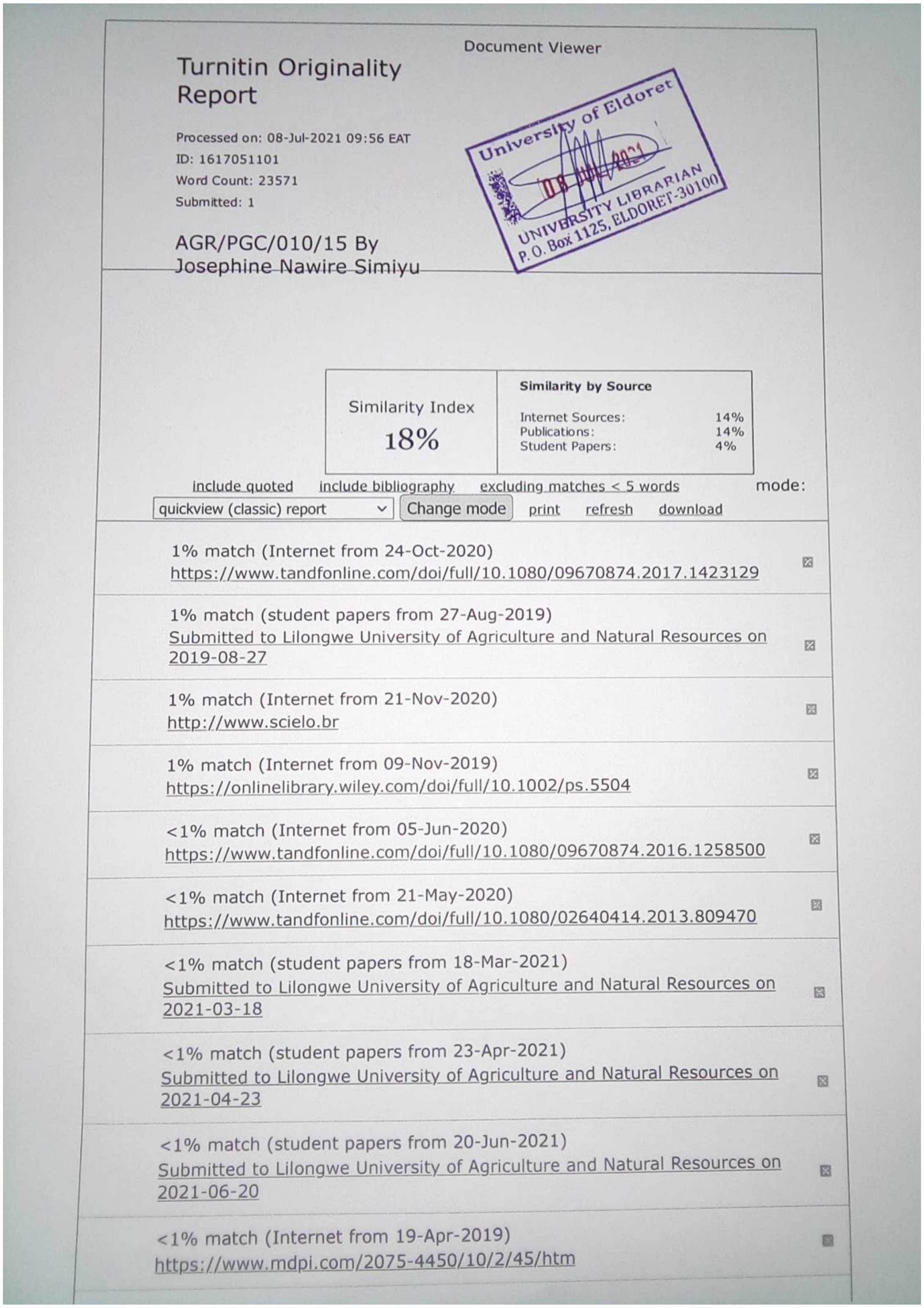
Mean±SE for Leaf damage and number of entry holes of OPVs at Icipe

	Leaf damage				Entry holes
Genotype	56 days	70 days	84 days	98 days	
KAT 8-6-7	8.0± 0.0	8.25± 0.25	8.5± 0.5	9.0± 0.0	0.0± 0.0
KINYANAYA 4-5-3	8.0± 0.0	9.0± 0.0	9.0± 0.0	9.0± 0.0	0.0± 0.0
KIKAMBA 4-3-1	8.5± 0.5	8.25± 0.75	9.0± 0.0	9.0± 0.0	2.0± 1.0
KIKAMBA 4-4-1	8.5± 0.5	8.0± 1.0	9.0± 0.0	9.0± 0.0	2.0± 0.0
LOCAL 4-1-1	8.5± 0.5	8.25± 0.25	8.75± 0.25	9.0± 0.0	2.0± 1.0
LOCAL 4-3-4	6.0± 1.0	7.0± 1.0	9.0± 0.0	9.0± 0.0	2.0± 0.0
DLC 3-1-4	7.5± 0.5	8.0± 1.0	9.0± 0.0	9.0± 0.0	0.0± 0.0
KAT 4-5-1	8.5± 0.5	8.0± 1.0	9.0± 0.0	9.0± 0.0	5.0± 1.0
LOCALKKG	8.0± 0.0	5.5± 0.5	7.75± 0.75	9.0± 0.0	3.0± 1.0
KINYANAYA3-1-4	9.0± 0.0	9.0± 0.0	9.0± 0.0	9.0± 0.0	3.0± 0.0
KIDUMU	7.5± 0.5	5.75± 0.25	8.0± 0.5	9.0± 0.0	7.0± 1.0
KINANA	7.5± 0.5	6.5± 0.0	9.0± 0.0	9.0± 0.0	2.0± 1.0
LOCALMCKS	7.5± 0.5	6.5± 0.5	9.0± 0.0	9.0± 0.0	4.0± 1.0
LOCALBGM	8.0± 0.0	7.5± 0.5	8.75± 0.25	9.0± 0.0	2.0± 1.0
KATEH 16-03	7.0± 0.0	7.5± 0.5	8.0± 0.5	6.5± 1.5	3.0± 1.0
KATEH14-03	8.0± 0.0	8.0± 0.0	8.0± 0.0	9.0± 0.0	0.0± 0.0
OHOO5	8.0± 0.0	8.0± 0.0	8.5± 0.0	9.0± 0.0	1.0± 0.0
KIKAMBA	7.5± 0.5	7.75± 0.25	8.75± 0.25	9.0± 0.0	3.0± 1.0
KATEH 16-02	8.0± 0.0	7.5± 0.5	8.25± 0.75	8.5± 0.5	4.0± 1.0
OHVIRI-01	7.5± 0.5	7.5± 1.5	8.5± 0.5	9.0± 0.0	3.0± 2.0
OHOO2	8.5± 0.5	8.5± 0.5	8.0± 1.0	9.0± 0.0	2.0± 2.0

KATEH 14-05	7.0± 0.0	8.0± 0.0	9.0± 0.0	9.0± 0.0	3.0± 1.0
KATML 3022	8.0± 0.0	6.5± 1.5	9.0± 0.0	9.0± 0.0	2.0± 1.0
KATEH 14-02	7.0± 0.0	6.0± 0.0	7.0± 0.0	9.0± 0.0	2.0± 0.0
KATEH 16-01	8.0± 0.0	8.0± 0.0	7.25± 0.0	7.0± 1.0	0.0± 0.0
KATEH 14-09	8.0± 0.0	6.0± 0.0	7.0± 0.0	7.5± 1.5	0.0± 0.0
Mean±SE	**7.85± 0.13**	**7.49± 0.19**	**8.42± 0.13**	**8.75± 0.113**	**2.15±0.27**

Among the OPVs percentage plant survival ranged between 25- 75 % with 3 genotypes surving the injury.

Appendix V: Similarity Report



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