EFFICACY OF SEED DRESSERS AND RESISTANCE OF SORGHUM VARIETIES IN THE MANAGEMENT OF FALL ARMYWORM

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A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF MASTER OF SCIENCE IN CROP PROTECTION

DEPARTMENT OF PLANT SCIENCE AND CROP PROTECTION

FACULTY OF AGRICULTURE

UNIVERSITY OF NAIROBI

2020

DECLARATION

This thesis is my own original work and has never been presented for any degree or examination to any institution of higher learning or University.

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To My mother, Mrs. NYIBOL MADUT MAJOK, elder brother, Mr. AJAAL MOU BOL for their encouragement and tireless support throughout the course of this study, and finally, to my sister, Mrs. ADHET DENG for her selfless support that led to the completion of this thesis.

ACKNOWLEDGEMENT

My sincere thanks and gratitude go to the Alliance for a Green Revolution in Africa (AGRA) and the University of Nairobi for granting me the financial support throughout the period of this study. In a special way, I would love to express my gratitude to my supervisors, Prof. Florence Olubayo, Dr. Dora Kilalo and Dr. Eric Manyasa for their support and guidance throughout the course of this project. Finally, my sincere thanks and appreciation go to AGRA project co-ordinators and staff, Prof. Florence Olubayo, Prof. James Muthomi, Dr. Felister Nzuve, Dr. Jane Ininda and Dr. Newton Ochanda for granting me this rare opportunity to pursue my studies at the University of Nairobi.

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LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
ASA	Arid and Semi-arid
ASL	Above Sea Level
AI	Active ingredient
CABI	Centre for Agriculture and Bioscience International
CGIAR	Consultative Group on International Agricultural Research
DAP	Diammonium Phosphate
DNA	Deoxyribonucleic acid
EABL	East African Breweries Limited
EPPO	European Plant Protection Organization
EU	European Union
FAO	Food and Agriculture Organization of United Nations
FAOSAT	Food and Agriculture Organization Statistics
FAW	Fall armyworm
GOK	Government of Kenya
Ha	Hectare
HPR	Host Plant Resistance
ICRISAT	International Crops Research Institute for Semi-arid Tropics
IITA	International Institute of Tropical Agriculture
IPCC	Intergovernmental Panel on Climate Change
IPM	Integrated Pest Management
IPPC	International Plant Protection Convention

KALRO	Kenya Agricultural and Livestock Research Organization
KARI	Kenya Agricultural Research Institute
Kg	Kilogram
KMoA	Kenya Ministry of Agriculture
KSh	Kenya Shilling
MoA	Ministry of Agriculture
MSc	Master of Science
MT	Metric Ton
NRC	Norwegian Refugee Council
pH	Potential of Hydrogen
RCBD	Randomized Complete Block Design
RIRDC	Rural Industries Research and Development
SAT	Semi-Arid Tropics
USA	United States of America
USAID	United States Agency for International Development
USDA	United States Department for Agriculture
USEP	United States Environmental Protection

ABSTRACT

Sorghum is a food security crop for millions of people in E. Africa but its production is negatively impacted by fall armyworm damage, leading to food insecurity. The aims of this study were to evaluate the efficacy of seed dressers and the resistance of sorghum varieties to manage FAW under field conditions. The study tested four seed dressers (Thiamethoxam, Imidacloprid, Lindane and Carbofuran) and screened five varieties of sorghum (Wagita, Seredo, Gadam hamam, KARI Mtama 1 and IESV24029SH) for resistance to FAW. A local check, Nakhadabo was included for comparison. The experiments were carried out at Kiboko and Alupe KALRO/ICRISAT Research Stations in a randomized complete block design in a factorial arrangement with 3 replications for two seasons of 2018/2019 respectively. The data collected included; dead heart symptoms, FAW leaf feeding damage, number of larvae per plant and days to 50% flowering, panicle damage symptoms, plant height and grain weight. Lindane (4) recorded the lowest dead heart symptoms compared to untreated controls (6.2). All seed dressers compared to untreated controls, recorded less leaf feeding damage. However, Lindane (9) was the most effective among the seed dressers on the leaf feeding damage. Seed dressers varied for the number of days to 50% flowering. Imidacloprid (147 days) showed earliness at Alupe, while Thiamethoxam (125 days) showed earliness at Kiboko. Lindane (3.3 larvae) and Thiamethoxam (3.9 larvae) recorded a lower number of FAW larvae per plant compared to other seed dressers and untreated controls. Lindane (5.5) was the most effective seed dresser compared to other seed dressers and untreated controls (7.4) on FAW panicle damage symptoms. Lindane (295cm), Carbofuran (296cm) and Thiamethoxam (296cm) recorded shorter plant heights compared to other seed dressers and untreated controls. Carbofuran (2.34g) recorded the highest grain weight per plot compared to other seed dressers and untreated controls.

Significant differences (P≤0.05) were observed among sorghum varieties, and KARI Mtama 1 (5) recorded the lowest dead heart symptoms compared to other varieties. Alupe recorded the highest FAW leaf feeding damage compared to Kiboko. Nakhadabo (4.2), KARI Mtama 1 (5.3) and Wagita (5.9) showed resistance by recording the less leaf feeding damage, while IESV24029SH (10), Gadam hamam (8.2) and Seredo (8.1) showed susceptibility by recording a higher leaf feeding damage. Alupe recorded a higher number of FAW larvae per plant compared to Kiboko. Nakhadabo (1.3 larvae), KARI Mtama1 (2 larvae) and Wagita (2.3 larvae) recorded a lower number of larvae per plant, whereas the other varieties showed susceptibility. Sorghum at Kiboko flowered earlier compared to Alupe, and Gadam hamam (52.3days) was the earliest at Kiboko, while Nakhadabo (67days) was the earliest at Alupe. Higher panicle damage symptoms were recorded at Alupe compared to Kiboko. KARI Mtama 1 (1), Wagita (1.3) and Nakhadabo (2.3) recorded a moderate resistance to panicle damage symptoms compared to other varieties. Plant height was higher at Kiboko, but lower at Alupe. Gadam hamam (103cm) and IESV24029SH (105cm) recorded shorter plant heights compared to other varieties. Grain weight was higher at Kiboko compared Alupe, and Wagita (3.6g) recorded the highest grain weight compared to the other varieties. The study has identified Thiamethoxam, Imidacloprid, Lindane and Carbofuran to be effective against FAW at vegetative stages of sorghum and development, and may be incorporated prior to planting to protect sorghum seeds from early FAW infestations. The study also identified varieties Nakhadabo, KARI Mtama1 and Wagita to be resistant to FAW feeding damage on sorghum and therefore, can be considered in the management of FAW where its infestations are high or anticipated during the growth periods.

CHAPTER ONE

INTRODUCTION

1.1 Background information

Grain sorghum *Sorghum bicolor* L. Moench, (Family: *Poaceae*), takes the fifth position globally after maize, rice, wheat and barley as a vital cereal grain in terms of area under cultivation and production (FAOSAT, 2017). The world sorghum production is 64.7 million tons (USDA, 2016). USA is the world leading producer of sorghum with 9.2m metric tons. In Africa, Nigeria is the largest producer of sorghum with 6.9m metric tons. In Eastern Africa, Ethiopia leads in sorghum production with 4.8m metric tons (Table 1) (FAOSAT, 2017). Sorghum follows maize as the most important cereal in Africa with 22% of the total cereal area (Feeding Africa, 2015). Sorghum accounts for 76% of grain consumption in South Sudan (FEWS NET, 2018), while the total production in 2017 was 667,000 tons (FAOSAT, 2017). Sorghum ranks first in South Sudan (Richard. Z *et al.*, 2015) and comes fourth after maize, wheat and rice in Kenya as reported by Central Bureau of Statistics (CBS, 2016). Sorghum is adapted to the environments prone to droughts that receive 300-760 mm of annual rainfall. It does well in areas between 500m to 1700m above sea level (ASL) (Muui, 2014). In E. Africa, sorghum is a food security crop, mainly for smallholder farmers (Timu *et al.,* 2012; Muui *et al.*, 2013).

As reported by Kilambya and Witwer (2013) and Gichangi *et al*. (2015), sorghum crop gives hope that Sub-Saharan Africa can still attain maximum levels of production even in areas occasioned by climate change. Because of being drought tolerant, sorghum is referred to as the plant kingdom’s camel (Fetene *et al*., 2011). The characteristics that make sorghum a drought-resistant crop are the deep root system and its ability to cease growth during the dry spells

(Whiteman and Wilson, 1965; FAO, 2015). The crop has smaller leaf area, heavy and waxy cuticles that cover the leaf surface, making them well adapted to high temperatures and efficient in reducing the rate of transpiration during drought conditions (Munyua, 2010). Sorghum requires one-half to two-thirds the amount of rainfall compared to maize (Hancock, 2000). Sorghum is a vital diet for over five hundred million people in more than thirty countries in Arid and Semi-Arid (ASA) parts of Africa (ICRISAT, 2015), Asia and Central America. Sorghum has many uses as food, feed, fibre and fuel (ICRISAT, 2015; FAO, 2015). In South Sudan, sorghum is a key cereal crop widely grown in the country, that serves many purposes such as 'Kuin' (ugali) with meat or vegetables' broth, kisera (leavened pancake), and local brewed wine (mou) and sorghum grain stew (nyiny). These also include the most famous dishes called 'Akop or Wal-wal' a food prepared from sorghum flour (unfermented dough) and 'Diong' (ugali with cow's butter or ghee).

Sweet sorghum cultivars with high sugar content are the only types of sorghums that provide stems which can be chewed like sugarcane, production of sugar and syrup (Laopaiboon *et al*., 2007; CGIAR, 2015). Sorghum is a wellspring of nutritional elements for millions of the poor small-scale farmers (Makokha *et al.,* 2002). The nutritional values of grain sorghum have been found to have the healing properties that prevent the lifestyle diseases and chronic disorders. Sorghum food is free of gluten and is recommended for patients who are intolerant to gluten and those having abdominal pains. Sorghum food has a low glycemic index that reduces the risks of diabetes. Sorghum is also rich in antioxidants, polyphenols, dietary fibre and magnesium and contains a low content of fat (Ciacci *et al*., 2007; Dayakar *et al*., 2014). Dried stalks of sorghum serve different purposes that include; bedding, roofing, fencing and paper production (CGIAR, 2015). Norwegian Refugee Council (NRC, 2004) reported that, in the developing countries, sorghum products are not only used as food or as fuel for cooking, but also as leather dye and as physical supports for the climbing crops like cucumbers and yams.

1.2 Problem Statement

Sorghum is one of the most important food crops, especially for the poor and hunger-stricken families in eastern Africa (Timu *et al.,* 2012). Despite the ability of sorghum to grow successfully in drier regions of Sub-Saharan Africa, its production is constrained by about 150 insect pests, and of these, more than hundred (100) pests have been reported in Africa alone (Kruger *et al.,* 2008). The damage by insect pests results in an annual yield loss of over $ 1billion in drier areas of the globe (ICRISAT, 1992). Among the major insect pests in E. Africa that devastate sorghum production, is the recent introduced fall army worm (*Spodoptera frugiperda*). FAW is reported to be an important economic pest of sorghum in Brazil and El Salvador (Molina *et al.,* 2001; FAO, 2017). Andrew (1988) reported that, FAW feeding damage in sorghum causes yield loss that ranges from 55 to 80% in the Americas. In E. Africa, no seed dressers and resistant sorghum varieties that have been used for the control of FAW infestation. Therefore, this study was undertaken to investigate the efficacy of seed dressers and resistance of sorghum varieties in the management of fall armyworm in Eastern Africa.

1.3 Justification

As part of an IPM being widely used today against FAW, seed treatment with insecticides such as Thiamethoxam (Apron star) and Imidacloprid (Gaucho) is a crucial part of an effective fall armyworm control measure that could be used for the management of FAW in E. Africa. According to Cosette (2014), seed dressers have good efficacy on many below ground soil pests and the insect pests that attack sorghum at seedling stage yet they are still not widely screened for use against FAW in sorghum, especially in E. Africa. ICRISAT (2017) reported that, seed dressing can protect the seedlings from pests and fungi up to 40 days, improves crop density by a quarter and yields by up to 50%. Protecting the seeds and young plants from the very start gives them a chance to develop vigour and to survive during the critical first days after planting, even under high insect pressure (Syngenta, 2017). Not much has been done to evaluate the efficacy of seed dressers and the resistance of sorghum varieties in managing the FAW in Eastern Africa. On the other hand, no sorghum varieties have been identified and evaluated for resistance to fall armyworm infestation in the region. In E. Africa, much attention is being directed to the damage the pest causes to maize and not much is known about its impact on sorghum. Therefore, this study focused on evaluating the efficacy of seed dressers and the resistance of selected sorghum varieties to the infestation of FAW for control and management of this pest. Smallholder farmers are the most negatively impacted by the fall armyworm infestation and therefore, the results of this research will help them in a bit to control this pest in sorghum.

1.4 Research objectives:

1.4.1 Main objective

The main objective of this study was to evaluate the efficacy of seed dressers and the resistance of sorghum varieties to FAW and in managing early FAW infestation to improve sorghum production.

1.4.2 Specific objectives

The specific objectives of this study were:

1- To determine the efficacy of seed dressers in the management of fall army worm on sorghum varieties.

2- To assess the resistance of sorghum varieties in response to fall army worm infestation under field conditions.

1.4.3 Hypotheses

1- Sorghum seed dressing is effective against fall armyworm in selected sorghum varieties.

2- Selected sorghum varieties have existing resistance to fall armyworm infestation.

CHAPTER TWO

LITERATURE REVIEW

2.1 Importance of Sorghum in Eastern Africa

Cultivated sorghum (*S. bicolor* L. Moench) is a security food crop in Africa and Asia after maize (FAO, 2017). Farmers prefer sorghum because of its ability to yield better even in the presence of severe insect infestations and environmental stresses compared to other cereals (FAO, 2017). According to Ejetat and Knoll (2007), sorghum is considered resilient to various constraints including insect pests, water deficit, waterlogging, extreme heat intensity and saline soil as compared to other cereal crops (FAO, 2017). Sorghum is important because it serves as an inexpensive source of all nutritional elements to both humans and animals (FAO, 2017). In South Sudan, sorghum is the country's most important staple cereal grown in most parts of the country (FEWS NET, 2018). It is a dual-purpose crop whose uses include; food, feed and beer production. Sweet sorghum stems are chewed as sugar cane and stalks left after harvest are used for roofing of houses and for fencing. Sorghum in Sudan is not only a main food security crop for the country but also important for international trade. Locally, it is used as food, base ingredient in syrup production, beverage production and for animal feed (Altuna, 2014). In Kenya, sorghum provides food and nutritional security in harsh environmental conditions (FAO, 2017).

As food, sorghum has various uses like sorghum stew, ugali, chapatti, porridge and sorghum lager beer (MOA, 2007). Among other uses, sorghum is used as fodder, industrial production of animal feed and dry stalks as fencing materials. In Uganda, sorghum comes third as an important cereal and its economic importance is given by its various uses. The grain is used for human nutrition as bread, porridge and for lager beer (Tenywa *et al.*, 2018). In Tanzania, sorghum plays an important role for small-scale farmers in the country as a source of food and income (Bucheyeki *et al.,* 2010). Sorghum in Rwanda is important both economically and socially, as it is used for human consumption as porridge, animal feed, production of sorghum beer known as Ikigage, and fodder for livestock (One Acre Fund, 2016). In Burundi, sorghum is traditionally and culturally an important cereal consumed all over the country, especially during the cultural rituals as ugali. Sorghum has also for long been used for beer production in the country (MoA, 2010). In Ethiopia, sorghum ranks third after maize and tef in terms of the area under cultivation and production (FAOSAT, 2017). The crop is utilized as bread, injera, boiled grain, and for local beverages like tela and areki. Sorghum stalks are used as animal fodder and for fencing and house construction (Solomon *et al.,* 2017). Grain sorghum in Eritrea is a vital staple cereal in the country, with 90% consumed as injera, 5% as bread, and 5% as porridge and for the local production of alcoholic beverages (Tesfamichael *et al.*, 2013).

2.2 Sorghum production and productivity

In Eastern Africa, sorghum is a staple food security crop grown for both subsistence and commercial basis by small scale farmers (FAO, 2017). In South Sudan, sorghum is grown mainly in the regions of Bahr el Ghazal, Upper Nile and some parts of Central and Eastern Equatoria (FAO, 2018). According to FAO (2017), South Sudan sorghum production was 667,000 tons from an area of 545,719ha, which accounted for 76% of the total cereals production in the country. In Kenya, Sorghum is known as a resilient traditional staple crop grown by small scale resource-poor-farmers (Ngugi *et al.,* 2013). Sorghum is mostly grown in Nyanza, Western and Eastern provinces that account for 99% of Kenya’s Sorghum production (MoA, 2012). The area under sorghum cultivation increased in 2010 from 225,762ha to 254,125ha in 2012, a 13% increase. This increase is due to the crop being drought tolerant and yields better in an area where other crops cannot produce, especially in marginal areas (MoA, 2012). According to FAOSAT (2017), Kenya produced 144,000 metric tons of sorghum in 2017. In Uganda, sorghum ranks third as the most importance cereal food crop, which takes up to 400,000 ha of arable land according to Uganda Bureau of Statistics (2010). It is grown mainly in the south western highland districts that include; Ntungamo and Kabale, and in the lowland areas which include; eastern and northern regions of the country (UBoS, 2010). Although sorghum is an important crop grown and consumed locally in Uganda, its production has drastically decreased from 457,000 tons in 2007 to 299,000 tons in 2013 and stands at 400,000 hectares (Tenywa *et al.*, 2018). In 2017, the country's total production was 316,748 tons (FAOSAT, 2017). In Tanzania, sorghum occupies an area of 663,000ha in the southern part of the country that covers 21% of the total area of cereals countrywide (Tulole *et al.*, 2010). The average yield is estimated at approximately 1000kg/ha, which is too low to sustain a family for up to twelve months (FAO, 2008). According to FAOSAT (2017), the country's production was 796,570 tons.

In Rwanda, 70-80% of sorghum is grown in southern districts of Nyaruguru, Gisagara and Huye while 50% is grown in eastern districts Rwamagana and Gatsibo. The average yields stand at around 2.7 t/ha (One Acre Fund, 2016). The country's total production according to FAOSAT (2017) was 151,447 tons from an area of 408,529ha. In Ethiopia, sorghum is grown in the lowland and intermediate altitudes of the country, covering an area of 1.7million hectares with production of 4.8M tons (FAOSAT, 2017) (Table 1). In Eritrea, 33% of the total area is under sorghum cultivation and 26% of total national sorghum production is from the four sub regions of the country, namely; Hamelmalo, Segeneyti, Teesseney and Goluj (Tesfamichael *et al.*, 2013). The country's total production of sorghum in 2017 from an area of 431,276ha was 140,000 tons (FAOSAT, 2017). In Burundi, the area under sorghum cultivation is 62,000ha. The crop is mainly grown in the areas of north-western provinces of Muramvya, Gitega, Ruyigi and Rutana (USAID, 2010). According to FAOSAT (2017) report, the country's sorghum production (T) stood at 24,306 tons. In Sudan, the total area under sorghum in 2016 was 9.1m hectares. Most of the country's production occurs in eastern Sudan in the states of Kassala, El Gedarif, Sennar and Blue Nile, that accounts for 60% of all area under sorghum cultivation countrywide (FAO, 2018). Sorghum total production in 2017 according to FAOSAT (2017) was 3.7M tons, lower than the acreage due to insect pests (*Quelea quelea*) and diseases (Table 1).

Table 2.1: **Sorghum area and production in Eastern Africa (2017)**

Rank	Country	Area in ha^{-1}	Total Production in (MT)
1	Ethiopia	1.7m	4.8m
2	Sudan	9.1m	3.7m
3	Tanzania	663,000	796,570
4	South Sudan	545,719	667,000
5	Uganda	400,000	316,748
6	Rwanda	408,529	151,447
7	Kenya	254,125	144,000
8	Eritrea	431,276	140,000
9	Burundi	62,000	24,306

Source: FAOSAT (2017)

2.3 Production constraints to sorghum

Sorghum productivity and production are constrained by several abiotic and biotic factors. Among the abiotic factors include the erratic rainfall, drought, and low soil fertility (Wortmann *et al.,* 2006; Olembo *et al.,* 2010). The major biotic factors of economic importance of sorghum include; insect pests such as spp of stalk borers, fall army worm (*Spodoptera frugiperda*), sorghum midge (*Stenodiplosis sorghicola*), and shoot fly (*Antherigona soccata*). The major diseases include; anthracnose (*Colletotrichum graminicola*), leaf blight (*Exserohilum turcicum*), rust *(Puccinia graminis*) and ergot (*Claviceps purpurea*) (Ngugi *et al.,* 2002). Over the last years, fall armyworm has become a major pest of sorghum in major sorghum production regions of Africa (FAO, 2017).

2.4 Fall armyworm (FAW) (*Spodoptera frugiperda)*

Fall armyworm (FAW) is classified in the order: Lepidoptera and the family: Noctuidae (Pogue, 2002). The pest is indigenous to tropical and subtropical Americas (CABI, 2017). FAW is reported to infest 350 plant species, belonging to 27 families (CABI, 2018) in the Americas, preferring wild and cultivated grasses (Casmuz *et al.,* 2010). Fall armyworm is an international pest that threatens food security. Its appearance in most parts of African continent from the Americas heightens the level of risk to other countries of the continent not yet reached by the pest, and other tropical and subtropical regions of Europe and Asia (USAID, 2017). The suitable environment along the Mediterranean coastal countries of Morocco, Algeria, Tunisia and Libya, increases the possible spread of FAW to southern Europe, while suitable climate in E. Africa makes the Middle East and Asia vulnerable to the spread of fall armyworm (USAID, 2017).

2.4.1 Threat of FAW to food security

Yield losses are due to the largest instars consuming over 75% of the total foliage during development (Sparks, 1979). Fall armyworm feeding injury in sorghum reduces plant height, delays plant maturity and reduces the size of panicles (McMillian and Starks, 1967; Starks and Burton, 1979). According to Andrew (1988), the leaf and panicle feeding damages in sorghum cause yield losses that range from 55 to 80% in Brazil. FAO reported that US $600m is spent yearly on the management of FAW in Sorghum in Brazil (Wild, 2017). In Eastern Africa, much attention is being paid to the loss it causes to maize but not much is known about the pest impact on sorghum. However, the estimates by CABI (2017) indicate that, if there are no proper control measures put in place, the potential impact of FAW in maize production on the continent could lead to yield losses between 2.5 to USA $ 6.2 billion per year of the total expected value of USA $ 11.6 billion per year. The yield loss due to FAW infestation in sorghum in Africa is not yet clear, however, the Intergovernmental Panel on Climate Change puts the yield losses roughly above 31% per year (IPCC, 2017). The presence of FAW in Africa as a whole and in E. Africa in particular is an addition to the previous problems caused by native insect pests in the tropics. Hence, the economic consequences of FAW establishment on the continent may not only impact on agricultural production but can also negatively affect access to foreign markets (Goergen, 2017).

2.4.2 Distribution of fall armyworm globally

FAW seasonal distribution, especially in winters, is limited to extreme southern areas of Florida and Texas (Snow and Copeland, 1969). In Middle East, especially in Israel, FAW originated from Caribbean and USA (Luginbill, 1928). FAW distribution is favored by environmental factors such as cool and wet climatic conditions which encourage the development (Snow and Copeland, 1969). Wind and human movement aid the dispersal of FAW from areas that are highly infested to areas that are less infested (Sparks, 1979). In South Sudan, the first official report of FAW was in Magwi County, Imatong State in 2017 (FAO, 2017) and has now spread to other areas of Equatoria, Jonglei in Upper Nile, Western and Northern Bahr el Ghazal States (FAO, 2017). In Kenya the first official report of *S. frugiperda* was in 2017 in Trans Nzoia, Bungoma and Busia Counties (MoA, 2017). FAW is an ever-hungry pest and being polyphagous, its spread to Africa poses a problem to several important crops. FAW infests many plant species belonging to 27 families (Pogue, 2002) in North and Central America (Casmuz *et al.,* 2010), preferring wild and domesticated grasses.

2.4.3 Species of FAW and their geographical location

In Africa, fall armyworm infestation is widespread and it is believed to have arrived in Nigeria in January 2016 and rapidly spread to Southern, Central and Eastern Africa by 2016 and 2017 (FAO, 2017) (Table 2.2). The rapid spread of fall armyworm in part is accelerated by favorable environmental conditions including temperature, warm-wet weather and food that favor survival, oviposition and colonization of new habitats (FAO, 2017). FAW spread and subsequent introduction in new areas threatens biodiversity, functioning of natural and agriculture ecosystem as well as food security (FAO, 2017). Eight armyworm species from two genera *Mythimna* and *Spodoptera* significantly damage the rice in china (Jung–Yuang, 1982). Thirteen armyworm species from genera *Spodoptera*, *Prodenta* and *Pseudaletia* that cause sporadic damage are found in many countries in China, South America and North America (FAO, 2017).

Table 2.2: Official confirmation of FAW presence on the African continent by country as of 2016-2018

Africa	**Distribution**	**Origin**	**First report**	**Invasiveness**	**Reference**
Country					
Angola	Present	Introduced	2017	Invasive	FAO, 2017a
Benin	Present	Introduced	2016	Invasive	IITA, 2016
Botswana	Present	Introduced	2017	Invasive	FAO, 2017a
Burkina Faso	Widespread	Introduced	2017	Invasive	IPPC, 2017f
Burundi	Present	Introduced	2017	Invasive	FAO, 2017a
Cameroon	Restricted	Introduced	2017	Invasive	Abrahams *et al.*, 2017
Cape Verde	Present	Introduced	2017	Invasive	FAO, 2017
C.A.R	Present	Introduced	2017	Invasive	FAO, 2018a
Chad	Present	Introduced	2017	Invasive	Abrahams *et al.*, 2017
Congo	Present	Introduced	2017	Invasive	FAO, 2018a
D.R.C	Present	Introduced	2017	Invasive	Abrahams *et al.*, 2017
Ivory Coast	Present	Introduced	-	-	FAO, 2018b
Equatorial Guinea	Present	Introduced	2017	Invasive	FAO, 2018a
Ethiopia	Present	Introduced	2017	Invasive	Abrahams *et al.*, 2017
Gabon	Present	Introduced	-	Invasive	FAO, 2018a
Gambia	Present	Introduced	-	Invasive	FAO, 2017b
Ghana	Widespread	Introduced	2017	Invasive	CABI, 2017

Guinea	Present	Introduced	2017	Invasive	Abrahams *et al.*, 2017
Guinea Bissau	Present	Introduced	2017	Invasive	FAO, 2017b
Kenya	Present	Introduced	2017	Invasive	Abrahams *et al.*,2017
Liberia	Present	Introduced	-	Invasive	FAO, 2018a
Madagascar	Present	Introduced	2017	Invasive	Abrahams *et al.*, 2017
Malawi	Present	Introduced	2017	Invasive	FAO, 2017b
Mali	Present	Introduced	-	Invasive	FAO, 2017b
Mozambique	Present	Introduced	2017	Invasive	Abrahams *et al.*, 2017
Namibia	Present	Introduced	2017	Invasive	Abrahams *et al.*, 2017
Niger	Present	Introduced	2017	Invasive	Abrahams *et al.*, 2017
Nigeria	Present	Introduced	2016	Invasive	IITA, 2016
Rwanda	Present	Introduced	2017	Invasive	Abrahams *et al.*, 2017
Sao Tome & Principe	Widespread	Introduced	2016	Invasive	IITA, 2016
Senegal	Present	Introduced	2017	Invasive	FAO, 2017b
Seychelles	Present	Introduced	2017	Invasive	FAO, 2017b
Sierra Leone	Present	Introduced	2017	Invasive	FAO, 2017a
Somalia	Present	Introduced	2017	Invasive	FAO, 2017b
South Africa	Present	Introduced	2017	Invasive	Abrahams *et al.*, 2017
South Sudan	Present	Introduced	2017	invasive	FAO, 2017b
Sudan	Present	Introduced	2017	Invasive	Abrahams *et al.*, 2017
Swaziland	Restricted	Introduced	2017	Invasive	IPPC, 2017b
Tanzania	Present	Introduced	2017	Invasive	Abrahams *et al.*, 2017
Togo	Present	Introduced	2016	Invasive	IITA, 2016
Uganda	Present	Introduced	2017	Invasive	Abrahams *et al.*, 2017
Zambia	Present	Introduced	2017	Invasive	IPPC, 2017d
Zimbabwe	Present	Introduced	2017	Invasive	Abrahams *et al.*, 2017

Source: CABI (2017)

2.4.4 Genetic diversity of fall armyworm and its host range

FAW occurs in the Americas in two strains, namely; ‘rice strain’ (R strain) and a ‘corn strain’ (C strain) (Pashley *et al.*, 1985). R strain prefers rice, Bermuda grass, and other small grasses, and the C strain attacks maize, sorghum, cotton and other large grasses. However, the preference may be geographically varied, like in Argentina; this is not consistent (Juarez, *et al.*, 2012a). Here, two strains feed on maize. FAW strains are physically the same, but can be differentiated by the use of DNA barcodes. The *S. frugiperda* strain that was identified in Togo appears to be haplotype found in southern Florida and the Caribbean (Nagoshi *et al.*, 2018). However, both the FAW strains are said to have arrived in Africa and are spreading throughout the regions of the continent (Cock *et al.*, 2017). According to USAID (2017), knowledge about the FAW strains is significant for two main reasons: (1) different haplotypes have different host ranges and (2) different biotypes carry different pesticide resistance genes.

FAW host range in Africa is yet established, however, its infestation is reported to occur on 350 host plants (CABI, 2018) in the Americas (Casmuz *et al.,* 2010), preferring mostly wild and domesticated grasses. Other host plants infested by FAW include; vegetables, legumes as well as several ornamental plants (Smith, 1982; CABI, 2017). FAW was also observed in Uganda attacking cotton and banana (Tajuba, 2017).

2.4.5 Biology of fall armyworm

Adult FAW is noctuid and feeds for a period which extends from shortly after dusk to two hours after sunset depending on temperature and time of the cropping season (FAO, 2017). Previous research findings indicate that FAW is always active in the warm and humid conditions (Sparks, 1979). The adult starts movement in the evening towards the host plant for feeding, oviposition and mating (CABI, 2017). Virgin female moths begin signaling male moths for mating by emitting windborne pheromone to portray their readiness for mating (Luginbill, 1928). Active oviposition starts from the initial four to five days of life (Sparks, 1979). Females oviposit on the underside of the leaves. However, in the event of high FAW population density, oviposition can be on any plant parts or plant debris (Luginbill, 1928). The average adult lifespan lasts only ten days with an average range of 7 to 21 days (Sekul and Sparks, 1976).

2.4.5.1 FAW lifecycle

Eggs

FAW egg is dome-shaped and the base is flat (CIMMYT, 2018). Egg measures 0.4mm in diameter and 0.3mm in height (Sparks, 1979). Female moths often lay eggs on light colored surfaces such as fence rails, tree trunks and the underside of the tree leaves (CABI, 2017). Eggs-laying occurs in four to nine days of female pupation (FAO, 2017). The egg mass is covered by greyish scales of female's body (Luginbill, 1928). Eggs within the same mass hatch at the same time (Sparks, 1979) and the eggs contained per egg mass range are between 50 to 200 depending on the moth strains (FAO, 2017). The female moth produces an average of 1,000 eggs in its lifespan (CIMMYT, 2018). Eggs hatch in 2 to 3 days during the warm months of the summer (FAO, 2017).

Larval stage

FAW larval stage is the longest in its lifecycle (Luginbill, 1928). The stage comprises of 6 larval instars (FAO, 2017). FAW larvae are greenish in color with a black head which turns orange in the second instar (Sparks, 1979). Larvae may be up to $1^1/2$ inches long and color varies from light-green to virtually black with several stripes along the body (Cock *et al.*, 2017). The stripes run across the length of the segments (FAO, 2017). The larvae initiate feeding on the fourth day after molting and last for about 14 days in summer and 22 days in winter implying that larvae stage development in warm summer is temperature driven (FAO, 2017). The net average development time period for 1st instar is 3.3 days, 2nd instar is 1.7 days, 3rd instar is 1.5 days, 4th instar is 1.5 days, 5th instar 2.0 days and 6th instar is 3.7 days at a temperature of 25°C (Pitre and Hogg, 1983). When larvae hatch from eggs, they eat the shell; initiate feeding on the host plants and progress to inflict foliage damage until 6th instars are completed, followed by pupation (Crumb, 1956). Larvae require an average of 14,000mm of crabgrass per caterpillar to complete their development (Luginbill, 1928). Significant damage is done by larval 6th instars (FAO, 2017). In the first 3 stages, larvae are still small and may only utilize less than 2% of the total leaf consumed implying low damage during these larval stages (Luginbill, 1928). 2nd and 3rd instars are discriminated from 5th and 6th instars by their brownish body color at the dorsal parts while white lines are formed in the lateral region in 4th to 6th instars (CABI, 2017). The next vital identifying features of 4th, 5th and 6th instars are a set of four spots that form a square on the upper surface of the last part of the insect's body and Y-marks on the forehead (CABI, 2017).

Pupal stage

The 6 instars drop to the ground and get pupated at 1.3 inches deep in the soil depending on the soil texture, moisture, and temperature (Vickery, 1929). They spin in a cocoon which is oval and of the length of 20-30mm (Capinera, 2014b), that has a brown, shiny noctuid pupa of 18-20 mm length. Pupation varies from 7 to 37 days depending on soil optimal temperature at 25 degrees Celsius (Luginbill, 1928), but may take eight to nine days during warm summer, however, twenty to thirty days during cooler weather are required (Pitre and Hogg, 1983). Immature adult, which is reddish brown in color emerges out from the soil after 10 days in warm summer, and then cling onto plants. They then stretch out their wings and become adult moths (Sparks, 1979).

Adult stage

FAW adults have wing span of 32-28 mm and can be mistaken for other spp of *Spodoptera*. However, in FAW, the hind-wings have veins that are brown and distinct and the forewings of the male are pale and the stigma has a pale 'tail' distally. In the male genitalia, the valve is rectangular and no marginal notch at the position of the tip of the harpe, while the female bursa does not have a signum (Sparks, 1979). An adult female longevity is from 10-21 days. Fall armyworm moths are active in the evenings and hide during the day. Sometimes they hide in sorghum whorls and between the leaves (FAO, 2017).

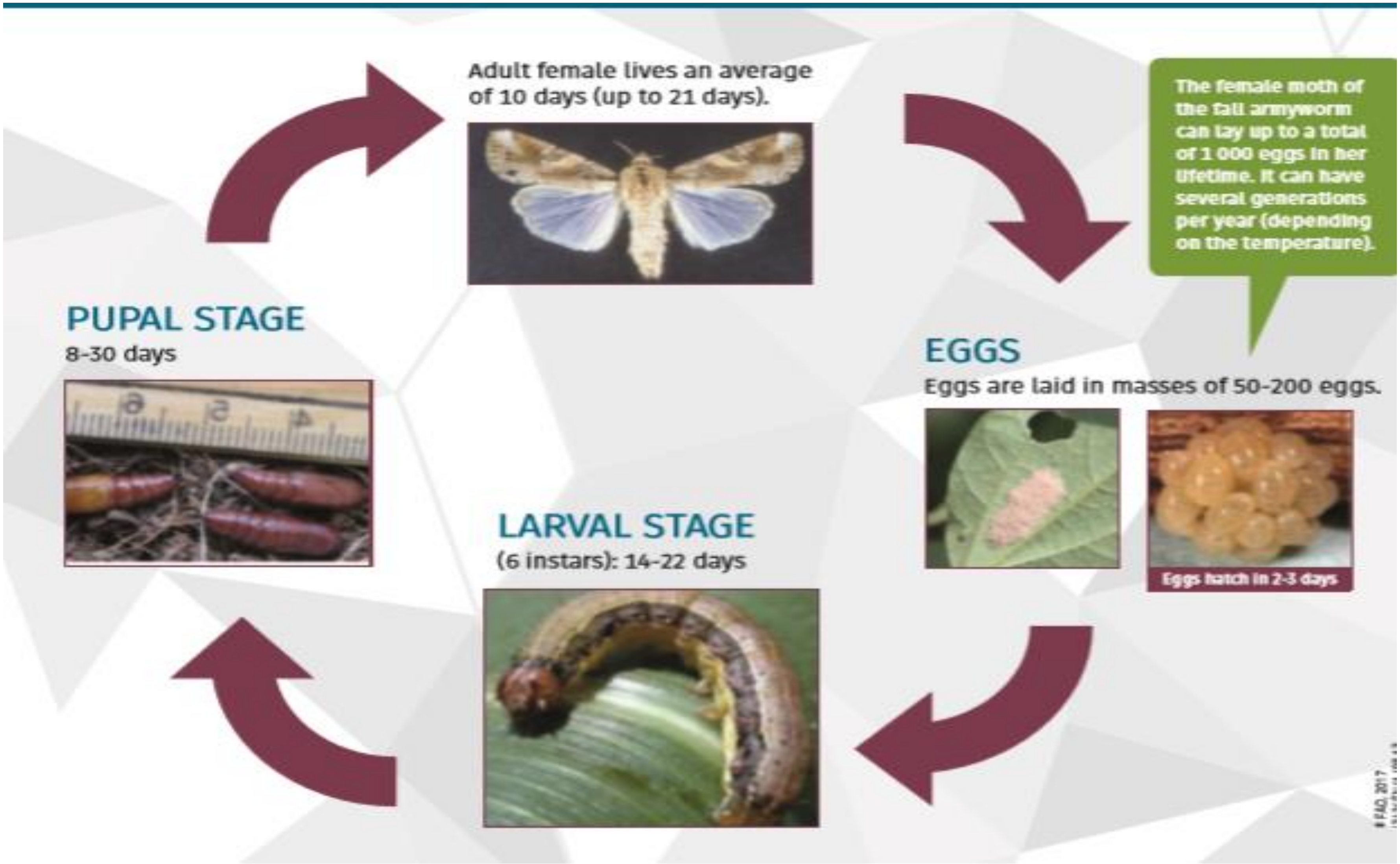

Plate 2.1: FAW lifecycle

Source: FAO (2017)

2.4.6 Identification of FAW

Larval stage identification in the field requires expertise and skills as fall armyworm is easily confused with other family members such as African armyworm (*S. exempta*), African bollworm (*H. armigera*), cotton leaf worm (*S. littoralis*), Spotted stem borer (*Chilo partellus*), lesser armyworm (*S. exigua)*, as well as African maize stalk borer (*Busseola fusca*) (USAID, 2017). However, there are certain marks developed by taxonomists for identifying the FAW (Plate 2.2). These include; head with dark net-like pattern and inverted white 'Y' marking, four dark spots at the eighth abdominal segment and the broad, pale band running along the top body, contrasted by dark stripes at both sides (USAID, 2017).

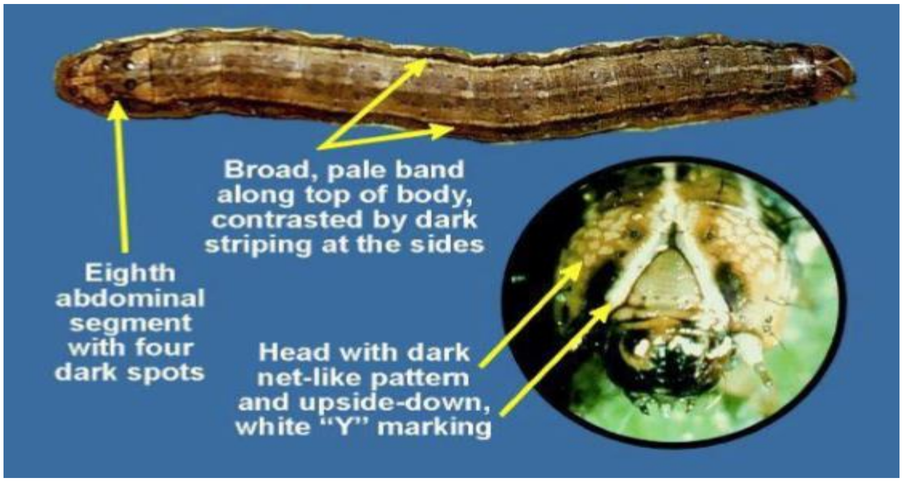

Plate 2.2: identification of FAW

Source: University of Nebraska

2.4.7 Epidemiology of FAW

FAW presents serious damage to cereals, vegetables, legumes and wild grasses. High density concentration of fall armyworm was native to the US and Latin America. However, of recent, severe infestation has been observed in West, Central and Eastern Africa where caterpillars damage staple food crops from corn, sorghum, millet to pasture grasses (FAO, 2017). The adult moth is nocturnal, able to fly to reach out to areas where environmental conditions are favorable with abundance of food, favorable temperature, suitable oviposition habitat and shelter (FAO, 2017). It is not clear if there is a correlation between migratory ability and the inhibition of reproductive development with regards to FAW (Johnson, 1969). Migration of adult moth may be a behavioral response to environmental and seasonal changes. Moth migration is dictated by specific needs including fecundity, fitness, better habitat and survival. Migration promotes distribution, establishment of new colonies and recurrence of infestation in areas where there was less or no infestation (Johnson, 1987). In dry and semi-arid region, mortality increases at 32 degrees Celsius and fecundity decreases. High extent and severity of infestation occur in areas with cooler temperatures (Hattingh, 1971).

2.4.7.1 Mobility and dispersal

FAW is a noctuid, generally considered a strong flier and reported to migrate at night and downwind (USAID, 2017). Adults are nocturnal and their early evening movement near the fields is mostly with the wind. There are records of 16-30 hours of flight by FAW male. In Central America, fall armyworm moths mostly fly about 500 km before egg-laying, from seasonally dry habitats (Johnson, 1969). Moths fly downwind so that the direction of movement depends entirely on the prevailing winds. FAW follows wind direction and can fly variable distances on weather fronts. For this reason, fall armyworm has a great potential to spread quickly as it has already spread to western, eastern and southern regions of the continent of Africa in a period of about eighteen months since its first report in West Africa (USAID, 2017).

2.4.7.2 Means of introduction and spread

FAW has spread beyond West Africa onward to southern and eastern Africa since its first report in 2017. There is no documented evidence on the possible methods or pathways of spread within Africa but according to USAID (2017), there are three pathways of possible spread of FAW into the continent, namely; unaided spread through flight, as a stowaway in aircrafts or other transportation means like shipments and through trade. Introduction might have occurred through eggs, caterpillars, pupae or adults, or the combination of those stages (CABI, 2017).

2.4.7.3 Symptoms of fall army worm damage in Sorghum

2.4.7.3.1 Signs of infestation

The first signs of FAW infestation are the small feeding scratches made by first instars. They feed superficially on one side of the leaf. FAW caterpillars use ballooning, that is by spreading by wind on the thread of silk from one plant to the next and this happens soon after hatching. Ballooning is said to be one of the reasons why FAW infestation levels may go up to 100% (FAO, 2017). FAW damages sorghum plants by infesting both the whorl and panicle (Plates 2.3 and 2.4). FAW larvae infest the whorl by feeding on young leaves of sorghum plants thus, ragging the leaves (Plate 2.3) (Cock *et al.*, 2017). Mature larvae break the stem at seedling stage of growth and development leading to reduced plant stands (Luginbill, 1928). On the unfolded leaves, damage can be seen as irregular and elongated rows of holes (Plate 2.3) (Pitre and Hogg, 1983). FAW reduces sorghum grain yield by feeding on pre-emerged panicle inside the whorl leading to damaged panicle or reduced panicle size (Plate 2.6) (Sparks, 1979). The scale of feeding damage inside the leaf whorl manifests as saw-dust in the whorl area where the larvae feed (FAO, 2017). FAW also infests the panicle after panicle emergence (Plate 2.7) (Andrew, 1988). Young larvae feed on florets while mature larvae feed on growing kernels leading to yield loss (Andrew, 1988). Significant panicle damage is caused by mature larvae at 5 and 6 instars which create load of frass and molds on infested panicles (Cock *et al.*, 2017).

Plate 2. 3: FAW leaf feeding damage

Plate 2. 4: FAW larval panicle feeding

Plate 2. 5: FAW larva feeding in funnel

Plate 2. 6: Larval damage at flowering

Plate 2. 7: FAW dead-heart symptom

Plate 2.8: Damage on emerging panicle

Severe outbreaks of FAW at whorl phase of sorghum crop reduces grain yield by 55 to 80% (Andrew, 1988), while fall armyworm seedling injury in sorghum crop reduces plant growth by reducing plant height, delays flowering and physiological maturity as well as promoting tillering and panicles per plant (Starks and Burton, 1978). Damages attributed to fall armyworm are high because of the polyphagous nature of the insect, high reproductive and dispersal rates and the ability to feed at all stages of its life cycle on virtually all stages of sorghum growth and development (FAO, 2017). Sorghum crop has limited pest resistance at 7 days of germination which makes it more vulnerable at emergence. Resistance in sorghum is induced after injury by fall armyworm at 14 days of infestation and above and such resistance is mediated by jasmonic acids or ethylene (Harris *et al.,* 2015. Yield reductions due to FAW (Rice *et al.,* 1982) are caused by FAW feeding on the grain, anthers of the flower (Papel *et al.,* 1981), leaves and spikelets (Jung-Huang, 1998). Damage is achieved through defoliation, plant stand reduction, reduced panicle density, reduced kernel weight, reduced biological weight and all yield components which results into reduced grain yield (Harris *et al.,* 2015). FAW feeding damage depends on the plant density, larvae density per plant and the climatic conditions enhancing infestation of fall armyworm as well as presence of bio-control agents. FAW larvae whorl damage is always higher at 14 days of infestation because at 14 days, the larvae have reached development stage at which feeding damage is much higher (Harris *et al.,* 2015). Reduced plant height by FAW is due to reduced regrowth after heavy defoliation (Capinera and Roitech, 1980), while yield reduction is associated with reduced plant stands, reduced panicle size and weight (Harris *et al.,* 2015).

2.5 Management of fall army worm

Integrated fall armyworm management is an ideal control strategy that involves insect monitoring and forecasting, cultural practices, chemical control, biological control and legal approaches (FAO, 2017).

2.5.1 Monitoring and forecasting

Monitoring is meant to quickly track the presence or absence of FAW, their population, and their movement within a specified field (FAO, 2017). Monitoring typically relies on scouting and pheromone traps (Plates 2.9 and 2.10). Scouting consists of visual inspection of the crop to assess the damage level of the crop and the presence or abundance of the pest in an area (CABI, 2017). According to CABI (2017), a commonly used scheme is to examine twenty consecutive plants from five different sites in the farm where the following is recorded: plant growth stage, number of plants showing the damage symptoms, egg masses and number of larvae per plants. Threshold level that warrants the insecticide application is when 20% damage is observed in the field. Pheromone traps are erected near the fields to attract and trap FAW adult male moths and the numbers are counted, recorded, and used for appropriate action (typically reporting)**.** Sex and aggregation pheromones are the most common types of pheromones in use (FAO, 2017). Leaves and whorls of plants are regularly monitored for the availability of larvae and the damage caused to plants, egg masses and larval migration among the crops. The recommended pheromone traps are the Universal Bucket Trap for smallholder farms and the *Heliothis*-style Pheromone Trap for regional monitoring (FAO, 2017).


R. Meagher– USDA-ARS

Plate 2.8: Universal Bucket Trap

Plate 2.9: *Heliothis*-style Pheromone Trap

2.5.2 Cultural control

Cultural control and mechanical management techniques have proven effective for control of fall army worm (FAO, 2017). Small-scale farmers in America and Africa hand-pick and destroy FAW larvae by applying mud into the whorl to inoculate larvae with soil inhabiting pathogens (Andrew, 1988). Early planting also avoids FAW damage, while fertilization is to stimulate plant recovery ability in order to compensate for plant damage (Altieri, 1980). Mechanical approaches equally work in circumstances where other control practices prove hard. In US for instance, small-scale famers always pay regular field visits, search for egg masses and young larvae from underside the leaves and funnels of plants, collect and crush them during heavy oviposition (FAO, 2017). Uses of ash, sand, sawdust or dirt have given significant success too in controlling FAW larvae (CABI, 2018). These substances (ash, sand, sawdust) are placed into the whorl to control FAW larvae, since sand contains entomopathogenic nematodes, nucleopolyhedrosis virus (NPV) and bacteria such as Bacillus spp (FAO, 2017). Use of alkaline substances obtained from lime, salt, oil and soap have yielded successes in some parts of West Africa (FAO, 2017). In certain cases, botanicals including neem and hot pepper, also yield success against FAW larvae. Pouring water into the whorl also drown the FAW larvae (FAO, 2017).

2.5.3 Chemical control

FAW has shown resistance to commonly used insecticides including synthetic pyrethroid (Bowling, 1978). Therefore, severe infestation by FAW can be controlled by multiple insecticide applications (Bowling, 1978). Seed treatment prevents early damage of the seedlings after emergence and helps plants establish vigor required to resist fall armyworm infestation (FAO, 2017). In Southern Africa, there are few broad spectrum insecticides that have shown efficacy in the management of fall armyworm at seedling, vegetative and anthesis stages of plant growth and development (FAO, 2017). According to Cosette (2014), Thiamethoxam (Apron Star), Imidacloprid (Gaucho) and Lindane (Murtano Super) have good efficacy on many below ground soil pests and the insect pests that attack cereals, vegetables, pulses and fruits. These seed dressers have been recommended, especially for seed treatment for the management of fall armyworm by Food and Agriculture Organization of the United Nations (FAO, 2017). However, their efficacy against fall armyworm has not yet been studied in E. Africa, therefore, it is necessary to evaluate their efficiency for informed management of fall armyworm in Eastern Africa.

Imidacloprid (Gaucho) is a broad spectrum contact insecticide (MoA, 2017) and it is effective at higher rates (0.4 l ha^{-1}) against fall armyworm (FAO, 2017). In South Africa for example, farmers have reported its efficacy in controlling fall armyworm at crop seedling stage when used as a seed dresser (FAO, 2017). Similarly, Imidacloprid is an effective insecticide for treatment of seeds that could be used for studies in controlled environment such as in the greenhouse (FAO, 2017). Thiamethoxam (Apron Star) is a broad spectrum and preventive insecticide (Cosette (2014). It is recommended by FAO for seed dressing and seedling treatments but the degree of its efficacy, control spectrum and impact on larvae feeding has not been quantified (FAO, 2017).

In South Africa, Thiamethoxam has shown its effectiveness when used in high rates in the management of fall armyworm (Cosette, 2014). It is also recommended that effective management at seedling stage should factor-in proper agronomic practices including early and timely planting (FAO, 2017). Lindane (Murtano) is an organochloride insecticide and fumigant used on many soil-inhabiting and plant-eating insects (IPCS, 1991). The use of Lindane has been restricted but can be applied only by certified pesticide applicators primarily for seed treatment against below-ground insect pests (IPCS, 1991).

Carbofuran (Furaha) is a broad spectrum insecticide used in control of several important pests of sorghum (Kishore, 1984). It can be applied as granule or in liquid form. Carbofuran is very effective in the management of fall armyworm (Khan, 1983). However, its efficacy is more pronounced in the rice-strain compared to the corn-strain (Adamczyk *et al.,* 1999). Carbofuran is used for seed dressing, dusted in furrows during sowing and applied at vegetative stage of sorghum growth and development (Kishore, 1984). Carbofuran (2, 3-dihydro-2, 2-dimethyl-7-benzofuranyl-N-methylcarbamate) also known as Furadan is a widely used systemic and contact insecticide, acaricide and nematicide with a broad spectrum activity against many agricultural pests (Otieno *et al.,* 2010). The insecticide has been reported to have a relatively high mammalian toxicity (oral LD_{50} 8-11mg/kg in rats) and very toxic to invertebrates, fish and birds and must therefore, be handled cautiously to avoid environmental contamination and incidental exposure (Mineau, 2001). It has been used globally for the control of various pests such as green leafhoppers, brown planthoppers, stem borers and whorl maggots in crops like sugar cane, maize, rice, sugar beet and coffee (Otieno *et al.,* 2010). In respect to its high acute toxicity and threats to birds and animals, its use has been restricted or banned in USA, Canada and EU (Otieno *et al.,* 2010). However, Furadan is still used in Kenya, especially for seed dressing at the rate of 0.5-4kg/ha for the control of soil-dwelling and foliar-feeding insects (Otieno, 2009). According to Pest Control Products Board of Kenya (PCPB), the national pesticide regulating authority in the country has allowed into the country Carbofuran with up to 10% active ingredient (a.i.) for restrictive use, only by informed users (Otieno *et al.,* 2010).

2.5.4 Integrated Pest Management (IPM)

This is an ecosystem approach to crop production and protection that combines different management strategies and practices to grow healthy crops and minimize the use of pesticides (FAO, 2017). A number of elements of IPM in the eastern African context involve habitat management (Gurr *et al.,* 2004). The crop habitat or agro-ecosystem is managed to reduce insect pests' damage even though it involves a variety of mechanisms, but often by the encouragement of natural enemies. Intercropping, mixed cropping, crop rotation and trap crop planting, companion crops and agroforestry are all considered as habitat management that can be used to reduce FAW infestation (CABI, 2017).

2.5.5 Regulatory control

Quarantine or eradication program directed by governmental agencies according to federal and state ideas are used to prevent the introduction and spread of insect pests of economic importance (CABI, 2017). Quarantine is a legal approach of pest prevention design to avoid entry of pests (Pupae in case of FAW) into pest free areas (FAO, 2017). Regulatory agencies monitor all ports of entry into the country-in order to prevent unwanted entry of pests of economic importance (FAO, 2017). Quarantine also prevents movement of restricted pests within states such as nursery stocks, plant seedlings and budding and grafting materials as per the provisions of quarantine laws (CABI, 2018). Eradication refers to the elimination of pests from designated areas by use of area-wide sprays, rearing and releasing natural enemies and intensive monitoring for pests within and around the borders of the infested areas (FAO, 2017).

2.5.6 Biological control

Several many natural enemies such as wasps, predators (lady bird beetles), and pathogens reduce the population of fall armyworms. The egg parasitoid *Telenomus remus* is introduced to check fall armyworm and other *Spodoptera spp*. Species of *Cortesia* (*vestalis* ,Haliday and *sesamia*e, Cameron), endoparasitoids that parasitize on insect pests have been used to control diamond back moth (DBM) and stem borers (Amalina *et al.*, 2016), could also be used to control FAW. The uses of entomopathogens, like viruses, bacteria, and fungi have been reported to be effective against FAW (CABI, 2017). Bio-pesticides: effective Bio-pesticides against FAW include pheromones and semiochemicals (synthetic analogues of hormonal substances secreted by plants, animals and microbial pesticides such as solution of bacteria, virus, algae, fungi and protozoa) (FAO, 2017). A "Push-Pull'' method can also be employed, in which the pest-repellent (Napier grass) plants are intercropped with the main crop to repel (push) pests out of the crop plants (Midega *et al.*,2017). The field is also surrounded by a border of a pest-attractive (Desmodium grass) plant species to pull both the pests and the natural enemies into it (Feed the Future, 2017).

2.6 Genetic variation

Varietal resistance to FAW larvae and female adult oviposition is achieved through development of resistant varieties through exploitation of genetic variability and introduction of exotic resistant elite' lines (Soejitno and Vreden, 1976). Manipulation of plant diversity within cropping systems reduces FAW, incidence, severity and damage (Andrew, 1988). Differences in resistance levels can be detected through percentage damaged panicle (Dar, 1979), yield losses (Pophali *et al.*, 1980) and whorl damage (Bowling 1978). Plant resistance to FAW is through insect repulsion or non-preference (Pophali *et al.*, 1980) attributed to plant morphological and growing characteristics.

2.7 Host plant resistance (HPR)

Host plant resistance for FAW has been reported in several crop species including pearl millet (Leuck *et al.*, 1972), Sorghum (Wiseman and Gourley, 1982) and Bermuda grass (Combraw and Valerio, 1980). FAW causes plant injury by causing abnormal tissue function and metabolism which create irreversible physical and chemical changes in susceptible genotypes (Huang *et al.*, 2013). Plants have developed self-defense and insect-pest-induced defense mechanisms called host-resistance to enhance survival in response (Huang *et al.*, 2013). Host plant resistance alters plant-insect pest relationship and could be due to antibiosis, antixenosis and tolerance (Luginbill, 1928).

2.8 Antibiosis

Antibiosis is a plant heritable quality that adversely affects the life history, growth and development of insect pests (Panda and Khush, 1995). Antibiosis uses the resistant plant to affect insects need for food, oviposition and shelter (FAO, 2017). Antibiosis increases mortality, prolonged development and fecundity (CABI, 2017). Previous research findings indicate that resistance to fall armyworm in sorghum can be achieved through higher genotypic level of lignins (Wiseman and Gourley, 1962), tannins (Diawara *et al.*, 1991) and leaf nitrogen content (Teetes *et al.*, 1975). All these components of resistance form the basis of antibiosis. The effectiveness of antibiosis is based on its impact on FAW biology resulting into reduced FAW abundance and damage to crop (Bowling, 1978). Antibiosis expressed at vegetative stages of sorghum growth is due to nitrogen, acid fiber, neutral fiber, chemical non-preference and tannins. However, this resistance is referred to as whorl feeding resistance (Luginbill, 1928). Antibiosis expressed at panicle phase of sorghum growth is referred to as panicle feeding resistance and is due to higher levels of tannins on the spikelet (Diawara *et al.,* 1991). Total nitrogen concentration kills fall armyworm at various stages of larval development due to the presence of all defensive amino acids in the nitrogen chain while the acid detergent fiber and neutral detergent fiber lethality on fall armyworm is due to their indigestibility and subsequent interference with larvae protein utilization (Diawara *et al.*, 1991). Tannins kill FAW because of their polyphenols that form insoluble complexes with protein. Previous research findings have also showed a correlation between susceptibility to FAW and low lignin content in sorghum panicle which is an indication that higher level of lignin in sorghum genotypes subdues FAW infestation (Teetes *et al.,* 1975; Harris *et al.,* 2015).

2.9 Antixenosis (non-preference)

Antixenosis is a plant-resistant property that allows insect to disregard plants as bad host (FAO, 2017) and comprises of all plant responses that denote the absence of insect desired characteristics to serve as potential hosts (War *et al.,* 2012). Such characteristics range from negative reactions to total avoidance during search for feeding, oviposition and shelter (Owens, 1975). Antixenosis is expressed as absolute or relative (Owens, 1975). Relative antixenosis entails the insect pest feeding on multiple choices while absolute antixenosis ensures the insect pest feeds, oviposits and establishes its feeding process on a single plant species (FAO, 2017).

2.10 Tolerance

Tolerance (recovery resistance) is defined as the plant’s ability to tolerate, resist and recovers from insect pest damage (FAO, 2017). Tolerant plant genotypes do grow, reproduce, repair injury and recover from damage in the presence of the insect population. To identify tolerant cultivars among susceptible ones, tolerance cultivars are characterized by lower percentage damage on panicle (Dar, 1979); less yield losses (Pophali *et al.,* 1980) and mild whorl damage (Bowling, 1978). Under heavy pest infestation, after the central shoot is killed, plants do tiller is a potential form of recovery resistance (Dogget, 1972). Seedling vigor and high rate of recovery are said to be vital characteristics of resistant varieties (Sharma *et al.,* 1985). Host plant tolerance can be constitutive or inducible (FAO, 2017). Constitutive defenses include physical and chemical barriers or traits that are formed regardless of the presence of insect pest. Examples include; thorns and cuticles that prevent insect attacks, while inducible defenses involve plants producing defense compounds such as resins, lignins, and wax which alter plant tissue in a way that discourages insect pests. Phenolic acids are also shown to have some effects on whorl feeding insects. Constitutive and inducible defenses differ in that constitutive defenses are expressed before insect attacks while inducible defenses are activated only after plant is attacked by insect pests (FAO, 2017).

2.11 Methods of screening sorghum varieties for resistance to fall army worm

Defendable and reputable techniques have been developed for any phase of plant resistance program to make regular progress (Wiseman *et al.,* 1980). The techniques must be simple, efficient, and accurate (Guthrie, 1980). The methods that are developed should produce maximum difference between the resistant and susceptible varieties (Wiseman *et al.,* 1986**).**

2.11.1 Seedling stage screening (Greenhouse screening)

Infesting sorghum seedlings sown in the greenhouse proved to be an efficient method to identify sources of resistance (Harris *et al.,* 2015). Wilde and Apostol (1983) developed greenhouse technique that involves infesting plants with first instar larvae dispersed with Davis innocular (Davis and Oswalt, 1969). Similarly, screening can be done in the greenhouse or in the field as greenhouse techniques have been used to detect resistance to sorghum seedlings against *S. frugiperda* (Wilde and Apostol, 1983). 10-20 FAW larvae are inoculated onto crop funnels after two weeks of emergence in the morning mechanically by camel hair (Wiseman *et al.,* 1966). FAW leaf feeding damage is visually rated and recorded after 2 weeks of infestation on the damaged plants and scoring is done by using the scale of 1-9. With 1 being highly resistant and 9 being highly susceptible due to FAW damage as described by Davis and Williams (1992). Number of larvae per plant is counted through destructive sampling at different growth stages, 2 weeks after infestation in each plot and the mean percentage recorded as described by FAO (2017).

2.11.2 Whorl stage screening (Field screening)

Whorl stage screening for plant resistant to fall armyworm is achieved by visual ratings that is made in 10 and 14 days after infestation (Wiseman *et al.,* 1966). Evaluation of treatments for panicle stage resistance is made directly in the field after flowering and seed setting (Sparks, 1979). Treatments under test are planted in the greenhouse (Wiseman, 1966) using clean sand soils collected from the river in rows measuring 30cm x 28cm x 20cm respectively (Wiseman *et al.,* 1966). Treatments are visually scored for damage on the scale of 1 to 9, with 1 being highly resistant and 9 being highly susceptible due to FAW damage as described by Davis and Williams

(1992). Damage is always visually observed at 4 days after inoculation (Wiseman, 1966). Second scoring can be made in the succeeding days to detect treatments that have outperformed the check variety for resistance (Wiseman *et al.*, 1966).

2.11.3 Panicle stage screening

FAW neonates are mixed in sorghum-head grills. They are infested into the developing panicle at the pre-flower stage to evaluate for resistance in the panicle stage. Neonates are dispensed at the rate of about 10-20 neonates per panicle and about 10 to 15 panicles per plot are infested. Paper pollinating bags are used to cover panicle to protect neonates from contamination by other insect species and to prevent adverse environmental effects that may reduce the infestations. Infested and un-infested rows are used to compare the yield recorded. Visual observation on the panicle damage is recorded after 2 weeks of anthesis. Panicle damage is scored from the scale of 1-9. With 1 being highly resistant and 9 being highly susceptible (Davis *et al.*, 1992).

CHAPTER THREE

EVALUATION OF SEED DRESSERS IN THE MANAGEMENT OF FALL ARMY WORM INFESTING SORGHUM VARIETIES UNDER FIELD CONDITIONS

Abstract

Sorghum is a food security crop for millions of people in E. Africa but its productivity is challenged by FAW infestation. This study was undertaken to evaluate the efficacy of four seed dressers that included; Thiamethoxam, Imidacloprid, Lindane and Carbofuran in the management of FAW under field conditions. The experiments were laid out in a randomized complete block design in a factorial arrangement in 3 replications. The data collected included; dead heart, leaf feeding damage, number of larvae per plant and days to 50% flowering, panicle damage symptoms, plant height, number of panicles harvested and grain weight. Lindane (4) recorded the lowest dead heart symptoms compared to untreated controls (6.2). All seed dressers compared to untreated controls, recorded less leaf feeding damage. However, Lindane (9) was the most effective among the seed dressers on the leaf feeding damage. Seed dressers varied for the number of days to 50% flowering. Imidacloprid (147 days) showed earliness at Alupe, while Thiamethoxam (125 days) showed earliness at Kiboko. Lindane (3.3 larvae) and Thiamethoxam (3.9 larvae) recorded a lower number of FAW larvae per plant compared to other seed dressers and untreated controls. Lindane (5.5) was the most effective seed dresser compared to other seed dressers and untreated controls (7.4) on FAW panicle damage symptoms. Lindane (295cm), Carbofuran (296cm) and Thiamethoxam (296cm) recorded shorter plant heights compared to other seed dressers and untreated controls. Carbofuran (2.34g) recorded the highest grain weight per plot compared to other seed dressers and untreated controls. Seed dressing of sorghum seeds has the potential to protect sorghum growth from early FAW infestation leading to better yields.

3.1 Introduction

Sorghum is tolerant to harsh environmental conditions; however, its production is negatively impacted by insect pests (Guo *et al.,* 2011). One of these insect pests that impacts sorghum production is the fall armyworm (*Spodoptera frugiperda*). Fall armyworm (FAW) is a serious pest of sorghum that may constraint on-farm yields of sorghum in Eastern Africa (FAO, 2017). Unlike African armyworm, FAW is hard to control due to several reasons; it is easily dispersed by wind, burrows inside sorghum funnels and compacted panicles, making it difficult to quickly detect and lays six generations in one season which may lead to a serious yield loss (USDA, 2017). The high yield loss is attributed to foliage damage at whorl stage where whorl-feeding leads to reduced plant growth, delayed physiological maturity, increased tillering, reduced panicle size (Sparks, 1979) and at panicle phase where panicle and flag leaf feeding leads to reduced net photosynthates, and assimilates, leading to reduced grain yield (Andrew, 1988). One of the IPM control methods in managing FAW is seed treatment or seed dressing. Seed treatment is done by covering seeds surface with the recommended pesticides or fungicides, which can be powder or water soluble before sowing. Seed dressing ensures seed protection during emergence and plant health at the start of growth and development. ICRISAT (2017) reported that, seed treatment can protect the seedlings from below ground and above ground pests up to 40 days and improves crop density. In comparison to foliar application, Taylor *et al.* (2001) reported that seed dressing can reduce environmental contamination as it decreases the amount of active ingredients applied and also reduces the risk of exposure to the applicator. Therefore, screening of different seed dressers in Eastern Africa is essential to identify effective ones for control of fall armyworm in sorghum. The aim of this study was therefore, to determine the efficacy of selected seed dressers under field conditions for the control of fall armyworm in sorghum varieties.

3.2 Materials and methods

3.2.1 Description of the research locations

KALRO/ICRISAT KIBOKO: the research center is situated at Kiboko in Makindu Sub-County of Makueni County, about 169 km south east of Nairobi, along Mombasa-Nairobi Highway. According to Jaetzold and Schmidt (1982), the center lies between latitude 2° 20' and 2° S and longitude 37° 40' and 37° 55' E, with 960m above sea level (a.s.l). It is located in the dry lowland agro-ecological zone of Eastern Kenya and experiences average daily minimum temperatures of 16.6° with the maximum of 29.4° and with February and October being the hottest months of the year. The area receives an average annual rainfall of approximately 604 mm and has well-drained soils and a soil pH of 7.9 as reported by Jaetzold and Schmidt (1982) and KARI (2007).

KALRO/ICRISAT ALUPE: The Centre is located 9 km from Busia town along the Busia-Malaba road at latitude 0º 29′ 50′ N and longitude 34˚ 7′ 31′ E with an altitude 1,010m above sea level (KARI, 2007). The center lies in the humid lower midland agro-ecological zone. Jaezold *et al.* (2006) classified the soil compositions in this area as 47.57% sand, 35.76% silt/loam and 16.67% clay.

3.2.2 Seed dressers with active ingredients

The following seed dressers were used in the experiments (Table 3.1)

Table 3.1: Seed dressers used in the experiments

Active ingredient	Dose/ha	Dose used
5% Imidacloprid	350g/L	1ml/g seed
20%Thiamethoxam	200g/100kg	1.25g/g
26%Lindane	10g/2kg	2.5g/g
10% Carbofuran	300ml/100kg	3ml/g

3.2.3 Experimental treatments

The following treatment combinations in Table 3.2 were used in the experiments

Table 3.2: **Treatment combinations with sorghum varieties**

Code	Treatment	Dose used	Vol. of water	Amount of seeds (kg)
T0-SCo	**Seredo+Control**	**0**	**0**	**0.5**
T1-ST	Seredo+Thiamethoxam	1.25g	2.5ml	0.5
T2-SI	Seredo+Imidacloprid	1ml	1.5ml	0.5
T3-SL	Seredo+Lindane	2.5g	3ml	0.5
T4-SC	Seredo+Carbofuran	3ml	-	0.5
T0-24Co	**IESV24029SH+Control**	**0**	**0**	**0.5**
T1-24T	IESV24029SH+ Thiamethoxam	1.25g	2.5ml	0.5
T2-24I	IESV24029SH+ Imidacloprid	1ml	1.5ml	0.5
T3-24L	IESV24029SH+ Lindane	2.5g	3ml	0.5
T4-24C	IESV24029SH+ Carbofuran	3ml	-	0.5
T0-KM1Co	**KARI Mtama1+Control**	**0**	**0**	**0.5**
T1-KM1T	KARI Mtama 1+Thiamethoxam	1.25g	2.5ml	0.5
T2-KM1I	KARI Mtama 1+Imidacloprid	1ml	1.5ml	0.5
T3-KM1L	KARI Mtama 1+Lindane	2.5g	3ml	0.5
T4-KM1C	KARI Mtama 1+Carbofuran	3ml	-	0.5
T0-GHCo	**Gadam hamam+control**	**0**	**0**	**0.5**
T1-GHT	Gadam hamam+Thiamethoxam	1.25g	2.5ml	0.5
T2-GHI	Gadam hamam+Imidacloprid	1ml	1.5ml	0.5
T3-GHL	Gadam hamam+Lindane	2.5g	3ml	0.5
T4-GHC	Gadam hamam+Carbofuran	3ml	-	0.5
T0-WCo	**Wagita+Control**	**0**	**0**	**0.5**
T1-WT	Wagita+Thiamethoxam	1.25g	2.5ml	0.5
T2-WI	Wagita+Imidacloprid	1ml	1.5ml	0.5
T3-WL	Wagita+Lindane	2.5g	3ml	0.5
T4-WC	Wagita+Carbofuran	3ml	-	0.5
T0-NCo	**Nakhadabo+Control**	**0**	**0**	**0.5**
T1-NT	Nakhadabo+Thiamethoxam	1.25g	2.5ml	0.5
T2-NI	Nakhadabo+Imidacloprid	1ml	1.5ml	0.5
T3-NL	Nakhadabo+Lindane	2.5g	3ml	0.5
T4-NC	Nakhadabo+Carbofuran	3ml	-	0.5

3.2.4 Experimental design and field operations

To evaluate the efficacy of different pesticides as seed dressers against fall armyworm damage, four seed dressers were evaluated on six sorghum varieties (5 released and 1 local) using a randomized complete block design (RCBD) in a factorial arrangement in three replications (6x5x3). Each replication comprised of 30 plots. The thirty plots were allocated the different combinations of varieties treated with seed dressers. Untreated control was included for comparison. Land for experiments was cleared of the previous crop stubbles and ploughed to a fine tilth and the final levelling by hand-hoes at Alupe while in Kiboko, a tractor was used to plough and harrow the plots and the final tilth and leveling done by hand-hoes. The experimental plots were measured and demarcated into experimental units measuring 4 rows of 3m length with inter-row and intra-row spacing of 75x20cm and 60x20cm for Kiboko and Alupe respectively. Four furrows were opened using hand-held openers in each plot, after which basal application of diammonium phosphate (DAP) fertilizer at the recommended rate of 60kg P_2O_5 /ha and 60kg N/ha was spread evenly in the furrows and mixed with the soil prior to planting. The seeds were dressed and left to dry on paper bags at room temperature for 24hrs prior to planting and sown in furrows at the depth of 2-5cm. Three weeks after crop emergence, the plots were thinned leaving 16 plants per 3m row. For easy movement and the separation of plots, a buffer zone of 1m wide was kept between plots. 45kg of Urea (46% N) were used to top dress the plots at two intervals, after two and four weeks of planting. The experiments were rain fed at Alupe while at Kiboko, supplementary irrigation was given. Weeding was done as soon as weeds appeared and monkeys and the birds were scared away at all stages till harvest.

3.2.5 Data collection

The following parameters were assessed and data collected to determine the efficacy of seed dressers in managing the fall armyworm infestation and damage:

1. A soil was taken from the field, cleaned and placed in a plastic pot measuring 60x40cm and a hundred seeds from each variety were planted. After emergence, the data on percentage seed emergence was taken by counting the number of plants that emerged over hundred seeds that were planted times hundred.
2. Plant stand was recorded from the 2 middle rows per plot soon after thinning in the fields.
3. Leaf feeding damage was visually rated and recorded after every 2 weeks in each plot on damaged plants after the occurrence of natural infestation and scored on a scale of 1-9, with 1 being highly resistant and 9 being highly susceptible (Table 3.3).

Table 3.3: FAW scoring scale

Rating	Damage description	Sorghum reaction
1	No visible damage on plant leaves	Highly resistant
2	Pinholes and small circular hole damage on plant leaves	Resistant
3	Pinholes, small circular lesions and a few elongated lesions on the whorls	Resistant
4	Several small to medium elongated lesions on a few whorls	Moderately resistant
5	Several large elongated lesions and a few uniform to irregular shaped holes eaten from the whorls/leaves	Moderately resistant
6	Several large elongated lesions on several leaves and whorls	Moderately resistant
7	Many elongated lesions of all sizes on several whorls and leaves	Susceptible
8	Many elongated lesions of all sizes on most whorls and leaves	Susceptible
9	Whorl leaf almost destroyed	Highly susceptible

Source: Modified from Davis and Williams (1992)

4. Dead-heart symptom by FAW was visually observed and taken soon after occurrence of natural infestation. The plant dead heart is not only caused by FAW but also by species of

stalk borers. FAW dead heart incidence was scored by opening the funnels of plants with dead hearts to identify larvae and the average number of the plants with dead heart symptoms was counted and recorded.

5. Number of larvae per plant was counted by destructive sampling at different growth stages, 2 weeks after emergence (WAE) by checking any plant exhibiting signs of damage on each plot and the number recorded at the following growth stages: seedling stage (0-2 WAE), early whorl stage (3-4 WAE), mid-whorl stage (5-6 WAE) and late whorl stage (7 WAE).
6. Days to 50% flowering: This was recorded from the 2 central rows when half of the plants had reached the flowering stage.
7. Visual observation on the panicle damage symptoms was recorded 2 weeks after anthesis on a score of (1-9).
8. Agronomic score. Rating of all agronomic attributes (grain potential, lodging resistance, maturity) was scored and recorded on a scale (1-5) (1= very good, 5= very poor) (USDA, 2014).
9. The height of ten plants in the two middle rows per plot was measured from the base to the tip of the plant at maturity.
10. Plant stands at harvest- The number of plants at harvest was counted and recorded.
11. Number of productive tillers-The number of productive tillers of each plot in the middle two rows were counted and recorded during harvest.
12. Number of panicles harvested. At harvest, the number of heads harvested was counted and recorded.

13. Panicle weight. The panicles from 2 middle rows were sun dried, weighed and recorded in grams.
14. Threshing percentage was recorded after drying, threshing and winnowing and calculated as: $\textbf{Threshing (\%)} = \frac{\textbf{Grain weight (g)}}{\textbf{Panicle weight (g)}}\ \boldsymbol{x}\ \mathbf{100}$
15. Yield per plot: grain yield per plot (kg) was calculated as grain weight = (plot yield kg/plot size in square meters.
16. Hundred seed mass. After harvest, drying and threshing, a hundred seeds were sampled and counted from each variety and weighed using a weighing balance at a recommended moisture content of 10-12% and the weight expressed in grams.

3.2.6 Data analysis

The data collected on each parameter at two locations for the efficacy of seed dressers were subjected to analysis of variance (ANOVA). The analysis was done to determine the efficacy of seed dressers against fall armyworm. Combined analysis of data was performed using GenStat 15th edition software (Payne *et al.,* 2015) and the means were separated by the least significant difference (L.S.D) at $P \leq 0.05$.

3.3 Results

Two experiments were conducted at Kiboko and Alupe field stations for two seasons to determine the efficacy of seed dressers against FAW sorghum damage. The results obtained over two seasons indicated that FAW incident was more severe in the first season compared to the second season across the sites.

3.4 Effect of seed dressers on FAW damage and on growth parameters of sorghum varieties at Kiboko for season 1 (2018/2019)

The tested seed dressers showed no significant effect on agronomic score, plant vigor, plant stands after thinning, number of larvae per plant, plant height and the number of tillers per plant. However, there were significant differences observed among the seed dressers for leaf feeding damage, plant vigour and days to 50% flowering. Seed dressers differed significantly with untreated control in the leaf feeding damage observed on sorghum affected by FAW, with Carbofuran scoring less leaf feeding damage. Seed dressers showed significant differences for plant vigor compared to untreated control. Lindane had higher plant vigor but did not significantly differ from the tested seed dressers and the untreated control. The seed dressers tested, exhibited variability and Thiamethoxam showed earliness compared to untreated control and Carbofuran but was similar in effect with Lindane and Imidacloprid. Seed dressers significantly differed with untreated control in the number of days it took for sorghum to flower (Table 3.4).

Table 3.4: Effect of seed dressers on FAW damage and on growth parameters of sorghum varieties at Kiboko for season 1 (2018/2019)

Seed dressers	Concentration	AGS (1-5)	PV (1-3)	PST (scored)	DFL (scored)	LFS (1-9)	NLPP (scored)	PH (cm)	NT (scored)
Control	0	2.22a	2.28ab	31.39a	69.11b	4.22b	1.17a	132.9a	12.39a
Thiamethoxam	1.25g	2.22a	2.39ab	31.61a	67.44a	3.78ab	1.22a	133.7a	13.28a
Imidacloprid	1ml	2.17a	2.11a	31.33a	67.78ab	3.72ab	1.17a	136.6a	12.44a
Lindane	2.5g	2.39a	2.44b	31.72a	68.67d	3.67a	1.06a	130.4a	14.72a
Carbofuran	3ml	2.28a	2.11a	31.11a	69.11b	3.61a	1.22a	134.6a	14.83a
	Mean	2.26	2.27	31.43	68.42	3.80	1.17	133.65	13.53
	CV%	2.3	5.1	0.5	1.5	15.2	9.9	2.6	9.3
	L.S.D (p≤0.05)	0.30	0.28	0.83	1.35	0.55	0.24	6.29	5.24

Key; AGS= agronomic score, PV=plant vigor, PST= plant stands at thinning, DFL= days to 50% flowering, LFS= leaf feeding score, NLPP= number of larvae per plant, PH= plant height and NT= number of tillers, mean within a column followed by same letter(s) are not significantly different (P≤0.05)

3.5 Effect of seed dressers on FAW damage and on yield parameters of sorghum varieties at Kiboko for season 1 (2018/2019)

The seed dressers tested showed no effect on threshing percentage. However, seed dressers exhibited variations for plant stand at harvest, number of panicles harvested, panicle damage symptoms, panicle weight and 100-seed mass. The tested seed dressers significantly differed on plant stand at harvest, with Lindane and Imidacloprid recording high plant stands at harvest compared to the tested seed dressers and untreated control (Table 3.5). Lindane recorded the highest number of panicles harvested, followed by Imidacloprid and Thiamethoxam compared to other seed dressers and the untreated control. All seed dressers were effective compared to untreated control in reducing panicle damage symptoms (Table 3.5). Seed treatment containing Thiamethoxam registered the lowest panicle damage symptoms, but it did not vary in effect with other tested seed dressers, while untreated control had the most panicle damage symptoms recorded. The seed dressers tested did not have any effect on panicle weight compared to untreated control except that which contained Imidacloprid. The highest panicle weight was in seed treatment containing Imidacloprid, while the lowest was in seed treatment containing Lindane. Like in panicle weight, the seed treatment containing Imidacloprid had a significantly higher grain weight and hundred seed mass (HSM) compared to the tested seed dressers and untreated control. The seed treatment with Imidacloprid had the highest grain weight, while the least was recorded in the seed treatment with Lindane. Again, the highest hundred seed mass was recorded in the seed treatment containing Imidacloprid, followed closely by that with Carbofuran (Table 3.5).

Table 3.5: Effect of seed dressers on FAW damage and on yield parameters of sorghum varieties at Kiboko for season 1 (2018/2019)

Seed dressers	Concentration	PSH (scored)	NPH (scored)	PDS (scored)	PWT (kg)	GWT (kg)	TH (g)	HSM (g)
Control	0	26.44a	39.50a	3.39c	0.87a	0.63a	1.41a	2.17ab
Thiamethoxam	1.25g	27.56ab	40.28c	2.50a	0.94ab	0.69a	1.38a	2.08a
Imidacloprid	1ml	28.33b	40.39c	2.56ab	1.11b	0.85a	1.32a	2.41c
Lindane	2.5g	28.61b	41.22b	2.78ab	0.79a	0.61a	1.41a	2.22b
Carbofuran	3ml	26.67ab	38.78a	2.72ab	0.98ab	0.67a	1.41a	2.31bc
	Mean	27.52	40.0	2.79	0.94	0.69	1.38	2.24
	CV%	3.2	7.0	20.9	9.8	5.1	6.1	13.6
	L.S.D (p≤0.05)	2.05	6.84	0.84	0.19	0.14	0.13	0.23

Key: PSH= plant stands at harvest; NPH= number of panicles harvested, PDS= panicle damage symptom, PWT= panicle weight, GWT= grain weight, TH%= threshing percentage and HSM= hundred seed mass, mean within a column followed by same letter(s) are not significantly different (P≤0.05)

3.6 Effect of seed dressers on FAW damage and on growth parameters of sorghum varieties at Kiboko for season 2 (2018/2019)

The tested seed dressers did not have effect on agronomic score, plant stand after thinning, dead heart and number of larvae per plant. However, there were significant differences observed among the seed dressers on percentage seed emergence, plant vigor, days to 50% flowering, leaf feeding damage, plant height and number of tillers per plant. Thiamethoxam recorded the highest percentage seed emergence followed by Lindane, while the rest of the tested seed dressers including the untreated control were not significant on percentage seed emergence. Seed treatment containing Carbofuran scored the lowest percentage seed emergence. There were variations among the seed dressers for plant vigor and all the seed dressers performed better than untreated control. The highest plant vigor was recorded in seed treatment containing Thiamethoxam but did not significantly differ from other seed dressers tested. Thiamethoxam showed earliness for days to 50% flowering, while untreated control recorded the latest. The tested seed dressers showed significant differences for leaf feeding damage, with Lindane recording the lowest leaf feeding score compared to untreated control. Treatments with seed dresser Lindane varied significantly from other tested seed dressers for the number of tillers, recording the highest tiller counts. Untreated control recorded the highest plant height compared to seed dressers (Table 3.6).

Table 3.6: Effect of seed dressers on FAW damage and on growth parameters of sorghum varieties at Kiboko for season 2 (2018/2019)

Seed dressers	Conc.	EMG% (scored)	AGS (1-5)	PV (1-3)	PST (scored)	DH (scored)	DFL (scored)	LFS (1-9)	NLPP (scored)	PH (cm)	NT (scored)
Control	0	86.39b	2.50a	1.67a	28.83a	6.17a	59.28ab	7.33a	2.52a	169.4b	14.1ab
Thiamethoxam	1.25g	91.39c	2.61a	2.11b	29.22a	7.06a	57.33a	6.36b	2.38a	167.2a	13.3ab
Imidacloprid	1ml	86.33b	2.28a	1.78ab	28.00a	8.06a	58.44a	6.33b	2.19a	164.7a	13.4ab
Lindane	2.5g	88.44d	2.39a	1.89ab	29.50a	6.56a	58.33a	5.28c	2.22a	164.8a	15.4b
Carbofuran	3ml	80.72a	2.33a	1.94ab	32.11a	7.17a	60.72b	6.58b	2.34a	161.7a	12.1a
	Mean	86.66	2.42	1.88	29.53	7.00	58.82	6.377	2.33	165.5	13.66
	CV%	1.1	2.1	5.7	0.6	10.6	1.1	1.5	11.1	5.3	13.2
	L.S.D	3.57	0.40	0.39	1.97	2.32	2.09	0.34	0.49	14.15	2.68

Key; EMG%= emergency percentage, AGS= agronomic score, PV=plant vigor, PST= plant stands at thinning, DH= dead heart, DFL= days to 50% flowering, LFS= leaf feeding score, NLPP= number of larvae per plant, PH= plant height and NT= number of tillers, mean within a column followed by same letter(s) are not significantly different (P≤0.05).

3.7 Effect of seed dressers on FAW damage and on yield parameters of sorghum varieties at Kiboko for season 2 (2018/2019)

The tested seed dressers had no effect on panicle weight, grain weight, threshing percentage and 100-seed mass. However, there were significant variations observed among the seed dressers for plant stand at harvest, number of tillers per plant and panicle damage symptoms. Seed treatment containing Thiamethoxam registered the highest plant stands after thinning, while the lowest was recorded in seed treatment containing Carbofuran and untreated control. There were significant differences observed among the seed dressers for the number of panicles harvested, with Lindane recording the highest, followed closely by Thiamethoxam, while the lowest was recorded in seed treatment containing Carbofuran, Imidacloprid and untreated control. The tested seed dressers significantly differed on panicle damage symptoms with Lindane recording the lowest compared to Carbofuran and untreated control, while Imidacloprid and Thiamethoxam did not significantly differ based on the panicle damage symptoms (Table 3.7).

Table 3.7: Effect of seed dressers on FAW damage and on yield parameters of sorghum varieties at Kiboko for season 2 (2018/2019)

Seed dressers	Concentration	PSH (scored)	NPH (scored)	PDS (scored)	PWT (kg)	GWT (kg)	TH% (g)	HSM (g)
Control	0	27.11ab	38.67ab	4.00c	1.96a	1.50a	1.31a	2.31a
Thiamethoxam	1.25g	30.56c	41.67bc	3.28b	1.97a	1.51a	1.33a	2.29a
Imidacloprid	1ml	28.17ab	39.61ab	3.17b	1.94a	1.49a	1.31a	2.33a
Lindane	2.5g	28.83bc	42.50c	2.72a	1.88a	1.43a	1.33a	2.51a
Carbofuran	3ml	26.39a	36.56a	3.61bc	1.82a	1.38a	1.36a	2.25a
	Mean	28.21	39.8	3.36	1.92	1.46	1.33	2.34
	CV%	1.9	6.3	10	6.2	6.5	1.5	25.3
	L.S.D (P≤0.05)	2.00	3.47	0.8	0.27	0.23	0.06	0.35

Key: PSH= plant stands at harvest; NPH= number of panicles harvested, PDS= panicle damage symptom, PWT= panicle weight, GWT= grain weight, TH%= threshing percentage and HSM= hundred seed mass, mean within a column followed by same letter(s) are not significantly different (P≤0.05)

3.8 Effect of seed dressers on FAW damage and on growth parameters of sorghum varieties at Alupe season 1 (2018/2019)

The tested seed dressers did not have significant effect on agronomic score, plant vigor, and number of tillers per plant. However, seed dressers exhibited significant differences on plant stand after thinning, days to 50% flowering, leaf feeding score, plant height and number of larvae per plant. Plant stand after thinning varied significantly with Imidacloprid exhibiting the best performance compared to the rest of the tested seed dressers including the untreated control. There was a significant reduction in days to 50% flowering, with Imidacloprid showing earliness compared to the rest of the tested seed dressers and untreated control. There were significant differences observed among the seed dressers on leaf feeding score, and all the seed dressers were significant compared to untreated control based on feeding score. Lindane and Thiamethoxam recorded a lower leaf feeding score compared to the rest of the seed dressers tested, while untreated control showed susceptibility by recording the highest leaf feeding score. There was variability among the seed dressers for the number of larvae per plant. Untreated control recorded the highest plant height compared to seed dressers. Thiamethoxam and Carbofuran recorded the lowest number of larvae per plant; however, the rest of the tested seed dressers including untreated control did not significantly differ for the number of larvae per plant (Table 3.8).

Table 3.8: Effect of seed dressers on FAW damage and on growth parameters of sorghum varieties at Alupe season 1 (2018/2019)

Seed dressers	Concentration	AGS	PV	PST	DFL	LFS	NLPP	PH	NT
Control	0	4.28a	2.50a	23.06a	73.61b	7.39c	1.44ab	143.5b	1.33a
Thiamethoxam	1.25g	4.56a	2.33a	23.67ab	73.17b	5.89a	1.17a	137.2a	1.22a
Imidacloprid	1ml	4.44a	2.22a	24.39b	71.22a	6.22b	1.50b	141.4a	1.22a
Lindane	2.5g	4.50a	2.22a	24.06ab	72.72ab	5.77a	1.44ab	141.9a	1.28a
Carbofuran	3ml	4.44a	2.39a	23.72ab	73.61b	6.28b	1.17a	141.2a	1.22a
	Mean	4.44	2.33	23.78	72.87	6.31	1.34	141.1	1.26
	CV%	8.3	6.5	2.5	0.8	3.2	11.7	10.4	8.1
	L.S.D (P≤0.05)	0.39	0.30	1.26	1.69	0.65	0.32	8.47	0.34

Key; AGS= agronomic score, PV=plant vigor, PST= plant stands at thinning, DFL= days to 50% flowering, LFS= leaf feeding score, NLPP= number of larvae per plant, PH= plant height and NT= number of tillers, mean within a column followed by same letter(s) are not significantly different (P≤0.05)

3.9 Effect of seed dressers on FAW damage and on yield parameters of sorghum varieties at Alupe for season 1 (2018/2019)

The tested seed dressers did not have effect on the number of panicles harvested, panicle damage symptoms, panicle weight, grain weight, threshing percentage and 100 seed mass. However, there were significant differences observed among the seed dressers for plant stand at harvest, perhaps due to a combination of insect pests, diseases and environmental factors. Imidacloprid and Lindane recorded the highest plant stand at harvest while the lowest plant stand was given by the rest of the seed dressers including untreated control (Table 3.9).

Table 3.9: Effect of seed dressers on FAW damage and on yield parameters of sorghum varieties at Alupe for season 1 (2018/2019)

Seed dressers	Concentration	PSH	NPH	PDS	PWT	GWT	TH%	HSM
Control	0	20.17a	9.78a	7.94a	0.12a	0.06a	2.17a	0.73a
Thiamethoxam	1.25g	20.83ab	9.17a	8.06a	0.11a	0.07a	1.74a	0.80a
Imidacloprid	1ml	22.11b	9.61a	8.06a	0.12a	0.06a	2.13a	0.77a
Lindane	2.5g	21.94b	10.44a	8.05a	0.16a	0.08a	2.26a	0.79a
Carbofuran	3ml	20.67ab	9.44a	8.17a	0.13a	0.08a	1.87a	0.81a
	Mean	21.14	9.69	8.06	0.13	0.07	2.03	0.78
	CV%	1.9	37	3.8	74.7	56.6	12.9	9.5
	L.S.D(P≤0.05)	1.71	2.75	0.7	0.05	0.03	0.53	0.17

Key: PSH= plant stands at harvest; NPH= number of panicle harvested, PDS= panicle damage symptom, PWT= panicle weight, GWT= grain weight, TH%= threshing percentage and HSM= hundred seed mass, mean within a column followed by same letter(s) are not significantly different (P≤0.05)

3.10 Effect of seed dressers on FAW damage and on growth parameters of sorghum varieties at Alupe for season 2 (Year 2018/2019)

The tested seed dressers did not have effect on agronomic score, plant vigor, dead heart symptoms and days to 50% flowering. However, there were significant differences observed among the seed dressers on percentage seed emergence, plant stand after thinning and leaf feeding, number of larvae per plant, plant height and number of tillers per plant. There were significant differences among the tested seed dressers on percentage seed emergence and the results ranged from 86.61-91.83%. Seed treatment containing Imidacloprid and Carbofuran showed significant effect by recording the highest percentage seed emergence, however, the lowest was recorded for untreated control (Table 3.10). In regard to plant stand after thinning, there were significant effects among the tested seed dressers. Imidacloprid, Lindane and Carbofuran did not differ on plant stands after thinning but were more effective compared to Thiamethioxam and untreated control. There were significant differences observed among the seed dressers for leaf feeding score and all the seed dressers performed better than the untreated control. Seed treatment containing Lindane recorded the lowest compared to the tested seed dressers, while untreated control recorded the highest leaf feeding score. There was variability among the seed dressers for the number of larvae per plant, with Lindane and Imidacloprid showing significant reduced number of larvae per plant compared to the tested seed dressers and the untreated control. All seed dressers exhibited significant differences on plant height, with Lindane exhibiting significant difference from Thiamethoxam and untreated control. The tested seed dressers showed significant differences for the number of tillers, with Imidacloprid recording the highest number of tillers compared to the tested seed dressers and untreated control (Table 3.10).

Table 3.10: Effect of seed dressers on FAW damage and on growth parameters of sorghum varieties at Alupe for season 2 (Year 2018/2019)

Seed dressers	Concentration	EMG%	AGS	PV	PST	DH	DFL	LFS	NLPP	PH	NT
Control	0	86.61a	2.39a	2.17a	28.89a	5.78a	78.83a	7.48c	3.09b	158.8a	8.33a
Thiamethoxam	1.25g	89.44ab	2.33a	2.00a	29.67a	4.72a	80.17a	6.62b	2.74a	159.1a	9.67ab
Imidacloprid	1ml	91.83c	2.44a	2.11a	33.00b	5.83a	76.00a	6.77b	2.58a	163.8ab	12.44b
Lindane	2.5g	89.22ab	2.44a	2.11a	32.67b	4.00a	81.17a	5.77a	2.29c	169.1b	10.78ab
Carbofuran	3m	91.72c	2.50a	2.17a	32.11b	4.33a	78.00a	6.81b	3.16b	161.4ab	9.17a
	Mean	89.77	2.42	2.11	31.27	4.93	78.83	6.69	2.77	162.4	10.08
	CV%	3.6	6.5	15.5	1.9	22.2	2.6	0.9	0.2	4.2	3.6
	L.S.D ($P\leq0.05$)	4.41	0.34	0.34	2.41	1.84	4.63	0.23	0.48	9.38	2.88

Key: EMG%= percentage seed emergency, AGS= agronomic score, PV=plant vigor, PST= plant stands after thinning, DH= dead heart, DFL= days to 50% flowering, LFS= leaf feeding score, NLPP= number of larvae per plant, PH= plant height and NT= number of tillers, mean within a column followed by same letter(s) are not significantly different ($P\leq0.05$)

3.11 Effect of seed dressers on FAW damage and on yield parameters of sorghum varieties at Alupe for season 2 (Year 2018/2019)

The seed dressers had no significant differences for panicle weight, grain weight and threshing percentage. However, there were significant differences among the seed dressers for plant stand at harvest, number of panicles harvested and panicle damage symptoms. Seed dressers varied among each other for plant stand at harvest, with the seed treatment containing Imidacloprid and Lindane recording the highest plant stands but did not significantly differ with Carbofuran compared to Thiamethoxam and untreated control. There was a significant variability among the tested seed dressers for the number of panicles harvested, with Imidacloprid recording the highest number of panicles harvested compared to untreated control. There were significant effects among the seed dressers on panicle damage symptoms, however, Lindane showed the significant performance than the rest of the tested seed dressers and untreated control (Table 3.11).

Table 3.11: Effect of seed dressers on FAW damage and on yield parameters of sorghum varieties at Alupe for season 2 (Year 2018/2019)

Seed dresser	Concentration	PSH	NPH	PDS	PWT	GWT	TH%	HSM
Control	0	20.89a	29.22a	5.50b	0.39a	0.34a	0.41a	1.23a
Thiamethoxam	1.25g	22.83ab	32.5ab	5.33b	0.42a	0.37a	0.40a	1.21a
Imidacloprid	1ml	25.83c	38.28c	5.17b	0.46a	0.38a	0.39a	1.18a
Lindane	2.5g	25.17c	35.94bc	4.28a	0.43a	0.35a	0.39a	1.21a
Carbofuran	3m	24.22bc	33.39ab	5.17b	0.41a	0.34a	0.40a	1.23a
	Mean	23.79	33.87	5.09	0.42	0.36	0.40	1.21
	CV%	1.9	2.3	10.9	8.3	3.9	10.4	49.5
	L.S.D (P≤0.05)	3.04	4.70	0.51	0.08	0.10	0.06	0.28

Key: PSH= plant stands at harvest; NPH= number of panicle harvested, PD= panicle damage symptom, PWT= panicle weight, GWT= grain weight, TH%= threshing percentage and HSM= hundred seed mass, mean within a column followed by same letter(s) are not significantly different (P≤0.05)

3.12 Effect of seed dressers on FAW damage and on growth parameters of sorghum varieties across the seasons and sites (2018/2019)

The tested seed dressers did not have effect on agronomic score and plant vigor, however, there were significant differences observed among the seed dressers across the sites for the rest of the parameters studied. Significant effects were observed among the tested seed dressers on percentage seed emergence across the sites, and the overall means ranged from 86.4 to 91.8%.

Overall means showed that the highest percentage seed emergence was recorded for Imidacloprid at Alupe but did not significantly differ with Carbofuran, while at Kiboko, the highest percentage seed emergence was recorded for Thiamethoxam. The tested seed dressers showed significant differences for plant stands after thinning and means showed that the average plant stands at Kiboko was higher than that at Alupe. There were significant differences among the tested seed dressers for dead heart symptoms, with the seed treatment containing Lindane recording the lowest compared to the rest of the tested seed dressers and untreated control. The tested seed dressers showed a significant variability for days to 50% flowering, with earliness at Kiboko and later at Alupe. Earliness varied significantly across the sites with Imidacloprid showing earliness at Alupe, while Thiamethoxam recorded earliness at Kiboko but did not significantly differ from Imidacloprid (Table 3.12). The tested seed dressers showed significant differences across the seasons and sites for leaf feeding damage, with all the seed dressers exhibiting effectiveness to leaf feeding damage compared to untreated control. The seed treatment containing Lindane and Thiamethoxam recorded the lowest leaf feeding damage compared to the rest of the tested seed dressers and untreated control across the seasons and sites. Significant effects were observed among the tested seed dressers for the number of larvae per plant, and the means showed that Kiboko had the lowest number of larvae per plant across the seasons, while Alupe had the highest number of larvae per plant. The tested seed dressers showed significant differences on plant height, and the effect of FAW damage on plant height was more pronounced at Alupe than at Kiboko. There were significant differences observed among the tested seed dressers across the seasons and sites on the number of tillers, with a higher tillering counts recorded at Kiboko compared to Alupe (Table 3.12).

Table 3.12: Effect of seed dressers on FAW damage and on growth parameters of sorghum varieties across the seasons and sites (2018/2019)

	Alupe											**Kiboko**									
Seed dresser	**Conc.**	**EMG%**	**AGS**	**PV**	**PST**	**DH**	**DFL**	**LFS**	**NLPP**	**PH**	**NT**	**EMG%**	**AGS**	**PV**	**PST**	**DH**	**DFL**	**LFS**	**NLPP**	**PH**	**NT**
Control	0	86.6a	6.67a	4.67a	52.0c	5.8a	152a	14.9a	4.5a	302a	9.7a	86.4b	4.72a	4.0a	63a	6.2a	128a	11.6a	3.7a	302a	27a
Thiamethoxam	1.25g	89.4ab	6.89a	4.33a	53.3a	4.7b	153a	12.5b	3.9ab	296b	10.9b	91.4c	4.83a	4.5a	60b	7.1b	125b	10.1b	3.6a	301a	27a
Imidacloprid	1ml	91.8b	6.88a	4.33a	56.7b	5.8a	147b	13.0ab	4.1a	311c	13.7c	86.3b	4.78a	3.9a	59c	8.1c	126b	10.1b	3.4a	301a	26a
Lindane	2.5g	89.2ab	6.94a	4.33a	57.4b	4.0b	154ab	11.6b	3.7ab	305a	12.1c	88.4bc	4.45a	4.3a	61b	6.6a	127a	9.0c	3.3a	295b	30b
Carbofuran	3ml	91.7b	6.94a	4.56a	55.8a	4.3b	152a	13.1ab	4.3a	303a	10.4b	80.7a	4.61a	4.1a	61b	7.2b	130c	10.2b	3.6a	296b	27a
	Mean	**89.7**	**6.8**	**4.43**	**55.5**	**4.9**	**152**	**13.2**	**4.07**	**303**	**11.3**	**86.6**	**4.66**	**4.07**	**60**	**7**	**126**	**10.2**	**3.5**	**299**	**27**
	CV%	**3.6**	**6.5**	**15.5**	**1.9**	**22.2**	**2.6**	**0.9**	**0.2**	**4.2**	**3.6**	**1.1**	**2.1**	**5.7**	**0.6**	**10.6**	**1.1**	**1.5**	**11.1**	**5.3**	**13.2**
	LSD	**4.4**	**0.3**	**0.3**	**2.4**	**1.8**	**4.6**	**0.2**	**0.4**	**9.4**	**2.9**	**3.6**	**0.4**	**0.4**	**2.0**	**2.3**	**2.1**	**0.3**	**0.5**	**14.2**	**2.7**

Key: EMG%= percentage seed emergence, AGS= agronomic score, PV= plant vigour, PST= plant stand after thinning, DH= dead heart, LFS= leaf feeding score, NLPP= number of larvae per plant, PH= plant height and NT= number of tillers, CV%= coefficient of variance and LSD= least significant difference at 5%

3.13 Effect of seed dressers on FAW damage and on yield parameters of sorghum varieties across the seasons and sites (2018/2019)

The seed dressers showed significant differences on plant stand at harvest, number of panicles harvested, panicle damage symptom and panicle weight, however, no significant differences were observed on the rest of the parameters studied. The tested seed dressers showed significant differences on plant stand at harvest, and the highest plant stands at harvest across the seasons and sites was recorded at Kiboko compared to Alupe. Seed treatment containing Thiamethoxam recorded the highest plant stands at Kiboko, while Imidacloprid recorded the highest at Alupe. There was a significant variability among the seed dressers on the number of panicles harvested across the seasons and sites, with Lindane recording significant performances at Kiboko, while Thiamethoxam recorded the lowest number of panicles harvested at Alupe across the seasons and sites. Significant differences were observed among the tested seed dressers on panicle damage symptoms. At Kiboko, all the seed dressers recorded the lowest panicle damage symptoms, though they did not greatly differ from each other compared to untreated control. However, at Alupe there was no significant effect on panicle damage symptoms. Significant differences were observed among the seed dressers across the seasons and sites for panicle weight at Kiboko while Alupe showed no effect. Imidacloprid recorded the highest panicle weight at Kiboko compared to the rest of the tested seed dressers and untreated control (Table 3.13).

Table 3.13: Effect of seed dressers on FAW damage and on yield parameters of sorghum varieties across the seasons and sites (2018/2019)

	Alupe								Kiboko						
Seed dresser	**Conc.**	**PSH**	**NPH**	**PDS**	**PWT**	**GWT**	**TH%**	**HSM**	**PSH**	**NPH**	**PDS**	**PWT**	**GWT**	**TH%**	**HSM**
Control	0	41.0a	39.0a	13.0a	0.5a	0.43a	2.6a	2.47a	54.0a	80.0a	7.4a	2.8a	2.19a	2.7a	4.5a
Thiamethoxam	1.25g	44.0b	48.0b	13.0a	0.5a	0.39a	2.1a	2.41a	58.0b	81.0a	5.8b	2.9a	2.13a	2.7a	4.4a
Imidacloprid	1ml	48.0c	45.0bc	13.0a	0.6a	0.43a	2.5a	2.36a	57.0b	82.0a	5.7b	3.0b	2.04a	2.6a	4.7a
Lindane	2.5g	47.0c	45.0bc	12.0a	0.6a	0.43a	2.7a	2.41a	57.0b	84.0b	5.5b	2.7a	2.05a	2.8a	4.7a
Carbofuran	3ml	45.0b	42.0c	13.0a	0.5a	0.44a	2.3a	2.45a	53.0c	78.0c	6.3c	2.8a	2.34a	2.7a	4.6a
	Mean	**45.0**	**44.0**	**13.0**	**0.5**	**0.42**	**2.4**	**2.4**	**55.0**	**80.0**	**5.9**	**2.9**	**2.15**	**2.7**	**4.6**
	CV%	**1.9**	**2.3**	**10.9**	**8.3**	**3.9**	**10.4**	**2.6**	**1.9**	**6.3**	**10.0**	**6.2**	**6.5**	**1.5**	**25.3**
	LSD (P≤0.05)	**3.0**	**4.7**	**0.5**	**0.1**	**0.1**	**0.1**	**4.6**	**2.0**	**3.5**	**0.8**	**0.3**	**0.2**	**0.1**	**0.4**

Key: PSH= plant stand at harvest, NPH= number of panicles harvested, PDS= panicle damage symptom, PWT= panicle weight, GWT= grain weight, TH%= threshing percentage and HSM= hundred seed mass, mean within a column followed by the same letter(s) are not significantly different (P≤0.05), CV%= coefficient of variance and LSD= least significant difference at 5%

3.14 Discussion

The results reveal a variability in effect of seed dressers on percentage seed emergence after treatment across the sites. This variability among the seed dressers across the sites for percentage seed emergence could be due to ecological differences, insecticidal formulations and perhaps, the amounts of rainfall received. Plants from seeds treated with seed dressers showed improved percentage seed emergence, which led to enhanced growth and eventually improved yield. This finding agrees with Duan *et al*. (2012) who revealed the effectiveness of seed dresser Imidacloprid in increasing percentage seed emergence.

Reduction of plant stands after thinning at Alupe could be attributed to high FAW infestation at the site during the experimental periods. However, this reduction could be due in part to other insect pests and environmental conditions at the site. FAW mature larvae bore into the sorghum stem, feed through and break the stem at seedling stage of growth and development leading to reduced plant stands (Luginbill, 1928). Seed dressers were able to reduce FAW damage at plant stand. This finding agrees with Somasundar and Kumar (2016) who found the similar results. Similarly, Hossain *et al*. (2013) suggested that Imidacloprid (Gaucho 70Ws) and Thiamethoxam controlled both sucking (like sorghum aphids) and chewing insect pests, and that it needed to be recommended for the cotton farmers.

The seed dressers revealed significant differences for dead heart symptoms, with the seed treatment containing Lindane recording the lowest dead heart symptoms at Alupe compared to the rest of the tested seed dressers and untreated control. Dead heart symptoms are not only caused by FAW feeding damage, but also by other insect pests like shoot flies. However, CABI (2018) reported that, FAW feeding damage causes dead hearts like shoot flies do. A high score of dead heart symptoms observed at Alupe could have resulted from high infestation levels, while the low levels of dead heart symptoms observed among the tested seed dressers at Kiboko could have been due to low FAW infestations. Seed dresser Lindane is a chlorinated hydrocarbon that provides contact, repellent, fumigant and systemic effects on soil borne and foliage feeding insects (Ashdown *et al.*, 1952). Kumar *et al.* (2017) reported the effectiveness of seed dresser Lindane in reducing the FAW dead heart damage.

The results reveal a variability in effect of seed dressers for days to 50% flowering across the sites. Environmental conditions, FAW infestation duration and pest incidence across the sites could account for such variability for days to 50% flowering. Imidacloprid showed earliness at Alupe, while Thiamethoxam showed earliness at Kiboko. Alupe had higher infestations and therefore, the earliness observed in plants treated with Imidacloprid suggests it is effective in the management of FAW on growth and yield parameters respectively. The earliness could also be due to varietal variations, however, Day *et al*. (2017) asserted that, fall armyworm delays sorghum maturity by causing significant damage to vegetative and reproductive structures.

The seed dressers showed significant differences across the sites on leaf feeding damage, with the seed treatment containing Lindane and Thiamethoxam recording the lowest leaf feeding damage compared to untreated control. The efficacy of seed dressers varied with the varying levels of FAW infestation, insecticidal effects and environmental conditions across the sites. Alupe recorded the highest leaf feeding damage and this could be attributed to the high infestation levels at the site during the experimental periods compared to Kiboko that recorded the less feeding damage. Research findings by Cock (2017) and Andrews (1988) reported that, FAW leaf feeding damage depends on FAW abundance and duration of infestation levels. Therefore, seed treatments that provide resistance and moderate resistance at whorl stages can be selected based on the FAW leaf feeding score.

Results showed that seed dressers varied across the sites for the number of FAW larvae per plant, and the existence of such differences across the sites among the tested seed dressers, could be due to different levels of insecticides formulations, high levels of infestation due to environmental factors and natural enemies. At Alupe where FAW infestations were severe, the seed dresser, Lindane and Imidacloprid recorded the lowest number of larvae per plant, implying the effectiveness of such seed dressers in reducing fall armyworm larval counts. The more the FAW larvae per plant, the more they cause the leaf damage. Wiseman (1966) suggested that, treatments with low larvae score are effective because of enhanced mortality of neonates. The effectiveness of Thiamethoxam in the management of chewing and sucking insects was also reported by Kumar *et al*. (2017) who found that, it minimized shootfly incidences on sorghum seedlings.

Plant height is affected by FAW feeding damage, and this tends to delay maturity. The effect of FAW damage on plant height was assessed and the effect was more pronounced at Alupe than at Kiboko. Although these variations among the tested seed dressers for plant height could not be entirely placed on FAW, it could also be attributed to varietal differences and abiotic factors. However, Capinera and Roitech (1980) reported that, reduced plant height by FAW is due to reduced regrowth after heavy defoliation.

Sorghum tillering is an important component of recovery resistance after the growing point is killed by insect pest feeding damage (Bruns and Horrocks, 1984). The effect of FAW whorl feeding damage was assessed by counting the number of productive tillers per plant. There were significant differences among the seed dressers across the seasons and sites for number tillers and the results showed that tillering was higher at Kiboko compared to Alupe, though this high tillering could be in part a varietal character. However, the findings by Starks and Burton (1979) asserted that fall armyworm injury in sorghum seedling can increase the number of tillers as a recovery resistance when the growing point is killed.

The health of plant stands throughout the period of growth and development mostly determines the number plants that remain at harvest. The effect of FAW damage on sorghum plant stands that remain at harvest was assessed and significant effects were observed among the seed dressers for this parameter. The highest plant stands at harvest across the seasons and sites was recorded at Kiboko compared to Alupe for this parameter. Thiamethoxam recorded the highest plant stands at Kiboko while Imidacloprid recorded the highest at Alupe, implying their effectiveness against FAW for this parameter. The reduction in the number of plant stand at harvest can also be caused by termites and other abiotic factors, however, Luginbill (1928) reported that, FAW mature larvae break the stem at seedling stage of growth and development, leading to reduced plant stands at harvest.

The seed dressers varied significantly across the sites for panicle damage symptoms, and the results showed higher panicle damage symptoms at Alupe than at Kiboko. Plants from the seeds treated with Lindane, Imidacloprid and Thiamethoxam recorded low panicle damage symptoms. Though the effect of seed dressers could not be expected to reach the post flowering stages, still the low panicle damage symptoms could be attributed to early protection provided by the seed treatment. Sorghum panicle damage is not only caused FAW feeding damage, but also by other biotic factors. However, Andrew (1988) reported that, sorghum panicle damage is caused by FAW young larvae feeding on sorghum florets which lead to panicle damage. Thus, when screening seed dressers for panicle damage resistance, differences in the efficacy levels of seed treatments can be detected through panicle damage symptoms caused by FAW (Dar, 1979).

A higher grain yield at Kiboko could be due to the fact that Kiboko scored lower larvae per plant, dead heart symptoms, leaf feeding damage and lower panicle damage symptoms. While the low yield at Alupe could not be ascribed only to a severe FAW infestation levels during experimental periods, but also to a severe sorghum midge infestation, drought and anthracnose that the site experienced over the experimental seasons. Yield losses are due to the largest instars consuming over 75% of the total foliage during development (Sparks, 1979). Previous findings by Pogue, (2002) and Sparks (1979) indicated that, FAW is always active in the wet, warm and humid conditions with wide host-range. Research by Kumar *et al*. (2017) found that both Imidacloprid and Thiamethoxam were effective for grain yield amidst high shoot-fly infestations.

CHAPTER FOUR

EVALUATION OF SORGHUM VARIETIES FOR RESISTANCE TO FALL ARMYWORM INFESTATION UNDER FIELD CONDITIONS

Abstract

Sorghum is an important staple food crop for millions of people in E. Africa but its productivity is negatively impacted by fall armyworm (FAW) (*Spodoptera frugiperda*). The aim of this study was to evaluate five sorghum varieties which included; IESV24029SH, Seredo, KARI Mtama 1, Gadam hamam and Wagita for resistance to fall armyworm infestation under field conditions. A local check, Nakhadabo was included for comparison. The experiments were laid out in a randomized complete block design in 3 replications. The data collected icluded; dead heart symptoms, leaf feeding damage, number of larvae per plant and days to 50% flowering, panicle damage symptoms, plant height, number of panicles harvested and grain weight. Significant differences ($P \leq 0.05$) were observed among sorghum varieties, and KARI Mtama 1 (5) recorded the lowest dead heart symptoms compared to other varieties. Alupe recorded the highest FAW leaf feeding damage compared to Kiboko. Nakhadabo (4.2), KARI Mtama 1 (5.3) and Wagita (5.9) showed resistance by recording the less leaf feeding damage, while IESV24029SH (10), Gadam hamam (8.2) and Seredo (8.1) showed susceptibility by recording a higher leaf feeding damage. Alupe recorded a higher number of FAW larvae per plant compared to Kiboko. Nakhadabo (1.3 larvae), KARI Mtama1 (2 larvae) and Wagita (2.3 larvae) recorded a lower number of larvae per plant, whereas the other varieties showed susceptibility. Sorghum at Kiboko flowered earlier compared to Alupe. Gadam hamam (52.3days) was the earliest at Kiboko, while Nakhadabo (67days) was the earliest at Alupe. Higher panicle damage symptoms were recorded at Alupe compared to Kiboko. KARI Mtama 1 (1), Wagita (1.3) and Nakhadabo

(2.3) recorded a moderate resistance to panicle damage symptoms compared to other varieties. Plant height was higher at Kiboko, but lower at Alupe. Gadam hamam (103cm) and IESV24029SH (105cm) recorded shorter plant heights compared to other varieties. Grain weight was higher at Kiboko compared Alupe, and Wagita (3.6g) recorded the highest grain weight compared to the other varieties. The study has identified Thiamethoxam, Imidacloprid, Lindane and Carbofuran to be effective against FAW at vegetative stages of sorghum growth and development, and may be incorporated prior to planting to protect sorghum seedlings from early FAW infestations. The study has identified varieties Nakhadabo, KARI Mtama1 and Wagita to have shown resistance to FAW feeding damage at different stages of growth and development and therefore, could be used in IPM for FAW.

4.1 Introduction

While sorghum (*S. bicolor)* is the third among the cereals grown in E. Africa, in South Sudan the crop is the major cereal crop grown in most parts of the country as the main source of food (FAO, 2017; FEWS NET, 2018). Among the uses of sorghum include; human consumption, income generation, animal feed, thatching materials and for brewing purposes. The crop is mostly grown under rain-fed agriculture by subsistence farmers mainly in the regions of Bahr el Ghazal, Upper Nile and in some areas of Eastern and Central Equatoria (FAO, 2017). Insect damage is one of the most challenging biotic stresses that constrain sorghum productivity. One of these biotic stresses is a FAW pest that targets different parts of sorghum plant at different growth stages, and its feeding reduces the leaf area, interfering with photosynthetic activities of plants (Andrew, 1988).

One of the ways of managing the FAW is the use of insecticides but this can be expensive since the penetration of the insecticides to the funnel of sorghum is difficult and may require repeated application. Pesticides can also reduce the abundance of predators and natural enemies that help reduce the FAW populations (Cock *et al.,* 2017). Due to repeated use of pesticides, FAW can develop pesticide resistance. As reported by Morrell *et al* (2005), FAW can also be controlled by the use of modified plant genes, where the bacterium, *Bacterium thuringiensis* (Bt) genes (each of these encodes a pesticidal toxin) are put into the genomes of plants. The planting of these transgenic plants can be controversial since it may require the prevention of pollen dispersal, particularly for sorghum, which may be able to cross-pollinate with the wild relatives like Johnson grass (*Sorghum halepense*) (Karen Harrris-Shultz *et al.,* 2015).

Similar to conventional insecticides, FAW can develop resistance to Bt toxins (Niu *et al.,* 2013). Therefore, the alternative to the use of these synthetic insecticides and transgenic crop plants is the identification and use of crop varieties that have genetic resistance or tolerance to FAW feeding damage in sorghum. Luginbil (1969) reported that the most effective and ideal way of reducing insect pests that infest crop plants is by growing insect-tolerant cultivars. Screening the host plants for resistance to fall armyworm as reported by Crubelati-Mulati *et al.* (2014) has been achieved by planting sorghum under natural infestation in the field where FAW occurs. According to ICRISAT (1992), hot-spots, areas where insects' infestations are known to occur regularly in large numbers across seasons, can be used effectively for large-scale screening of host-plants for insect tolerance. Therefore, the current study was conducted to screen the selected sorghum varieties under natural FAW infestation in the field and their responses to FAW feeding damage was evaluated to determine their tolerance to the fall armyworm.

4.2 Materials and methods

4.2.1 Description of the research locations

The description for research locations is as discussed in section 3.2.1.

4.2.2 Planting materials

Five sorghum varieties and a local check (Table 4.1) used for this study were obtained from International Crops Research Institute for the Semi-Arid Tropics (ICRISAT-Kenya) Gene Bank.

These sorghum varieties were preferred due to the following desired attributes:

Table 4. 1: Sorghum varieties used and their varietal attributes

Variety	**Amount (kg) /12m^2 plot**	**Attributes**
IESV24029SH	0.5	Adapted to sub-humid mid altitude, early maturing, high yielding, and good grain colour (red) and seed size, tolerant to birds and striga.
Seredo	0.5	Adapted to sub-humid mid altitude, early maturing, high yielding and good grain colour (brown) and seed size, tolerant to birds and striga, resistant leaf diseases.
KARI Mtama 1	0.5	Early maturing, high yielding, drought tolerant, resistant to important pests and diseases, good grain colour (cream white) and seed size.
Gadam hamam	0.5	Drought tolerant, early maturing, good malting qualities, good grain colour (white), short plant.
Wagita	0.5	Adapted to sub-humid mid altitude, high yielding, good grain colour (brown) and seed size tolerant to birds and striga and resistant to leaf diseases.
Nakhadabo (local check)	0.5	High yielding, good grain colour (brick-red) and seed size and tolerant to birds.

4.2.3 Experimental design and field operations

To evaluate the response of selected sorghum varieties to fall armyworm infestation, two field experiments were conducted in two different locations for one season at Kenya Agricultural and

Livestock Research Organization (KALRO) at Kiboko and Alupe respectively. The experiments were laid down in a randomized complete block design (RCBD) 6x3 in three replications for one season during the months of May/September and from November, 2018 to March, 2019.

Land for planting was cleared and ploughed to a fine tilth and the final levelling done by hand-hoes at Alupe while in Kiboko, a tractor was used to plough and harrow the plots and the final tilth and leveling done by hand-hoes. The experimental plots were measured and demarcated into experimental units measuring 6 rows of 3m length with inter-row and intra-row spacing of 75x20cm and 60x20cm at Kiboko and Alupe respectively. Two weeks after emergence, thinning was done leaving 64 plants in the four middle rows. The varieties were planted without seed dressing and were exposed to natural infestation of FAW without the application of pest management measures. Other field operations remained as explained in section 3.2.4.

4.2.4 Data collection

The data collected for this chapter, remained as described in section 3.2.5.

4.2.5 Data analysis

The data collected was analysed as described in section 3.2.6.

4.3 Results

Two experiments were conducted at Kiboko and Alupe field stations for one season to assess the resistance of sorghum varieties to FAW damage. The results obtained for two locations indicated that FAW damage was more severe at Alupe compared to Kiboko.

4.4 Effect of FAW damage on growth parameters of sorghum varieties at Kiboko (2018/2019)

The screened sorghum varieties had no any significant effect on plant vigour, however, there were significant differences observed among the varieties for the rest of the parameters studied. The screened varieties varied significantly for percentage seed emergence, and IESV24029SH scored the highest percentage seed emergence compared to the local check, Nakhadabo. There were significant differences among the screened varieties for agronomic score and Seredo scored the highest compared to the rest of the varieties. There were significant differences among the varieties for plant stand after thinning and IESV24029SH scored the highest plant plot-wise compared to the local check, Nakhadabo. There was a significant variation among the varieties for dead heart symptoms, with variety KARI Mtama1 exhibiting some level of relative resistance by recording the lowest dead heart symptoms, while IESV24029SH exhibited susceptibility by recording the highest dead heart symptoms. There were significant differences among the varieties for days to 50% flowering. The earliest variety was Gadam hamam and the latest was the local check, Nakhadabo for days to 50% flowering. All the screened varieties exhibited significant differences for leaf feeding damage, with the local check, Nakhadabo showing some level of relative resistance to FAW defoliation from the tested varieties. Varieties Wagita and KARI Mtama1 exhibited moderate resistance, while varieties Gadam hamam and Seredo recorded moderate susceptibility to FAW defoliation. A high susceptibility to defoliation by fall armyworm was exhibited by IESV24029SH. The screened varieties showed significant differences for number of larvae per plant. The lowest larvae count was recorded by the local check, Nakhadabo, while the highest larvae count was recorded by variety IESV24029SH. There was a significant variability among the varieties for plant height. Varieties Gadam Hamam and IESV24029SH were significantly shorter but did not differ from Seredo, while Wagita was the tallest, followed by the local check, Nakhadabo (Table 4.2).

Table 4.2: Effect of FAW damage on growth parameters of sorghum varieties at Kiboko (2018/2019)

Variety	EMG%	AGS	PV	PST	DH	DFL	LFS	NLPP	PH
Nakhadabo	76.67a	2.00c	2.33a	49.00c	5.33a	72.33d	4.23a	1.33a	197.5c
Wagita	80.67ab	2.33a	2.00a	63.00a	5.33a	68.00c	5.93c	2.67bc	197.8c
Seredo	86.67ab	3.67b	1.67a	65.33b	7.00ab	57.00b	7.13d	2.30ab	142.1ab
Gadam hamam	88.67ab	2.33a	1.33a	65.00b	9.00ab	52.33a	7.07d	2.83bc	123.3a
KARI Mtama1	89.00ab	2.00c	1.33b	67.67b	5.00a	58.00b	5.27b	2.03ab	143.7b
IESV24029SH	90.33b	2.33a	1.67a	68.00b	10.00b	62.00e	8.83e	3.80c	123.9a
Mean	85.3	2.44	2.44	63	6.94	61.61	6.41	2.49	154.7
CV%	7.3	10.4	10.4	4.5	5.0	2.7	2.5	16.5	3.8
LSD P≤0.05	12.89	0.79	0.79	11.38	4.06	4.35	0.67	1.33	19.64

Key: EMG%= Percentage emergence, AGS= agronomic score, PV= plant vigor, PST= plant stand after thinning, DH= dead heart, DFL= days to 50% flowering, LFS= leaf feeding score, NLPP= Number of larvae per plant, PH= plant height

4.5 Effect of FAW damage on yield parameters of sorghum varieties at Kiboko (2018/2019)

There were significant differences among the screened varieties for number of tillers, plant stand at harvest and panicle damage symptoms. However, no differences were observed among the varieties for panicle weight, grain weight, threshing percentage and 100-seed mass. The screened varieties exhibited significant differences for the number of tillers, with Gadam hamam recording the highest tiller count, while the lowest tiller count was given by KARI Mtama1. There were significant differences observed among the varieties for plant stand at harvest and the results showed that some level of resistance to FAW was observed on KARI Mtama1 which recorded the highest plant stands at harvest compared to the local check, Nakhadabo. There were significant variations among the varieties for panicle damage symptoms, and some level of resistance to FAW panicle damage symptoms was exhibited by variety KARI Mtama1 which recorded the lowest panicle damage symptoms, while susceptibility was exhibited by Seredo by recording the highest panicle damage symptoms (Table 4.3).

Table 4.3: Effect of FAW damage on yield parameters of sorghum varieties at Kiboko (2018/2019)

Variety	NT	PSH	PDS	PWT	GWT	TH%	HSM
Nakhadabo	18.33a	42.33a	2.33ab	3632a	2.93a	0.80b	3.30a
Wagita	16.33a	54.67b	1.33a	4540a	3.55a	0.78ab	3.13a
Seredo	36.67b	57.67b	3.67b	4499a	2.86a	0.64a	3.27a
Gadam hamam	52.00c	56.33b	3.33b	4389a	3.56a	0.81b	3.37a
KARI Mtama1	9.33a	63.00b	1.00a	3872a	2.99a	0.77ab	4.23b
IESV24029SH	18.33a	61.67b	2.67ab	3640a	2.68a	0.74ab	3.07a
Mean	25.2	55.9	2.39	4095	3.09	0.76	3.39
CV%	14.6	4.8	10.7	9.8	13.7	3.1	2.7
LSD P≤0.05	13.83	10.02	1.87	1115.1	0.936	0.15	0.78

Key: NT= number of tillers, NPH= number of panicles harvested, PSH= plant stand at harvest, PDS= panicle damage symptom, PWT= panicle weight, GWT= grain weight, TH%= threshing percentage and HSM= 100-seed mass

4.6 Effect of FAW damage on growth parameters of sorghum varieties at Alupe (2018/2019)

The screened varieties had no significant differences for plant vigor and agronomic score, however, there were significant variations observed among the varieties for the rest of the parameters studied. There were significant differences among the varieties for percentage seed emergence, with variety Gadam hamam recording the highest percentage seed emergence, while the lowest was given by KARI Mtama1. There was a significant variability among the varieties for plant stand after thinning, with the local check, Nakhadabo recording significantly the highest plant stands after thinning compared to the rest of the varieties tested. KARI Mtama1 recorded the lowest plant stands after thinning. In regards to dead heart symptoms, the varieties varied significantly, with KARI Mtama1 recording the lowest dead heart symptoms, while the highest dead heart symptoms were scored for Seredo. There was a significant variability among the varieties for days to 50% flowering, and the earliest was Gadam hamam, while the latest was Wagita. All the screened varieties exhibited significant differences for FAW leaf feeding damage, with the local check, Nakhadabo exhibiting moderate tolerance, while susceptibility was shown by IESV24029SH and Gadam hamam to FAW damage by scoring the highest leaf feeding score. The screened varieties varied significantly for the number of larvae per plant, with the local check, Nakhadabo recording the lowest FAW larval counts, while Seredo recorded the highest larval counts. The screened varieties exhibited significant differences for plant height, and the tallest variety was the local check, Nakhadabo, while the shortest was Gadam hamam (Table 4.4).

Table 4.4: Effect of FAW damage on growth parameters of sorghum varieties at Alupe (2018/2019)

Variety	EMG%	AGS	PV	PST	DH	DFL	LFD	NLPP	PH
Nakhadabo	88.30bc	2.00a	2.67a	62.70c	8.00ab	77.3bc	6.20a	1.97a	170.0c
Wagita	85.00abc	3.00b	2.33a	57.30bc	8.67ab	89.0d	7.03c	3.13ab	157.7c
Seredo	75.30ab	2.00a	2.00a	44.00d	10.67b	74.0ab	8.10d	4.87cd	120.7b
Gadam hamam	93.30c	2.00a	2.33a	59.00c	10.00b	67.0a	8.23d	4.03bc	102.7a
KARI Mtama1	72.30a	2.30a	2.33a	36.30a	6.67a	86.3d	6.53d	2.27a	113.7ab
IESV24029SH	84.30abc	2.00a	2.00a	38.70a	10.00b	83.0cd	8.93e	5.70d	104.7a
Mean	83.1	2.2	2.3	49.7	9.0	79.4	7.5	3.7	128.2
CV%	6.5	4.3	16.9	2.9	18.2	2.6	2.4	7.1	6.5
LSD P≤0.05	14.96	0.43	0.98	13.39	3.24	7.72	0.26	1.51	14.24

Key: EMG%= percentage seed emergence, AGS= agronomic score, PV= Plant vigor, PST= plant stand after thinning, DH= dead heart, DLF= days to 50% flowering, LFS= leaf feeding score, NLPP= number of larvae per plant, PH= plant height

4.7 Effect of FAW damage on yield parameters of sorghum varieties at Alupe (2018/2019)

Significant variations among the screened varieties were observed for number of tillers, with Seredo recording the highest tiller count compared to the local check, Nakhadabo. The screened varieties varied significantly for plant stands at harvest, with Seredo and Gadam hamam scoring the highest plant stands at harvest compared to the local check, Nakhadabo. In regards to panicle damage symptoms, there was a significant variability among the screened varieties, with the local check, Nakhadabo showing the least panicle damage symptoms followed by Wagita. The highest panicle damage symptoms were recorded on IESV24029SH. Significant differences were recorded among the varieties for panicle weight and the better performing varieties were Wagita and Seredo compared to the local check, Nakhadabo. The screened varieties showed significant variations for grain weight, and Wagita recorded the highest grain weight compared to the local check, Nakhadabo. There were significant differences observed among the screened varieties on threshing percentage, and the best performing variety was Wagita compared to the tested varieties and the local check, Nakhadabo. The tested varieties showed significant variations on 100-seed mass, and KARI Mtama1 and the local check, Nakhadabo were significantly the best performing varieites, while the least performing variety was Wagita (Table 4.5).

Table 4.5: Effect of FAW damage on yield parameters of sorghum varieties at Alupe (2018/2019)

Variety	NT	NPH	PSH	PDS	PWT	GWT	TH%	HSM
Nakhadabo	1.00a	1.97a	1.00a	3.67a	90.0a	0.10a	0.53bc	1.57b
Wagita	5.30bc	3.13ab	24.00b	4.67b	593.3d	0.73c	0.59c	1.20a
Seredo	17.30d	4.87cd	37.33c	6.67cd	523.3cd	0.47b	0.43a	1.30ab
Gadam hamam	6.67c	4.03bc	36.00c	6.67cd	346.7bc	0.38b	0.53bc	1.17a
KARI Mtama1	2.00ab	2.27a	19.00b	6.00c	233.3ab	0.23ab	0.47ab	1.93b
IESV24029SH	3.67abc	5.70d	16.67b	7.00d	393.3bcd	0.39b	0.46ab	1.17a
Mean	6.0	3.66	22.3	5.78	363	0.38	0.50	1.39
CV%	38.8	7.1	4.2	1.7	21.6	21.8	2.3	4.8
LSD P≤0.05	4.24	1.51	10.87	0.92	206.8	0.25	0.08	0.35

Key: NT= number of tillers, NPH= number of panicles harvested PSH= plant stand at harvest, PDS= panicle damage symptom, PWT= panicle weight, GWT= grain weight, TH%=threshing percentage and HSM= 100-seed mass

4.8 Comparison of means for the effect of FAW damage on growth parameters of sorghum varieties at Alupe and Kiboko field stations (2018/2019)

The comparison of means for the effect of FAW damage on growth parameters of sorghum varieties at Alupe and Kiboko field stations are presented in Table 4.6. There were significant variations observed among the varieties for percentage seed emergence across the sites, and the overall results showed that the highest percentage seed emergence at Alupe was recorded for

Gadam hamam, while the highest percentage seed emergence at Kiboko was recorded for IESV24029SH. The lowest percentage seed emergence at Alupe was given by KARI Mtama1, while the lowest at Kiboko was recorded for Nakhadabo. There were significant variations on agronomic scored between the two sites, and overall means showed that the highest was recorded for Seredo at Kiboko, while the highest at Alupe was scored for Wagita. The rest of the varieties including the local check, Nakhadabo performed exceptionally better by scoring the lowest agronomic score at both sites. The tested varieties varied in plant vigor, and the overall results showed that plant vigor was higher at Kiboko compared to Alupe. The tested varieties varied significantly for plant stands after thinning across the sites. The overall results showed that the local check, Nakhadabo had the highest plant stands after thinning at Alupe, while IESV24028SH recorded the highest at Kiboko. The lowest performing varieties for plant stands at thinning at Alupe and Kiboko were KARI Mtama1 and the local check, Nakhadabo respectively.

There were significant differences among the varieties across the sites in the number of tillers per plant. The results indicated that the highest tiller count was recorded for Gadam hamam at Kiboko compared to Alupe where the lower tiller count was recorded for Seredo. There were significant variations among the varieties across the sites on dead heart symptoms, and the overall results showed that dead heart symptoms were higher at Alupe and lower at Kiboko. The variety that recorded the lowest dead heart symptoms across the sites was KARI Mtama1 at Kiboko and at Alupe respectively. The varieties that exhibited susceptibility to FAW dead heart symptoms were Seredo at Alupe and IESV24029SH at Kiboko. There were significant variations among the varieties across the sites on days to 50% flowering, and the overall results showed that flowering was earlier at Kiboko and later at Alupe. The earliest maturing variety at both sites was Gadam hamam at Kiboko and Alupe respectively. The latest varieties were local check, Nakhadabo at Kiboko and Wagita at Alupe for days to 50% flowering.

Significant differences were observed among the varieties across the sites on leaf feeding damage, and the overall results showed that leaf feeding damage was higher at Alupe and lower at Kiboko. The local check, Nakhadabo showed some significant levels of resistance to FAW defoliation across the sites, scoring the lowest leaf feeding damage at Kiboko and at Alupe, followed by KARI Mtama1 and Wagita. Varieties IESV24029SH, Gadam hamam and Seredo showed susceptibility to defoliation by FAW across the sites. Significant differences were observed among all the tested varieties in the number of larvae per plant across the sites, with the overall results showing more larvae scored at Alupe compared to Kiboko. The variety that recorded the lowest larval count across the sites was Nakhadabo at Kiboko and Alupe. The highest number of larvae was recorded in IESV24029SH across the sites. The tested varieties showed significant variations among the varieties in plant height across the sites, and the results showed that Wagita and the local check, Nakhadabo recorded reduced heights at Alupe but recorded the highest plant heights at Kiboko (Table 4.6).

Table 4.6: Comparison of means for the effect of FAW damage on growth parameters of sorghum varieties at Alupe and Kiboko field stations (2018/2019)

	Alupe										**Kiboko**									
Variety	**EMG%**	**AGS**	**PV**	**PST**	**NT**	**DH**	**DFL**	**LFS**	**NLPP**	**PH**	**EMG%**	**AGS**	**PV**	**PST**	**NT**	**DH**	**DFL**	**LFS**	**NLPP**	**PH**
Nakhadabo	88.3	2.00	2.67	62.7	1.0	8.0	67.0	6.20	1.97	170	76.7	2.00	2.33	49.0	18.3	5.3	72.3	4.23	1.33	198
Wagita	85.0	3.00	2.33	57.3	5.3	8.7	89.0	7.03	3.13	158	80.7	2.33	2.00	63.0	16.3	5.3	68.0	5.93	2.67	198
Seredo	75.3	2.00	2.00	44.0	17.3	10.7	74.0	8.10	4.87	121	86.7	3.67	1.67	65.3	36.7	7.0	57.0	7.13	2.30	142
Gadam hamam	93.3	2.00	2.33	59.0	6.7	10.0	77.3	8.23	4.03	103	88.7	2.33	1.33	65.0	52.0	9.0	52.3	7.07	2.83	123
KARI Mtama1	72.3	2.33	2.33	36.3	2.0	6.7	86.3	6.53	2.27	114	89.0	2.00	1.33	67.7	9.3	5.0	58.0	5.27	2.03	144
IESV24029SH	84.3	2.00	2.00	38.7	3.7	10.0	83.0	8.93	5.70	105	90.3	2.33	1.67	68.0	18.3	10.0	62.0	8.83	3.80	124
Mean	**83.1**	**2.22**	**2.28**	**49.7**	**6.0**	**9.0**	**79.4**	**7.51**	**3.66**	**128**	**85.3**	**2.44**	**1.72**	**63**	**25.2**	**6.94**	**61.6**	**6.41**	**2.49**	**155**
CV%	**10.8**	**1.6**	**2.9**	**11.8**	**3.9**	**2.8**	**52**	**4.4**	**2.6**	**79**	**10.8**	**1.6**	**2.8**	**11.2**	**3.9**	**27.5**	**52.0**	**4.4**	**2.6**	**79**
LSD (P≤0.05)	**15.4**	**0.6**	**1.0**	**11.2**	**10.1**	**3.7**	**6.2**	**0.5**	**1.3**	**18.9**	**15.4**	**0.6**	**1.0**	**11.2**	**10.1**	**3.6**	**6.2**	**0.5**	**1.3**	**19.0**

Key: EMG%= percentage emergence, AGS= agronomic score, PV= plant vigour, PST= plant stand after thinning, NT= number of tillers, DH= dead-heart, DFL= days to 50% flowering, LFS= leaf feeding score, NLPP= number of larvae per plant, PH= plant height, CV%=coefficient of variance and LSD=least significance difference at 5%

4.9 Comparison of means for the effect of FAW damage on yield parameters of sorghum varieties at Alupe and Kiboko field stations (2018/2019)

The comparison of means for the effect of FAW damage on yield parameters of sorghum at Alupe and Kiboko field stations are presented in Table 4.7. There were significant variations observed among the varieties for all parameters studied at both sites, except for panicle weight, grain weight and a 100-seed mass at Kiboko. The tested varieties exhibited significant differences on plant stands at harvest, and the overall means showed that Kiboko recorded the highest plant stands at harvest compared to Alupe. IESV24029SH recorded the highest plant stands at harvest at Kiboko, while Gadam hamam gave the highest at Alupe. Significant variations were observed among the varieties on the number of panicles harvested across the sites, and the overall means indicated that the highest number of panicles harvested was recorded at Kiboko, while the lowest was recorded at Alupe.

There were significant differences among the tested varieties across the sites for panicle damage symptoms, and the overall means showed Alupe scoring a higher panicle damage symptoms compared to Kiboko. IESV24029SH, Gadam hamam and Seredo showed susceptibility to panicle damage symptoms at Alupe. The tested varieties showed a significant variability across the sites for the panicle weight and, Kiboko scored the highest panicle weight compared to Alupe. Wagita and Seredo showed some levels of resistance for panicle weight across sites, while the local check, Nakhadabo was not significant for panicle weight. Significant differences were observed among the varieties for grain weight across the sites, and the results showed that the grain weight was higher at Kiboko compared to Alupe. Wagita recorded the highest grain weight at Alupe, while Gadam hamam recorded the highest grain weight at Kiboko. The low performing varieties for grain weight were the local check, Nakhadabo at Alupe and

IESV24029SH at Kiboko. There were significant differences among the tested varieties on threshing percentage across the sites, and the overall results showed that threshing percentage was higher at Kiboko and lower at Alupe. The variety that recorded the highest threshing percentage at Kiboko was Seredo, while the local check, Nakhadabo and Gadam hamam recorded the highest threshing percentage at Kiboko. The varieties exhibited significant variations for a 100-seed mass across the sites, and the higher 100-seed mass was recorded at Kiboko compared to Alupe (Table 4.7).

Table 4.7: Comparison of means for the effect of FAW damage on yield parameters of sorghum varieties at Alupe and Kiboko field stations (2018/2019)

	Alupe							**Kiboko**						
Variety	**PSH**	**NPH**	**PDS**	**PWT**	**GWT**	**TH%**	**HSM**	**PSH**	**NPH**	**%PD**	**PWT**	**GWT**	**TH%**	**HSM**
Nakhadabo	1.0a	2.0a	3.7a	90a	0.1a	0.5bc	1.5b	42.0a	58.0a	2.3ab	3632a	2.9a	0.8b	3.3a
Wagita	24.0b	3.0ab	4.7b	593d	0.7c	0.6c	1.2a	55.0b	68.0a	1.3a	4540a	3.6b	0.7ab	3.1a
Seredo	37.0c	5.0cd	6.7cd	523cd	0.5b	0.4a	1.3ab	58.0c	90.0bc	3.7b	4499a	2.8a	0.6a	3.3a
Gadam hamam	36.0c	4.0bc	6.7cd	347bc	0.4b	0.5bc	1.2a	56.0bc	103.0c	3.3b	4389a	3.6b	0.8b	3.4a
KARI Mtama1	19.0b	2.0a	6.0c	233ab	0.2ab	0.5ab	1.9b	63.0d	69.0a	1.0a	3872a	3.0ab	0.8ab	4.2b
IESV24029SH	17.0b	5.7d	7.0d	393bcd	0.4b	0.5ab	1.2a	62.0d	76.0ab	2.7ab	3640a	2.6a	0.7ab	3.1a
Mean	**22**	**3.7**	**5.78**	**363**	**0.4**	**0.50**	**1.4**	**60**	**77**	**2.3**	**4095**	**3.09**	**0.76**	**3.4**
CV%	**14.3**	**1.7**	**1.8**	**22.2**	**27.5**	**10.1**	**13.2**	**14.3**	**18.7**	**1.9**	**22.2**	**27.5**	**10.1**	**13.2**
LSD (P≤0.05)	**3.24**	**0.7**	**1.3**	**340.7**	**309.6**	**0.04**	**0.22**	**3.24**	**1.80**	**0.53**	**340.7**	**309.6**	**0.04**	**0.22**

Key: PSH= Plant stand at harvest, NPH= number of panicles harvested, PDS= panicle damage symptom, PWT= panicle weight, GWT= grain weight, TH%= threshing percentage, HSM= 100-seed mass, CV%=coefficient of variance and LSD=least significance difference at 5%

4.10 Correlation analysis

4.10.1 Correlation of all the parameters at Kiboko field station (2018/2019)

Percentage seed emergence was positively correlated (r=0.8530) with plant stands after thinning. Grain weight exhibited significantly positive correlations (r=0.45) with number of panicles harvested and threshing percentage (r=0.53). There were significantly positive correlations (r=0.69) among leaf feeding damage and number of larvae per plant. There were significantly positive correlations (r=0.87) between number of tillers and number of panicles harvested. Plant height showed a significant correlation with plant vigor (0.50). Plant vigor exhibited a positive correlation (r=0.89) with plant stand at harvest. Significant correlations (r= 0.53) were observed between threshing percentage and grain weight.

Table 4.8: Correlations of all parameters at Kiboko field station (2018/2019)

	EMG%	**PWT**	**LFS**	**NLPP**	**NT**	**PDS**	**NPH**	**PH**	**PV**	**PST**	**TH%**	**GWT**	**PSH**
EMG%	-												
PWT	0.2974	-											
LFS	0.4155	-0.1391	-										
NLPP	0.2957	-0.1624	**0.699****	-									
NT	0.1113	0.4474	0.297	0.0483	-								
PDS	0.3332	-0.0046	0.4356	0.2654	0.5229								
NPH	0.4496	**0.4584***	0.4751	0.125	**0.8705****	0.4008	-						
PH	**-0.5928***	0.2384	**-0.714***	**-0.5475***	-0.3211	-0.4396	**-0.5422***	-					
PST	**0.8536***	0.1531	**0.5672****	0.4079	0.0029	0.2241	0.4115	**-0.6336***	-				
PV	-0.2842	-0.0774	-0.3592	-0.394	-0.2323	-0.1632	-0.305	**0.5523****	-0.4312	-			
TH%	0.0653	**0.5301***	-0.331	-0.1296	0.1063	-0.062	-0.0039	0.233	-0.1682	0.2246			
GWT	0.2974	1.0	-0.1391	-0.1624	0.4474	-0.0046	0.4584	0.2384	0.1531	-0.0774	**0.5301***	-	
PSH	**0.8164***	0.2146	0.4886	0.2859	0.0065	0.0021	0.4531	**-0.5887***	**0.8944***	-0.3436	-0.0788	0.2146	-

Key: EMG%= emergence percentage, GWT= grain weight, LFS= leaf feeding score, NLPP= number of larvae per plant, NT= number of tillers, PDS= panicle damage symptoms, NPH= Number of panicle harvested, PH= plant height, PST= plant stand after thinning, PV= plant vigor, TH%= threshing percentage, GWT= grain weight, PSH= plant stand at harvest

4.10.2 Correlation of all the parameters at Alupe field station (2018/2019)

There were significantly positive correlations among percentage seed emergence (r=0.70), plant stands after thinning and threshing percentage (r=0.51). Grain weight showed a significantly positive correlation (r=0.54) with the number of panicle harvested. Leaf feeding damage showed a positive correlation with the number of tillers (r=0.45) and panicle damage symptoms (r=0.50). This implies that, the more the leaf damage, the more the tillers. Number of tillers showed a positive correlation (r=0.83) with the number of panicles harvested, plant stand at harvest (r=0.66). Number of panicles harvested showed a significantly positive correlation with grain weight (r=0.54) and plant stands at harvest (r=0.96). Plant height was significantly and positively correlated (r=0.52) with plant stands after thinning. In regards to plant stands after thinning, a significantly positive correlation (r=0.64) was observed with threshing percentage, while grain weight showed a significantly positive correlation (r=0.57) with plant stands at harvest.

Table 4. 9: Correlation of all parameters at Alupe field station (2018/2019)

	EMG%	PWT	LFS	NLPP	NT	PDS	NPH	PH	PV	PST	TH%	GWT	PSH
EMG%	-												
PWT	0.111	-											
LFS	0.095	0.323	-										
NLPP	0.098	0.275	0.872	-									
NT	-0.338	0.341	**0.463****	0.4118	-								
PDS	-0.144	0.137	0.784	0.571	0.421	-							
NPH	-0.134	**0.544***	**0.537****	0.4382	**0.8326****	**0.6049***	-						
PH	0.132	0.093	**-0.637***	**-0.5652***	-0.1569	-0.8471	-0.4272	-					
PV	0.394	0.027	-0.361	-0.3797	**-0.4795**	-0.3043	-0.2958	0.2412	-				
PST	**0.705***	0.038	-0.300	-0.2937	-0.18	**-0.5124***	-0.1135	**0.5225***	0.284	-			
TH%	**0.520***	0.336	-0.354	-0.3596	-0.4243	**-0.5251***	-0.221	0.4271	0.4933	**0.6497***			
GWT	0.111	1.000	0.323	0.2747	0.3408	0.1367	**0.5435***	0.093	0.0266	0.0377	0.3356	-	
PSH	-0.026	0.577	**0.513****	0.4023	**0.6648****	0.623	**0.9673****	-0.5043	-0.1793	-0.0706	-0.1036	**0.5769***	-

Key; EMG%= percentage seed emergence, GWT= grain weight, LFS= leaf feeding score, NLPP= number of larvae per plant, NT= number of tillers, PDS= panicle damage symptom, NPH= Number of panicle harvested, PH= plant height, PST= plant stand after thinning, PV= plant vigor, TH%= threshing percentage, GWT= grain weight, PSH= plant stand at harvest

4.11 Discussion

Analysis of variance showed significant ($P \leq 0.05$) differences among the varieties across the sites for all the parameters studied. Differentiation of varieties, site and their interactions gave a clear insight of how sorghum varieties responded to fall armyworm damage across different environments. The presence of variability among the varieties for percentage seed emergence could be due to genetic diversity, coupled with environmental factors among the tested varieties. Percentage emergence has never been used before as a measure of sorghum resistance to FAW damage since FAW feeding damage starts at the seedling stage, but was used for this particular objective to test the viability of seeds.

Resistance of sorghum varieties to fall armyworm damage on plant stands after thinning was screened by counting plants population immediately after thinning. Reduction of plant stands after thinning at Alupe could be attributed to high FAW damage, however, it could also be due in part to other insect pests (shoot flies, sorghum midge and birds as the data taken indicated), varietal variability and environmental conditions at the sites. Luginbill (1928) also found the same result.

The differences observed among the varieties for dead heart symptoms could be due to different levels of FAW infestation, genetic differences among the varieties and other insect pests, such as shoot-flies as recorded during experimental periods. The variety that gave the lowest dead heart symptoms across the sites was KARI Mtama 1, showing some level of resistance to FAW damage. The use of dead heart symptom as a measure of sorghum resistance to FAW feeding damage has never been established, but since the dead heart symptoms caused by fall armyworm is the same as that one caused by stem borers, it was used to compare with the previous studies that used dead heart symptom as a measure of sorghum tolerance to stem borers in sorghum.

Based on that, a study done by Kakara (2017) in India to evaluate the reaction of sorghum genotypes to insect pests found that, the tolerant varieties recorded 17.41 plants compared to 43.27 plants for the susceptible varieties. Therefore, it can be suggested that, KARI Mtama 1 (5.0 plants) exhibited significant levels of resistance to FAW damage which recorded the lowest dead heart symptoms.

The effects of fall armyworm feeding damage in delaying sorghum phenology was assessed by recording the days to 50% flowering and the results varied across the sites. Nakhadabo is a tall local variety and its earliness at Alupe could be associated with the fact that it scored the lowest number of larvae per plant, moderate resistance to leaf feeding damage and lowest panicle damage symptoms. These results agree with Mcmillian and Starks (1967) and Starks and Burton (1979) who reported that sorghum genotypes exhibiting resistance to FAW leaf feeding damage do mature early relative to FAW susceptible genotypes. The variation for days to 50% flowering across the sites could also be attributed to fluctuations in the environmental conditions (temperature, humidity and rainfall). However, heavy infestation leads to delayed flowering through decreased photosynthates flow (Papel *et al*., 1981).

FAW leaf feeding damage was assessed and varieties Nakhadabo, KARI Mtama1 and Wagita recorded less leaf feeding damage, implying their resistance to FAW leaf feeding damage. The higher leaf feeding damage at Alupe could be due to higher infestation levels, varietal differences and environmental conditions that encouraged oviposition at the site. Andrew (1988) reported that, FAW leaf feeding damage is high in areas where environmental conditions favour fall armyworm feeding, oviposition and dispersal. This suggests that, the weather data (26.2℃) recorded at Alupe might have favoured a higher FAW leaf feeding damage at Alupe. These findings also agree with Luginbill (1928) who reported that, fall armyworm epidemics vary across the different agro-ecological zones due to varying environmental conditions such as temperature, humidity and wind and rainfall pattern. Results of correlation (complementary relation between two objects) analysis also showed that leaf feeding damage was significantly and positively correlated (r=0.69) with the number of larvae per plant. This means that, the more the number of larvae per plant, the more the damage on the plants. And this suggests that such correlation could be used for an indirect selection approach for sorghum varieties with resistance to leaf feeding damage.

Nakhadabo recorded the lowest larvae count, followed by KARI Mtama1 across the sites. The level of resistance shown by Nakhadabo and KARI Mtama 1 could be ascribed to the fact that, they scored the lowest FAW larval count and low leaf feeding damage. Their resistance could also be due to antibiosis. Additionally, resistance of Nakhadabo could also be due to the reason that its genetic makeup has never been altered since it is a local variety. Panda and Khush (1998) attributed the resistance among the sorghum cultivars to the role of host resistance mechanism, antibiosis. They indicated that sorghum cultivars exhibiting the highest level of antibiosis do host lower number of larvae per plant, because of the presence of high level of nitrogen and lignin in the leaf. Sometimes, the reduction in the number of larvae per plant may not be entirely attributed to antibiosis, but could also be alluded to three factors; (1) high temperatures: in dry regions (like Kiboko), fall armyworm mortality increases at 32℃ (Hattingh, 1971), (2) rains: heavy rains kill the 1st and 2nd in-stars of fall armyworm (CIMMYT, 2018) and (3) cannibalism: older larvae cannibalize on smaller instars as a result of overcrowding or when the food is scarce as a survival strategy, leaving one or two larvae per plant (Chapman, 1999).

Sorghum tillering is an important component of recovery resistance after the growing point is killed by insect pest feeding damage (Bruns and Horrocks, 1984). The tiller count was used as a measure of resistance to assess the response of sorghum varieties to FAW damage by counting the number of productive tillers per plant. Gadam hamam recorded the highest tiller count at Kiboko, while Seredo recorded the highest at Alupe. This high tiller count by Gadam hamam and Seredo across the sites could not only be attributed to the fact that the two varieties exhibited susceptibility to FAW damage but also seemed to be genetic in nature. However, Rana *et al.* (1985) observed that sorghum varieties with recovery resistance do compensate for the dead growing points by tillering under heavy pest damage.

Sorghum panicle damage symptom by FAW was higher at Alupe and lower at Kiboko. KARI Mtama 1, Nakhadabo and Wagita showed significant levels of resistance to FAW panicle damage symptoms across the sites. The high FAW panicle damage recorded at Alupe is supported by a high leaf feeding damage but could also be attributed to the high incidence of sorghum midge and aphids that occurred during the experimental periods. FAW panicle feeding damage starts at the booting stage before the head opens and continues to milky stage. The boot serves not only as a feeding ground but also as a place of refuge for the FAW larvae. The panicle damage by the FAW depends largely on the type of sorghum head. A damage could be much severe on the compact-headed sorghum while less severe on a loose-headed sorghum. Therefore, Nakhadabo and Wagita in this respect, being loose-headed could be suggested that the type of head is one of the attributes that contributed to their being resistant to panicle damage by the FAW. However, Diawara *et al*. (1991) reported that, the panicle feeding resistance to fall armyworm is related to higher concentrations of nitrogen, fiber and tannin in sorghum florets.

Effects of FAW damage in reducing the plant height by its heavy feeding at the seedling stage was more pronounced at Alupe than at Kiboko. Although this reduction could not be entirely placed on FAW, it could also be attributed to varietal differences and environmental factors across the sites. However, McMillian and Starks (1967) pointed out that, FAW injury in sorghum seedlings can reduce plant height and delays plant maturity.

The highest plant stands at harvest across the sites was recorded at Kiboko compared to Alupe. IESV24029SH and Gadam hamam recorded the highest plant stands across the sites, implying their high tillering rate and susceptibility to FAW. The reduction in the number of plant stands at harvest can also be caused by termites and other abiotic factors; however, Luginbill (1928) reported that, FAW mature larvae cut the stem at seedling stage of growth and development, leading to reduced plant stands.

Wagita and Gadam hamam recorded the highest grain weight compared to the tested varieties. Wagita crop recorded less damage across the sites which eventually led to improved grain weight. The low grain weight of sorghum is not exclusively caused by FAW damage, however, Andrew (1988) asserted that, young larvae feed on florets, while mature larvae feed on growing kernels, leading to low grain weight.

One hundred seed mass is an important parameter that determines market prices of grain sorghum. 100-seed mass was higher at Kiboko compared to Alupe. KARI Mtama1 maintained its best performance across the sites due to the fact that it scored lower number of larvae per plant, dead heart symptoms, leaf feeding damage and lower panicle damage symptoms. A low seed mass at Alupe is comparable to a study by Harris *et al.* (2015) who reported that, the reduced kernel weight is due to defoliation at flowering stage.

CHAPTER FIVE

GENERAL DISCUSSION, CONCLUSION AND RECOMMENDATIONS

5.1 GENERAL DISCUSSION

Sorghum productivity is affected by fall armyworm (FAW) infestation. The aims of this study were to determine the efficacy of seed dressers in the management of FAW and to assess the resistance of sorghum varieties to FAW infestation under field conditions. The seed dressers exhibited significant differences on percentage seed emergence, and the means showed that the highest was recorded for Imidacloprid at Alupe, while that at Kiboko was recorded for Thiamethoxam. According to Duan *et al*. (2012), the importance of seed treatment is to improve germination percentage of seeds and enhances seedling health against insect pests' damage, leading to improved growth and grain yield.

Lindane offered better protection hence, the less dead heart symptoms observed. This finding is supported by IPCS (1991) which reported that, Lindane is a chlorinated hydrocarbon that provides contact, repellent, fumigant and systemic effects on soil borne and foliage feeding insects. There was significant variability among the seed dressers for days to 50% flowering, and the sorghum flowered earlier at Kiboko and later at Alupe. Imidacloprid showed earliness at Alupe, while Thiamethoxam recorded earliness at Kibok. There were significant differences observed among the seed dressers on leaf feeding damage. The seed dressers exhibited effectiveness to FAW leaf feeding damage compared to untreated control. Lindane and Thiamethoxam were more effective against FAW leaf feeding damage. Similar results were reported by Cock (2017) and Andrew (1988).

Significant effects were observed among the seed dressers on the number of larvae per plant, and the means showed that Lindane recorded the lowest number of larvae per plant at both Kiboko and Alupe. Wiseman (1966) suggested that, treatments with low larvae score are effective because of enhanced mortality of neonates. There were significant differences observed among the seed dressers on plant height. Effects of FAW in reducing the plant height through its heavy feeding at the seedling stage was more pronounced at Alupe than at Kiboko due to heavy infestation. McMillian and Starks (1967) pointed out that, FAW injury in sorghum seedlings can reduce plant height and delays plant maturity. There were significant differences among the seed dressers on the number of tillers, and the tiller count was higher at Kiboko compared to Alupe, though this could be in part, a varietal character. However, Starks and Burton (1979) asserted that, fall armyworm injury in sorghum seedlings can increase the number of tillers as a recovery resistance when the growing point is killed.

Significant effects were observed among the seed dressers for plant stands at harvest, and the highest plant stands at harvest was recorded at Kiboko compared to Alupe. Thiamethoxam recorded the highest plant stands at Kiboko, while Imidacloprid recorded the highest at Alupe, implying their effectiveness. The reduction in the number of plant stands at harvest can also be caused by termites and other abiotic factors, however, Luginbill (1928) reported that, FAW mature larvae cut the stem at seedling stage of growth and development, leading to reduced plant stands. There was a significant variability among the seed dressers on the number of panicles harvested, and Kiboko recorded a higher number of panicles harvested compared to Alupe. Lindane and Thiamethoxam offered a significant protection to the crop throughout the growing periods, hence, a high number of panicles harvested.

At Kiboko, all the seed dressers recorded the lowest panicle damage symptoms compared to untreated control. Seed dressers protected the crop at the post flowering stage because little or no damage was made at the seedling stage. Sorghum panicle damage symptom is not only caused by FAW feeding damage but also by other biotic factors. However, Andrew (1988) reported that, sorghum panicle damage is caused by FAW young larvae feeding on sorghum florets which lead to panicle damage. Imidacloprid exhibited some level of effectiveness by recording the highest panicle weight at Kiboko compared to the rest of the seed dressers and untreated control. Imidacloprid offered protection to the crop at the seedling stage and therefore, the crop recorded less damage, and eventually, improved the panicle weight. The low panicle weight of sorghum is not exclusively caused by FAW damage, however, Andrew (1988) asserted that, young larvae feed on florets, while mature larvae feed on growing kernels, leading to low panicle weight.

In regard to resistance of sorghum varieties to FAW damage, the overall results showed that the highest percentage seed emergence at Alupe and Kiboko was recorded for Gadam hamam and IESV24029SH respectively. The lowest percentage seed emergence at Alupe and Kiboko was recorded for KARI Mtama1 and Nakhadabo. The presence of variability among the varieties for percentage seed emergence could be due to genetic diversity, coupled with favorable environmental conditions. The overall results showed that dead heart symptoms were higher at Alupe compared to Kiboko. KARI Mtama1 recorded the lowest dead heart symptoms at Kiboko and Alupe respectively. Seredo and IESV24029SH exhibited susceptibility to FAW dead heart symptoms at Alupe and Kiboko. Significance differences were observed among the varieties on leaf feeding damage, and the overall results showed that leaf feeding damage was higher at Alupe compared to Kiboko. Nakhadabo, KARI Mtama1 and Wagita showed resistance to FAW defoliation, by scoring the lowest leaf feeding damage at Kiboko and Alupe. IESV24029SH showed susceptibility to defoliation, scoring the highest leaf feeding damage at Kiboko and Alupe. Andrew (1988) reported that FAW leaf feeding damage is high in areas where environmental conditions favour fall armyworm feeding, oviposition and dispersal. Therefore, this suggests that environmental conditions might have favoured a higher FAW leaf feeding damage at Alupe. The varieties exhibited significance differences for the number of larvae per plant, with the results showing more larvae scored at Alupe compared to Kiboko. Nakhadabo recorded the lowest larvae counts at Kiboko and Alupe. The highest number of larvae was recorded for IESV24029SH across the sites. Panda and Khush (1998) attributed the variation in the average number of FAW larvae per plant among the sorghum cultivars to the role of host resistance mechanism, antibiosis.

There were variations among the varieties for days to 50% flowering, with earliness recorded for Kiboko and lateness for Alupe. The early maturing variety at both locations was Gadam hamam at Kiboko and Alupe respectively. The latest varieties were Nakhadabo at Kiboko and Wagita at Alupe. The variation for days to 50% flowering across the sites could also be attributed to fluctuations in the environmental conditions. However, heavy infestation leads to delayed flowering through decreased photosynthates flow (Papel *et al*., 1981). Significant variations were observed among the varieties on plant height, and Nakhadabo recorded a reduced height at Alupe, but recorded the highest plant height at Kiboko. Variety Wagita also recorded a reduced height at Alupe, but recorded the highest plant height at Kiboko, suggesting the effect of FAW leaf feeding in reducing the plant height at Alupe than at Kiboko. There were differences among the varieties for the number of tillers per plant, and the highest tiller counts was recorded for Gadam hamam at Kiboko, while Seredo recorded the lowest tiller counts at Alupe. Starks and Burton (1979) asserted that, FAW damage in sorghum at the early stage can increase the number of tillers as a recovery resistance when the funnel is killed. The highest plant stands at harvest was recorded at Kiboko compared to Alupe. IESV24029SH and Gadam hamam recorded the highest plant stands compared to the rest of the vareities. Luginbill (1928) reported that, FAW mature larvae cut the stem at seedling stage of growth and development, leading to reduced plant stands. Wagita and Gadam hamam recorded the highest grain weight compared to the tested varieties. The low grain weight of sorghum is not exclusively caused by FAW damage, however, Andrew (1988) asserted that, young larvae feed on florets, while mature larvae feed on growing kernels, leading to low grain weight. A hundred seed mass is an important parameter that determines marketing prices of grain sorghum. A higher seed mass was recorded for Kiboko compared to Alupe. KARI Mtama 1 recorded the highest seed mass compared to the tested varieties. Harris *et al.* (2015) reported that, the reduced kernel weight is due to defoliation at flowering stage.

5.2 CONCLUSION

The study has identified Thiamethoxam, Imidacloprid, Carbofuran and Lindane to have shown efficacy against FAW damage by improving percentage seed emergence, recording less FAW leaf feeding damage and low larval counts, low dead heart symptoms and maintained the days to 50% flowering. Seed dressers also were able to reduce the effect of FAW damage on plant height and recorded less panicle damage symptoms. This study has also identified varieties Nakhadabo, KARI Mtama1 and Wagita showed some levels of resistance to FAW infestation by recording less leaf feeding damage, low larval counts, low dead heart symptoms and less panicle damage symptoms.

5.3 RECOMMENDATIONS

1. Thiamethoxam, Imidacloprid, Carbofuran and Lindane could be recommended for seed dressing as part of IPM against FAW damage.
2. Nakhadabo, KARI Mtama1 and Wagita could be used for the management of FAW.
3. There is a need for regional and national trials to validate the efficacy results of these seed dressers in regards to the management of FAW in E. Africa.
4. More seed dressers need to be evaluated for efficacy to FAW damage in E. Africa in an attempt to control the pest.
5. Further multi-locational studies are required to validate these findings for varieties Nakhadabo, KARI Mtama1 and Wagita to ascertain their resistance to FAW damage at different stages of sorghum growth and development.
6. More sorghum varieties need to be screened for relative resistance to FAW for effective management of FAW in E. Africa.

REFERENCES

Abrahams, P., Bateman, M., Beale, T., Clottey, V., Cock, M., Colmenarez, Y., Corniani, N., Day, R., Early, R., Godwin, J., Gomez, J., Gonzalez Moreno, P., Murphy, S. T., Oppong-Mensah, B., Phiri, N., Pratt, C., Silvestri, S., Witt, A. 2017. Evidence Note on fall armyworm (FAW). CABI, Wallingford, UK.

ADAMCZYK, JR., J. J., LEONARD, B. R., AND GRAVES, J. B. 1999. Toxicity of selected insecticides to fall armyworms (Lepidoptera: Noctuidae) in laboratory bioassay studies. Florida Entomol. 82: 230-236.

Almodares, A., and Hadi, M, R. 2009. Production of Bioethanol from sweet sorghum: A review. *African journal of Agricultural Research*, vol. 4 (9), pp: 772- 780.

Altieri, M, A. 1980. Diversification of corn agroecosystem as a means of regulating fall armyworm population. *Journal of Fla*. *Entomol*, vol. 63, pp: 450-456

Andrew, K, L. 1988. The whorlworm, *Spodoptera frugiperda* in Central America and neighboring areas. *Journal of Fla*. *Entomol*. vol. 65, pp: 456-657.

ASHDOWN, D., and H. B. CORDNER. 1952. Some effects on insect control and plant response of a systemic insecticide applied as a spray, a seed treatment, or a soil treatment. J. Econ. Entomol. 45, 302 (1952). Google Scholar

Ashley, T, R. 1986. Georgraphical distribution and parasitization levels for parasitoids of the fall armyworm, *Spodoptera frugiperda*. *Florida Entomol*. Vol. 6. pp: 516-524

Ashley, T, R., Wiseman, B, R., Davis, F, M., and Andrew, K, L. 1989. The fall armyworm, a bibliography. *Florida Entomologist*. vol. 72, pp: 152-202

Ashley, T, R. 1979. Classification and distribution of fall armyworm parasites. Florida Entomol. Vol. 62, pp: 114-128.

Altuna (2014). https://nabc.nl/uploads/content/files/Sorghum-VCA-FINALdraft-circulation.pdf Accessed in Nov, 2018.

A.O. Makokha, R. K. Oniang'o, S. M. Njoroge and P. K. Kinyanjui. 2002. EFFECT OF MALTING ON PROTEIN DIGESTIBILITY OF SOME SORGHUM (*Sorghum bicolor*) VARIETIES GROWN IN KENYA.

B. Dayakar Rao, K. Kalpana, K. Srinivas, J.V. Patil. 2014. Development and Standardization of Sorghum-Rich Multigrain Flour and Assessment of Its Storage Stability with Addition of TBHQ. https/doi.org/10.1111/jfpp.12250.

Benerjee, P, K., and P, B, Chaterjee. 1982. Pests of hill rice in west Bengal, India. Int. Rice. Res. News. Vol. 7(2), pp: 11.

Bowling, C, C. 1978. Simulated insect damage to rice: effects of leaf removal. *Journal of Econ. Entomol.* Vol.71, pp: 377-378.

Bruns, H. A. and Horrocks, R. D. 1984. Relationship of yield components of main culms and tillers of grain sorghum. Field Crops Research 8:125-33. CrossRef/ Google Scholar

Bucheyeki, T.L., Shenkalwa, E. M., Mapunda, T.X., Matata, L.W. (2010). Yield performance and adaptation of four sorghum cultivars in Igunga and Nzega districts of Tanzania. Communications in Biometry and Crop Science 5 (1), 4-10.

CABI (Centre for Agriculture and Bioscience International). 2017. Fall Armyworm Status, Impact and Control Options in Africa. Preliminary evidence Note. April, 2017.

CABI. 2018. Invasive Species Compendium: *Spodoptera frugiperda* (fall armyworm). Available at http://www.cabi.org/isc/datasheet/29810

Capinera, J, E., and W, J, Roitech. 1980. Response of wheat seedling to actual and simulated migratory grasshopper defoliation. *Journal of Econ*. *Entomol*. Vol. 73, pp: 258-261.

Capinera JL. 2014b. Fall Armyworm, *Spodoptera frugiperda* (J.E. Smith) (Insecta: Lepidoptera: Noctuidae). University of Florida/IFAS Extension. Publication EENY-98. Available at: http://entnemdept.ufl.edu/creatures/field/fall_armywor./htm

CBS (Central Bureau of Statistics). 2016. Geographic dimensions of well-being in Kenya. Who and where are the poor. A constituency level profile (Volume Two), Nairobi: The Legal Press Kenya Limited.

CGIAR (Consultative Group for International Agricultural Research). 2015. Consortium of International Agricultural Research Centers (CGIAR Research Program on WLE). Building Resilience: Use of drought-tolerant crops as a strategy for efficient use of available water: Sorghum in same, Tanzania.

Catherine W. Muui. 2014. Identification and Characterization of Sorghum Landraces and Improvement of on-farm seed production in Eastern Kenya.

Casmuz, A., Juarez, M. L., Socias, M. G., Murua, M. G., Prieta, S., Medina, S., Willink, E., Gastaminza, G. 2010. Revision de los hospederos del gusano cogollero del maiz, Spodoptera frugiperda (Lepidoptera: Noctuidae). Revista de la Socie-dad Entomologica Argentina, 69. 209-231.

Chunshan Guo, Wei Cui, Xue Feng, Jianzhou Zhao and Guihua Lu. 2011. Sorghum Insect Problems and Management. Journal of Integrated Plant Biology (JIPB) 2011, 53 (3): 178-192

Ciacci C, Maiuri L, Caporaso N, Bucci C, Del Giudice L, Massardo D R, Pontieri P, Di Fonzo N, Bean S R, loerger B, Londei M. 2007. Celiac disease: In vitro and in vivo safety and palatability of wheat-free sorghum food products. Clinical Nutrition, doi: 10.1016/j.clnu.2007.05.006.

CIMMYT, 2018. Fall Armyworm in Africa: A Guide for Integrated Pest Management. First Edition, Prasana, B. M., Huesing, J. E., Eddy, R., Peschke, V. M., eds. CIMMYT, Mexico, 109 pp.

Cock, M. J. W., Beseh, P. K., Buddie, A. G., Cafa, G., Crozier, J. 2017. Molecular methods to detect *Spodoptera frugiperda* in Ghana, and implications for monitoring the spread of invasive species in developing countries. Scientific Reports, 7: 4103. Doi: 10. 1038/s41598-017-04238-y.

Combraw, R, L., and J, R, Valerio. 1980. Oviposition by the fall armyworm on four varieties of bermudagrass. *Journal*. *Ga*. *Entomol*. Soc. Vol. 15, pp: 164-167.

Cosette Khawaja. 2014. Sweetfuel Handbook. WIP Renewable Energies. http://www.wip-munich.de.

Crumb SE, 1956. The Larvae of Phalaenidae. Technical Bulletin No. 1135. Washington DC, USA: United States Department of Agriculture.

Dar, I, A. 1979. Occurrence of the rice ear-cutting caterpillar in the Punjab of Pakistan. Int. Rice. Res. News. Vol. 4(2), pp: 16.

Davis, F, M., and T, G, Oswalt. 1969. Hand inoculator for dispensing; epidopterous larvae. USDA/SEA/SR 9.

Davis FM, Ng SS, Williams WP. 1992. Visual rating scales for screening whorl stage corn for resistance to fall armyworm. Mississippi Agricultural and Forestry Experiment Station. Technical Bulletin 186. Google Scholar.

Dew, J, A. 1913. Fall armyworm, *Laphygma frugiperda* (S and A). *Econ*. *Entomol*. Vol. 6, pp: 361-366.

Dogget, H. (1972). Breeding for resistance to sorghum shoot-fly in Uganda, in control of sorghum shoot-fly (M.G. Jotwani and W.R. Young), Oxford and IBH Publishing Co., New Delhi, pp. 192-201.

Duan, Q., G. L. Zhao, and P. Liu. 2012. Effects of Imidacloprid seed dressing on the seed activity and the seedling growth of maize. J. Maize Sci. 20: 63-69.

Ejeta, G., and J, E, Knolll. 2007. Marker assisted selection in sorghum. *Int. Genome-assisted Crop Improvement Genome Application in Crops* Vol.2, pp: 187-205.

FAO (Food and Agriculture Organization of the United Nations). 1995. FAO statistics. Rome Italy.

FAO (Food and Agriculture Organization of the United Nations). 2015. SORGHUM: Post-harvest Operations. (www.fao.org/fileadmin/user_upload/inpho/docs/Post_Harvest_Compendium_-_SORGHUM). (Accessed in July, 2018).

FAO. 2017. Food and Agriculture Organization of the United Nations Statistics Divisions. (www. Document). URL.http://faostat3.fao.org/home/E

FAO. 2017. Production-Crops-Area harvested/yield/production quantity-sorghum-2014. FAO (online database), Food and Agriculture Organisation, www.fao.org/fao/en (accessed in July, 2018)

FAO. 2017a. FAO Advisory Note on Fall armyworm (FAW) in Africa, 7 pp. FAO, Rome, Italy.

FAO. 2017b. Briefing Note on FAO Actions on Fall armyworm (FAW) in Africa, 2017. http://www.fao.org/fileadmin/templates/fcc/map/map_of_affected_areas/Fall_Armyworm_brief_-_15Dec2017_.pdfFAO, Rome, Italy

FAO. 2018a. Briefing Note on FAO Actions on fall armyworm (FAW) in Africa. Rome, Italy, 6 pp.

FAO. 2018b. Briefing Note on fall armyworm (FAW), 7 pp. http://www.fao.org/3/a-bt415e.pdf

FAO. 2018. SPECIAL REPORT. FAO CROP AND FOOD SUPPLY ASSESSMENT MISSION TO THE SUDAN. Food and Agriculture Organisation of the United Nations. Rome, Italy.

FAOSTAT. 2017. Food and Agriculture Organization of the United Nations. Training manual on Fall Armyworm. URL.http;//faostat3.fao.org/home/

FOASTAT. 2017. Training manual on fall armyworm. Pp.11-201

FAO. 2018. SPECIAL REPORT. FAO/WFP CROP AND FOOD SECURITY ASSESSMENT MISSION TO SOUTH SUDAN. Pp.11-15

FAOSTAT. 2008. Available at http://faostat.fao.org/

Fetene, M., Okori, P., Gudu, S., Mnesney, E, E., and Tesfaye, K. 2011. Delivering new sorghum and finger millet innovations for food security and improving livelihoods in Eastern Africa. Available at https;//cgsapce.cgiar.org/handle/10568/10811 (accessed 3, July, 2018).

Feed the Future (USAID). 2017. Fall armyworm IPM Guide for Africa. http://www.push-pull.net/

FEWS Net (2018): South Sudan food security outlook: https://fews.net/sites/default/files/documents/reports/SOUTH%20SUDAN%20Food%20Security%20Outlook_06302018

Gichangi, E. M, Gatheru, M., Njiru, E. N., Mungube, E. O., Wambua, J. M, and Wamuongo, J. W. (2015). Assessment of climate variability and change in semi-ard Eastern Kenya. Climate Change, 130, 287-297. Visited in June, 2018, from http://dx.doi.org/S10584-015-1341-2

Goergen, G., Kumar, P, L., Sankung, S, B., Togola, A., and Tamo, M. 2016. First report of outbreaks of the fall armyworm, Spodoptera Frugiperda (JE Smith) (Lepidoptera, Noctuidae), a new alien invasive pest in west and central Africa. *PLOS ONE*, DOI: 10.137/journal.pone.0165632.

Gurr, G. M., S. D. Wratten, and M. A. Altieri, editors. 2004. Ecological Engineering for Pest Management: Habitat Management for Arthropods. CSIRO Publishing, Collingwood, Australia. 244 pp.

Guthrie, W. D. 1980. Breeding for resistance to insects in corn. In Biology and Breeding for Resistance to Arthropods and Pathogens in Agricultural Plants. 290-303pp. Texas A & M University College Station, Texas. Google Scholar.

Hancock, J, D., 2000. Value of sorghum and sorghum co-products in diets for livestock in Sorghum. Origin, History, Technology and Production. W, Smith and R, A, Fredencksen (ed), Willey Series. Crop Sci. pp: 731-751

Harold Macauley. 2015. Cereal Crops: Rice, Maize, Millet, Sorghum, Wheat. Background Paper, Feeding Africa, Dakar, Senegal. https://www.afdb.org/fileadmin/uploads/afdb/Documents/Events/DakAgri2015/Cereal_Crops-_Rice__Maize__Millet__Sorghum__Wheat

Hossain, S. M. A., M. A., Baque and M. R. Amin. 2013. Comparative effectiveness of seed treatment and foliar insecticides against sucking pests of cotton and impact on their natural enemies. Bangladesh J. Agril. Res. 38 (1): 61-70.

Huang, F., Qureshi, J, A., Meagher, R, L., Jr, Reisig, DD., Head G, P. 2014. Cry1F Resistance in Fall Armyworm, *Spodoptera Frugiperda*, and single gene versus pyramided Bt Maize. *PLoS One*. Vol.9 (11), e112958.

Huang, Y. 2004. Examining plant defense responses to greenbug attack in sorghum using DNA technology. *Sorghum millets Newlett*. Vol. 47, pp: 72-74.

ICRISAT. 2015. International Crops Research Institute for Semi-Arid Tropics. Smart Foods Flyer. URL. http://www.icrisat.org/wp-content/uploads/flyer on smart food.

ICRISAT. 2017. International Crops Research Institute for Semi-Arid Tropics. https://www.icrisat.org/wp-content.uploads/.../WCA-Report_English_web-version.pdf

ICRISAT. 1992. Annual report 1991. International Crop Research Institute for Semi-arid Tropics. Patancheru, Andhra Pradesh, India.

IITA. 2016. International Institute for Tropical Agriculture. First report of outbreaks of the "fall armyworm" on the African continent. IITA Bulletin, No. 2330. http://bulletin.iita.org/index.php/2016/06/18/first-report-of-outbreaks-of-the-fall-armyworm-on-the-african-continent/

IPCC. 2017. Intergovernmental Panel on Climate Change. IPCC Official Pest Report, (No. ZMB-02/2). Rome, Italy, FAO. http://www.ippc.int/

IPPC. 2017f. International Plant Protection Convention. IPPC Official Pest Report, (No. BFA-01/1). Rome, Italy, FAO. https://www.ippc.int/

IPCS. 1991. International Programme on Chemical Safety. Environmental Health Criteria 124. Lindane. www.inchem.org/documents/ehc/ehc124.htm

Jaetzold, R. and H. Schmidt (1982). Farm management handbook of Kenya, *Vol. IIC.* Eastern Province. Ministry of Agriculture and Livestock Department and Marketing, Nairobi, Kenya.

Jaetzold, R., Schmidt, H., Horrnetz, B., and Shisanya. 2006. Farm management Kenya and the United Nations Development Programme Report, Kenya. Vol, II. PP: 54. Natural conditions and farm management information, 2nd Edition.

Johnson, S, J. 1987. Migration and the life history strategy of the fall armyworm, *Spodoptera*

Frugiperda in the western hemisphere. *Insect Science and its application*. Vol.8, Pp: 543-549.

Johnson, C. G. 1969. Migration and Dispersal of insects by flight. Methuen, London. 763 pp. Google Scholar.

Jones, R. L., and Sparks, A. N. 1969. (Z)-9-Tetradecen-1-ol acetate: A secondary sex pheromone of the fall armyworm, *Spodoptera frugiperda* (J. E. Smith). J. Chem. Ecol. 5:721-725.

Jung-Yuang, W. 1982. Distribution, seasonal occurrence and natural enemies of armyworm attacking rice in China. *Int*. *Rice*. *Res*. *News*. Vol. 7: pp. 9-10

Juarez ML, Murua MG, Garcia MG, Ontivera M, Vera MT, Vilardi JC, Groot AT, Castagnaro AP, Gastaminza G and Willink E. 2012a. Host association *Spodoptera frugiperda* (Lepidoptera: Noctuidae) corn and rice strains in Argentina, Brazil and Paraguay. Journal of Economic Entomology, 105, 573-582.

Kabubo-Mariara, J., and Kabra, M., 2015. Climate change and Food security in Kenya, s. I: Environment for Development (EfD). Discussion Paper series 15-05; March, 2015.

Kahiu Ngugi, Wilson Kimani, Dan Kiambi, Eunice W. Mutitu. 2013. Improving Drought Tolerance in Sorghum bicolor L. Moench: Marker-Assisted Transfer of the Stay-Green Quantitative Trait Loci (QTL) from a Characterized Donor Source into a Local Farmer Variety (IJSRK), 1(6), pp. 154-162.

Karen Harris-Shultz, Xinzhi Ni, Hongliang Wang, Joseph E. Knoll and William F. Anderson. 2015. Use of Benzimidazole Agar Plates to Assess Fall Armyworm (Lepidoptera: Noctuidae) Feeding on Excised Maize and Sorghum Leaves. Florida Entomologist, 98(1): 394-397. DOI: http://dx.doi.org/10.1653/024.098.0169 URL: http://www.bioone.org/doi/full/10.1653/024.098.0169

Kavoi, J, Kisilu, R., Kaman, G., Wafula, J., Nyangungi, N., and Nyanga, T., 2013. Gadam sorghum production and marketing through a public private partnership in Eastern Kenya, Nairobi: KARI.

Kenya Ministry of Agriculture (MoA, 2012). Economic Review of Agriculture (ERA).

Kilambya, D., and Witwer, M., 2013. Analysis of incentives and disincentives for sorghum in Kenya, Rome, FAO, MAFAP technical notes series.

Kishore, P. 1984. Timing and schedule of application of endosulfan to control sorghum stem-borer. India J. Agric. Sci. 54, 415-417. Google Scholar.

Khan, B. M. 1983. Studies on the biology and control of maize stem borer in Peshawar. Bull. Zool. 1, 51-56. Google Scholar.

Kruger M, Berg JVD, Plessis HD. 2008. Diversity and seasonal abundance of sorghum panicle-feeding Hemiptera in South Africa. Crop Prot. 27, 444-451.

Leuck, D, B. 1970. The role of resistance in pearl millet in control of the fall armyworm. *Journal of Econ. Entomol*. Vol. 63: pp. 1579- 1681

Leuck, D, B. 1972. Induced fall armyworm resistance in pearl millet. *Journal of Econ. Entomol*. Vol. 65: pp.1608-1611.

Lakkana Laopaiboon. Pornthap Thanonkeo. Prasit Jaisil. Pattana Laopaiboon. 2007. Ethanol production from sweet sorghum juice in batch and fed-batch fermentations by *Saccharomyces cerevisiae*. World J Microbiol Biotechonol (2007) 23:1497-1501. Khon Kaen University, India.

Luginbill, R. 1928. The fall armyworm. *USDA technical Bulletin*. Bull. No 34, 92p.

McMillian, W, W., and K, J, Starks. 1967. Greenhouse and; laboratory screening of sorghum lines for resistance to fall armyworm larvae. *Journal Econ. Entomol*. Vol. 60. pp: 1462-

1463.

Mello, R, M., Lucio, A, D., Storck, L., Lorentz, L, H., Carpes, R, H., and Boligion, A, A. 2004. Size and form of plots for the culture of the Italians pumpkin in plastic greenhouse. *Scientia Agricola*. Vol. 61, pp: 457-461.

Midega CAO, Pittchar JO, Pickett JA, Hailu GW and Khan ZR. 2017. ICIPE. A climate-adapted push-pull system effectively controls Fall Armyworm, *Spodoptera frugiperda* (JE Smith), in maize in East Africa. Crop Protection. http://www.icipe.org/news/icipe-push-pull-technology-halts-fall-armyworm-rampage.

Mineau, P. 2001. Pesticide Acute Toxicity: References Values for Birds, Rev. Environ. Contam. Toxicol. 2001, 13, 71-80.

MoA (2007). Recipe Manual for Traditional and Underutilized Foods. Government of Kenya.

Molina-OCHOA, J. J. J. HAMM, R. LEZAMA-GUTIERREZ, M. LOPEZ-EDWARDS, M. GONZALEZ-RAMIREZ, AND A. PESCADOR-RUBIO. 2001. A survey of fall armyworm (Lepidoptera: Noctuidae) parasitoids in the Mexican States of Michoacan, Colima, Jalisco, and Tamaulipas. Florida Entomol. 84: 31-36.

Munyua, H., and Stilwell, C. 2010. A mixed qualitative and quantitative participatory methodology. A study of the agricultural knowledge and information system (AKIS) of small-scale farmers in Kirinyaga district, Kenya.

Muui, C., W, Muasya, R., M, Kirubi, D, T. 2013. Baseline Survey on Factors Affecting Sorghum Production and USE in Eastern Kenya; *African journal of food*, agriculture, nutrition and development. Vol, 13(1).

Nagoshi, R. N., Goergen, G., Agbeko, K. T., Agboka, K., Koffi, D., Meagher, R. L. 2018. Analysis of strain distribution, migratory potential, and invasion history of fall armyworm populations in northern Sub-Saharan Africa. Scientific Reports, 8, 3710. Doi: 10.1038/s41598-018-21954-1

Ngugi, H. K., King, S. B., Abayo, G. O., and Reddy, Y. V. R. 2002. Prevalence, incidence, and severity of sorghum diseases in western Kenya. Plant Disease 86 (1), 65-70.

Ngugi, K, and Maswilli, R. 2010. Phenotypic diversity in sorghum landraces from Kenya, *African Crop Science Journal*, Vol 18(4), pp: 165-173.

NRC. 2004. Biological Confinement of Genetically Engineered Organisms, National Academies Press, Washington, DC.

Olembo KN, Mmboyi F, Kiplagat S, Sitieney J.K, Oyugi, F. K. 2010. Sorghum breeding in Sub-saharan AAfrica: The success stories. www.absfafrica.org.

One Acre Fund. 2016. Crop mixed survey. www.oneacrefund.org

Otieno, P. O. 2009. Monitoring carbofuran residues in Laikipia and Isiolo districts in Kenya for ecological risk assessment. MSc thesis, Department of Chemistry, Maseno University, Kenya, 2009.

Owens, J. C. 1975. An explanation of terms used in insect resistance to plant. Iowa St. J. Res. 49, 513-517. Google Scholar.

Panda N, Khush G. S. 1995. Host Plant Resistance to Insects. Wallingford (UK): CAB International: 1-1214.

Papel, R, K., A, K, Khatri, and B, S, Choudharg. 1981. Rice ear-cutting caterpillar, an injurious pest at panicle stage. *Int. Rice Res. News*. Vol. 6 (3): 17.

Pashley, D, P., S, J, Johnson and A, N, Sparks. 1985. Genetic population structure of migratory noctuids: The fall armyworm (Lepidoptera: Noctuidae). *Ann. Entomol. Soc. Am.* Vol. 78, pp: 756-762.

Payne, R., Murray, D., Harding, S., Baird, D., and Soutar, D. (2015). Introduction to GenStat. http://www.genstat.org/

Pitre, H, N., and Hogg, D, B. 1983. Development of the fall armyworm on cotton, soybean and corn. *Journal of the Georgia Entomological Society*. Vol. 18: pp. 187-194.

Pogue, G. M. 2002. A world revision of the genius *Spodoptera* Guenee (Lepidoptera: Noctuidae). Mem. Am. Entomol. Soc. 43:1-202.

Pophali, D, J., P, D, Deshmukh., U, K, Kaushik., S, K, Shrivestars., S, L Patidar., and Q, A, Sangrade. 1980. Assessment of yield losses caused by ear-head cutting caterpillar Mythinma separate walker. *Int. Rice Res. News*. Vol. 5(3): pp. 8-9

P. O. Otieno, J. O. Lalah, M. Virani, I. O. Jondiko, K. W. Schramm. 2010. Soil and Water contamination with carbofuran residues in agricultural farmlands in Kenya following the application of the technical formulation of Furadan. J Environ Sci Health B, 45 (2) (2010), pp. 137-144. Doi: 10. 1080/10934520903425459.

Rice, S, E., A, A, Grigarick., and M, O, Way. 1982. Effect of leaf and panicle feeding by fall armyworm larvae on rice grain yield. *Journal of Econ. Entomol*. Vol. 75: pp. 593-595.

Roger Day, Phil Abrahams, Melanie Bateman, Tim Beale, Victor Clottey, Mattew Cock, Yelitz Colmenarez, Natalia Corniani, Regan Early1 Julien Godwin, Jose Gomez, Pablo Gonzalez Moreno, Sean T. Murphy, Birgitta Oppong-Mensah, Noah Phiri, Corin Pratt, Silvia Silvestri and Arne Witt. 2017. Fall armyworm: Impacts and Implications for Africa. www.pestoutlook.com

Sarah Wild. 2017. Invasive pest hits Africa. https://www.nature.com/news/polopoly_fs/

S. Amalina, Y. Mohd Hanifah, M.N. Mohamad Roff and A.B. Idris. 2016. Effects of Plant Age and Insect Densities on Parasitism by *Cortesia vestalis* (Haliday). Middle-East Journal of

Scientific Research 24 (5): 1839-1846, 2016. DOI:10.5829/idoi.mejsr.2016.24.05.22717

Sekul, A, A., and A, N Sparks, 1976. Sex attractant of the fall armyworm moth. *USDA Tech*. Bull. 1542. 6p.

Sharma, G. C., and B. S. Rana. 1985. Genetics of ovipositional non-preference and dead-heart formation governing shootfly resistance in sorghum. J. Entomol. Res. 9:104-105.

Smith, M, E. 1982. Studies on fall armyworm-resistance in Tuxpeno and Antigua maize populations. Ph.D., Thesis, Cornell University, Ithaca, NY, USA.

Snow, J. W., and W. W. Copeland. 1969. Fall armyworm: Use of virgin female traps to detect males and determine seasonal distribution. USDA Prod. Res. Rep. No. 110.9 p.

Soejitno, J., and G, Van, Vreden. 1976. Varietal screening for resistance to the armyworm, *Spodoptera mauritia*, in rice. *In Agric*. *Coop*. *Indonesia Netherlands Res*. *Rept*. *1968*-1976, Pp. 167-169. Agricultural Cooperative Indonesia Netherlands Research Report 1968-1976. Central Research Institute for Agriculture, Bogor, Indonesia.

Solomon Assefa Derese, Hussein Shimelis, Mark Laing & Fentahum Mengistu (2017). The impact of drought on sorghum production, and farmer's varietal and trait preferences, in the north eastern Ethiopia: implications for breeding, Acta Agriculturae Scandinavica, Section B-Soil and Plant Science.

Sparks, A, N. 1979. A review of the biology of the fall armyworm. *Journal of Florida Entomologist*. Vol. 62: pp. 82-87.

Stark, K, J., and R, J, Button. 1979. Damage to grain sorghum by fall armyworm and the corn earworm. *Journal of Econ. Entomol. Vol.* 72. Pp: 376-378.

Sudhir Kumar, DV Singh, Kantipudi Rajesh Kumar and Awaneesh Kumar. 2017. Efficacy of some novel insecticides and bio-products against shoot fly, *Atherigona soccata* (Rondani) in maize. Journal of Entomolgy and Zoology Studies 2017; 5 (3): 474-477. www.entomoljournal.com

Syngenta. 2017. www.syngenta-us.com/crop-protection/seed-treatment

Tahir, M, H, N., Imran, M., Hussain, M, K. 2002. Evaluation of sunflower (*Melianthus annuus* L) inbred lines for drought tolerance. *International Journal of Agriculture and Biology*. Vol 3. Pp: 398-400

Tajuba A. 2017. Army worm now turns to vegetables, bananas as government mulls aerial spray, Daily Monitor, POSTED 25/4/2017. http://mobile.monitor.co.ug/News/Army-worm-turns-vegetables-government-mulls-aerial-spray/2466686-3902296-format-xhtml-39kst2z/index.html

Taylor LH, Latham SM, Woolhouse ME. 2001. Risk factors for human disease emergence. Philos Trans R Soc Lond B Biol Sci 356: 983-989

Teetes, G. L., J. W. Johnson, and D. T. Rosenow. 1975. Response of improved resistant sorghum hybrids to natural and artificial greenbug populations. Journal of Economic Entomology 68:546-548.

Tefera, T., Mugo, S., Tende, R., Likhayo, P. 2011. Mass Rearing of Stem Borers, Maize Weevil and larger Grain Borers insect pests of Maize, CIMMYT: Nairobi, Kenya.

Tenywa, M.M., Nyamwaro, S.O., Kalibwani, R., Mogabo, J., Buruchara, R. and Fatunbi, A.O. 2018. Innovation Opportunities in Sorghum Production in Uganda. FARA Research Reports Vol 2 (18): pp 20.

Tesfamichael A., A.B. Nyende, S.M. Githiri, R.W.Kasili and Woldeamlak A. 2013. Documentation of sorghum (*Sorghum bicolor* L. Moench) landraces: production, utilization and challenges in Eritrea. Hamelmalo Agricultural College (HAC), Keren, Eritrea, Jomo

Kenyatta University of Agriculture and Technology (JKUAT), Nairobi, Kenya. https//www.researchgate.net/publication/272486991

Timu, A, G., Mulwa, M, R., Akello, J., and Kamau, M. 2012. The role of varietal attributes on adoption of improved seed varieties. The case of sorghum in Kenya. Tegemeo institute of agricultural policy development, Nairobi, Kenya.

Uganda Bureau of Statistics (UBoS). 2010. Uganda Census of Agriculture, Vol.4, Crop Production.

Uttakalla Somasundar, Mr. Nukala Naveen Kumar, Prof. P. Rajendra Prasad. 2016. Studies on New Seed Dressing Insecticides Against Insect Pests of Green Gram. International Journal of Agriculture Innovations and Research. Volume 4, Issue 6, ISSN (Online) 2319-1473.

USAID. 2017. United States Agency for International Development. Fall armyworm in Africa: A guide for Integrated Pest Management. Pp. 2-90

USDA, 2014. Crop production historical track-record. USDA-NASS. US Gov. Princ Office, Washington, DC.

USDA. 2017. World Agricultural Outlook Board. World Agricultural Supply and Demand Estimates. WASDE-533. Washington, DC.

War A, Paulraj M, Ahmad T, Buhroo A, Hussain B, Ignacimuthu S, Sharma H. 2012. Mechanisms of plant defense against insect herbivores. Plant Signaling and Behavior. 2012; 7:1306-1320. Doi: 10.4161/psb.21663. [Free Article] [Google Scholar].

Whiteman, P. C., and G. L. Wilson. 1965. Effects of water stress on the reproductive development of *Sorghum vulgare*. Pers. Univ. Queensl. Pap., Dep. Bot. 4:233-239.

Wilde, C., and R. Apostol. 1983. Armyworm resistance in rice. *Environ. Entomol*. Vol. 12: pp 376- 379.

Wiseman, B, R., F, M, Davis and J, E Campbell. 1980, Mechanical infestation devise used in fall armyworm plant resistance. *Fla.Entomol*. Vol. 63, pp 425-435.

Wiseman, B, R., F, M, Davis and W, P, Williams, 1983. Fall armyworm larval density and movement as an indication in resistant corn. *Prot Ecol.* Vol.5. pp: 135-141.

Wiseman, B, R. and L, Gourley. 1982. Fall armyworm (Lepidoptera: Noctuidae): Infestation procedures and the sorghum resistance evaluation. *Journal of Econ. Entomol*. Vol. 75: pp: 1048-1051.

Wiseman, B, R., H, H, Painter and C, E, Wassom. 1966. Detecting corn seedling differences in the greenhouse by visual classification of damage by the fall armyworm. *Econ. Entomol*. Vol. 59, pp: 1211-1214.

Wortmann CS, Mamo M, Abebe G, Kaizzi K, Mburu C, Letayo E, Xerinda S. 2006. An Atlas of sorghum production in eastern Africa. http://intsormil.org.

Wortmann, C, S., Mamo, M., Mburu, C., Letayo, E., Abebe, G., Kayuki, K, C., Chisi, M., Maltivavarira, M., Xerinda, S., and Ndacyayisenga, T. 2016. Atlas of sorghum (*Sorghum bicolor* (L) Moench) production in eastern and southern Africa. Lincoln, NE: University of Nebraska-Lincoln.

Ying Niu, Robert L. Meagher, Fei Yang, and Fangneng Huang. 2007. Susceptibility of Field Populations of the Fall Armyworm (Lepidoptera: Noctuidae) from Florida and Puerto Rico to Purified Cry1F Protein and Corn Leaf Tissue Containing Single and Pyramided Bt Genes. Florida Entomologist, 96(3): 701-713. Florida Entomological Society. URL: https://doi.org/10.1653/024.096.0302

Zozimo R. 2015. Enhancing sorghum production to improve South Sudan economy http://hub.africabioscience.org/blog/enhancing-sorghum-production-to-improve-south-sudan-economy

APPENDICES

Appendix 1: Treatment combinations with sorghum varieties

Code	Treatment	Dose used	Vol. of water	Amount of seeds (kg)
T0-SCo	**Seredo+Control**	**0**	**0**	**0.5**
T1-ST	Seredo+Thiamethoxam	1.25g	2.5ml	0.5
T2-SI	Seredo+Imidacloprid	1ml	1.5ml	0.5
T3-SL	Seredo+Lindane	2.5g	3ml	0.5
T4-SC	Seredo+Carbofuran	3ml	-	0.5
T0-24Co	**IESV24029SH+Control**	**0**	**0**	**0.5**
T1-24T	IESV24029SH+ Thiamethoxam	1.25g	2.5ml	0.5
T2-24I	IESV24029SH+ Imidacloprid	1ml	1.5ml	0.5
T3-24L	IESV24029SH+ Lindane	2.5g	3ml	0.5
T4-24C	IESV24029SH+ Carbofuran	3ml	-	0.5
T0-KM1Co	**KARI Mtama1+Control**	**0**	**0**	**0.5**
T1-KM1T	KARI Mtama 1+Thiamethoxam	1.25g	2.5ml	0.5
T2-KM1I	KARI Mtama 1+Imidacloprid	1ml	1.5ml	0.5
T3-KM1L	KARI Mtama 1+Lindane	2.5g	3ml	0.5
T4-KM1C	KARI Mtama 1+Carbofuran	3ml	-	0.5
T0-GHCo	**Gadam hamam+control**	**0**	**0**	**0.5**
T1-GHT	Gadam hamam+Thiamethoxam	1.25g	2.5ml	0.5
T2-GHI	Gadam hamam+Imidacloprid	1ml	1.5ml	0.5
T3-GHL	Gadam hamam+Lindane	2.5g	3ml	0.5
T4-GHC	Gadam hamam+Carbofuran	3ml	-	0.5
T0-WCo	**Wagita+Control**	**0**	**0**	**0.5**
T1-WT	Wagita+Thiamethoxam	1.25g	2.5ml	0.5
T2-WI	Wagita+Imidacloprid	1ml	1.5ml	0.5
T3-WL	Wagita+Lindane	2.5g	3ml	0.5
T4-WC	Wagita+Carbofuran	3ml	-	0.5
T0-NCo	**Nakhadabo+Control**	**0**	**0**	**0.5**
T1-NT	Nakhadabo+Thiamethoxam	1.25g	2.5ml	0.5
T2-NI	Nakhadabo+Imidacloprid	1ml	1.5ml	0.5
T3-NL	Nakhadabo+Lindane	2.5g	3ml	0.5
T4-NC	Nakhadabo+Carbofuran	3ml	-	0.5

Appendix 2: Analysis of variance for the effect of seed dressers on FAW damage and on growth parameters of sorghum varieties at Kiboko for season 1 and 2 (2018/2019)

Sources of variation	DF	**AGS**	**PV**	**PST**	**DFL**	**LFS**	**PH**	**NLPP**	**NT**
Seed dressers	4	0.2139ns	0.6194ns	26.61ns	34.2ns	7.666*	90.8ns	0.2691ns	26.29ns
Variety	5	2.0989**	0.6589ns	340.7**	864.54**	3.351ns	33619.8**	1.4484ns	1188.9**
Variety x Seed dressers	20	0.1572ns	0.1728ns	29.79ns	3.94ns	0.29ns	257.9ns	0.2711ns	44.3ns
Error	150	0.2922	0.3122	20.7	34.63	2.858	872.9	0.7911	42.91
Total	179								

Key; DF= degree of freedom, AGS= agronomic score, PV= Plant vigor, PST= Plant stand after thinning, DFL= Days to 50% flowering, LFS= Leaf feeding score, PH= Plant heights, NLPP= Number of larvae per plant, NT= Number of tillers, ns= no significance, **=significant at (P≤0.01) and *= significant at (P≤0.05)

Appendix 3: Analysis of variance for the effect of seed dressers on FAW damage and on yield parameters of sorghum varieties at Kiboko for season 1 and 2 (2018/2019)

Sources of variation	DF	PSH	NPH	PDS	PWT	GWT	TH%	HSM
Seed dressers	4	47.44ns	95.93ns	5.203*	0.1777ns	0.137ns	0.02584ns	0.2305ns
Variety	5	278.99**	1768.78**	1.032ns	1.1029*	0.5841ns	0.10268*	5.2163**
Variety x Seed dressers	20	35.29ns	102.13ns	1.313ns	0.2265ns	0.1665ns	0.02963ns	0.2173ns
Error	150	23.34	88.41	2.012	0.4625	0.2928	0.03144	0.407
Total	179							

Key; DF= Degree of freedom, PSH= plant stand at harvest, NPH= Number of panicle harvested, PDS= panicle damage symptom, PWT= Panicle weight, TH%= Threshing percentage and HSM= hundred seed mass, ns= no significant, **= significant at (P≤0.01) and *= significant at (P≤0.05)

Appendix 4: Analysis of variance for the effect of seed dressers on FAW damage and on growth parameters of sorghum varieties at Alupe for season 1 and 2 (2018/2019)

Sources of variation	DF	**AGS**	**PV**	**PST**	**DFL**	**LFS**	**PH**	**NLPP**	**NT**
Seed dressers	4	0.119ns	0.2222ns	48.31ns	63.16ns	13.1387**	254.1ns	0.91ns	22.12ns
Variety	5	5.2*	1.8356**	121.4*	1258.66**	20.2125**	37798.4**	4.834*	121.47*
Variety x SD	20	0.203ns	0.3022ns	8.05ns	30.97ns	0.5458ns	130.1ns	0.567ns	3.92ns
Error	150	1.611	0.3	28.52	40.17	0.5915	696.4	1.124	35.28
Total	179								

Key; DF= degree of freedom, AGS= agronomic score, PV= Plant vigor, PST= Plant stand at thinning, DFL= Days to 50% flowering, LFS= Leaf feeding score, PH= Plant heights, NLPP= Number of larvae per plant, NT= Number of tillers, ns= no significance, **= significant at (P≤0.01) and *= significant at (P≤0.05).

Appendix 5: Analysis of variance for the effect of seed dressers on FAW damage and on yield parameters of sorghum varities at Alupe for season 1 and 2 (2018/2019)

Sources of variation	DF	**PSH**	**NPH**	**PDS**	**PWT**	**GWT**	**TH%**	**HSM**
Seed dressers	4	68.52*	116.2ns	1.911ns	0.00854ns	0.00282ns	0.394ns	0.0151ns
Variety	5	187.08**	769.5*	3.859ns	0.04787ns	0.0872*	0.938ns	0.9377*
Variety x SD	20	12.1ns	26.7ns	0.864ns	0.0106ns	0.00838ns	0.176ns	0.0743ns
Error	150	19.72	224.5	3.892	0.04029	0.03801	1.159	0.3591
Total	179							

Key; DF= degree of freedom, PSH= plant stands at harvest, NPH= number of panicles harvested, PDS= panicle damage symptom, PWT= panicle weight, GWT= grain weight, TH%= Threshing percentage and HSM= hundred seed mass, ns=no significant, **= significant at (P≤0.01) and *= significant at (P≤0.05).

Appendix 6: Sorghum varieties used and their varietal attributes

Variety	**Amount (kg) /12m^2 plot**	**Attributes**
IESV24029SH	0.5	Adapted to sub-humid mid altitude, early maturing, high yielding, and good grain colour (red) and seed size, tolerant to birds and striga.
Seredo	0.5	Adapted to sub-humid mid altitude, early maturing, high yielding and good grain colour (brown) and seed size, tolerant to birds and striga, resistant leaf diseases.
KARI Mtama 1	0.5	Early maturing, high yielding, drought tolerant, resistant to important pests and diseases, good grain colour (cream white) and seed size.
Gadam hamam	0.5	Drought tolerant, early maturing, good malting qualities, good grain colour (white), short plant.
Wagita	0.5	Adapted to sub-humid mid altitude, high yielding, good grain colour (brown) and seed size tolerant to birds and striga and resistant to leaf diseases.
Nakhadabo (local check)	0.5	High yielding, good grain colour (brick-red) and seed size and tolerant to birds.

Appendix 7: Analysis of variance for the effect of FAW damage on growth parameters of sorghum varieties at Kiboko and Alupe (2018/2019)

S. of variation	DF	**EMG%**	**AGS**	**PV**	**PST**	**DH**	**DFL**	**LFS**	**NLPP**	**PH**
Site	1	44.44ns	0.4444ns	2.7778ns	1600**	38.028*	2862.25**	10.78028**	12.25**	6312.3**
Variety	5	100.24ns	0.6667*	0.4667ns	93.13ns	17.294*	154.29**	10.79583**	7.3311**	5901.3**
Variety x Site	5	176.78ns	0.9778**	0.1778ns	445.67**	3.028ns	215.72**	0.54028**	1.2433ns	93.3ns
Error	24	83.36	0.1389	0.3333	43.83	4.806	13.44	0.09278	0.6283	126.2
Total	35									

Key: DF= degree of freedom, EMG%=Percentage emergence, AGS= agronomic score, PV= Plant vigour, PST= plant stand after thinning, DH= dead heart, DFL= days to 50% flowering, LFS= leaf feeding score, NLPP= number of larvae per plant, PH= plant height

Appendix 8: Analysis of variance for the effect of FAW damage on yield parameters of sorghum varieties at Kiboko and Alupe (2018/2019)

S. of variation	DF	**NT**	**NPH**	**PSH**	**PDS**	**PWT**	**GWT**	**TH%**	**HSM**
Site	1	3306.25**	21462.25**	10167.36**	103.3611**	125350416*	66.0907**	0.579889**	36.20028**
Variety	5	595.58**	1706.45**	513.69**	6.3167**	509424ns	0.3913ns	0.019439*	0.7605**
Variety x Site	5	274.52**	156.85ns	197.56**	2.3611*	144552ns	0.1538ns	0.00312ns	0.06494ns
Error	24	36	72.83	31.53	0.5833	245229	0.2113	0.004009	0.09917
Total	35								

Key: NT= number of tillers, PSH= plant stand at harvest, PDS= panicle damage symptom, PWT=panicle weight, GWT= grain weight, TH% = threshing percentage and HSM= 100-seed mass

Appendix 9: Weather data during the experimental periods (2018/2019)

KIBOKO **Month**	**Maximum Temperature** (℃)	**Minimum Temperature** (℃)	**Relative Humidity** (RH %)	**Rainfall** (mm)
May	32.2	16	85.5	37.5
June	28.8	13.9	86	0.5
July	28.4	13	85.7	0.0
August	33.5	13.8	82.8	0.0
September	30.8	15.2	79.6	7.0
November	31.5	18	82.5	21.4
December	29.9	18	85.3	35.9
January	31.4	17.4	89.2	7.4
Mean	30.9	15.7	84.6	13.7
Total	239.5	125.3	676.6	109.7
ALUPE				
May	26.2	18	75	16.5
June	Nil	Nil	Nil	14.1
July	Nil	Nil	Nil	0.1
August	Nil	Nil	Nil	0.6
September	Nil	Nil	Nil	27.3
November	Nil	Nil	Nil	38.6
December	Nil	Nil	Nil	12.7
January	Nil	Nil	Nil	1.5
Mean	26.2	18	75	13.9
Total	26.2	18	75	111.4