ASSESSING THE MANAGEMENT STRATEGY AND THE POTENTIALITY OF FALL ARMYWORM (*Spodoptera frugiperda*) LARVAE AS POULTRY FEED

By

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DECLARATION AND APPROVAL

Declaration

This thesis is my original work and has not been presented for an award of a diploma or conferment of a degree in any other university or institution.

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ABSTRACT

Fall armyworm *Spodoptera frugiperda* is a serious pest of about 350 plant species such as maize and sorghum. Management of this pest through mass trapping and handpicking of the larvae to feed the chicken would reduce its population. The objectives of the study were; to assess the optimal visual cues of FAW for landing, to evaluate the effectiveness of mass trapping as a method of collecting FAW larvae, to determine the potentiality of FAW larvae as poultry feed. The research assessed optimal visual cues of *Spodoptera exigua* as a model insect for *S. frugiperda*. Freshly eclosed moths were tested in a wind tunnel using a water trap with Light emitting diodes (LED). Seven light colours (365, 385, 400, 470, 530, 592 and 650 nm) at one light intensity (brightness) were tested for attractiveness. Data was collected after 30 minutes and 14 hours. To determine the effectiveness of mass trapping FAW, field experiments were done during the long and short rains of 2020 and long rains of 2021. In the long and short rains of 2020, a water trap with UV-A (385 nm) LED light (LWT + UV-A) and a delta trap from Kenya Biologics Company were tested with two categories of pheromones. The pheromones used were *S. frugiperda* (2001, 2002, 2003, 2004/2005 and 2006) from Pherobank Company and Kenya Biologics pheromone (kbp). LWT was tested with the Pherobank pheromone while the delta trap was tested with Kenya Biologics pheromone. Further, three trap designs, namely: LWT + UV-A (385 nm), the funnel bucket trap from Pherobank, and delta trap, were tested using (2003 and four component (4C)) pheromones. Proximate analysis was performed on air dried samples of fall armyworm larvae and experimental data was compared to secondary data of other chicken feeds. The research found that *S. exigua* had optimal visual cues at (365, 385, and 400) nm wavelengths compared to (470, 530, 592, and 650) nm wavelengths at ($p = 0.01$ and $p = 0.001$). Results for the long rains 2020 showed that LWT + UV-A performed better than the delta trap over three weeks at ($p = 0.01$, 0.001, and 0.01). Long rains 2021 experiment showed that LWT + UV-A captured higher numbers of FAW moths than the delta and the bucket traps at ($p = 0.001$). The means of the protein content of FAW larvae (56.22) % was similar to those of BSF larvae (38.41) %, HF larvae (60.94) %, and Soya bean (40.12) %. This research concludes that LWT + UV-A (385nm) has the potential to be utilized for mass trapping *S. frugiperda,* and FAW larvae have sufficient nutrients to be used as poultry feed. The study recommends that the Ministry of Agriculture and FAO adopt the use of LED water trap in the Integrated Pest Management and also include FAW larvae in poultry diet to boost food security.

TABLE OF CONTENT

DECLARATION AND APPROVAL i
COPYRIGHT ii
ACKNOWLEDGEMENTS iii
ABSTRACT iv
LIST OF TABLES viii
LIST OF FIGURES ix
LIST OF APPENDICES xi
ABBREVIATIONS AND ACRONYMS xii
CHAPTER ONE 1
1 GENERAL INTRODUCTION 1
1.1 Background 1
1.2 Statement of the Problem 4
1.2.1 Specific Objectives 5
1.2.2 Hypotheses 5
1.3 Justification 5
1.4 Scope of the Study 7
1.5 Limitations 7
1.6 Definition of Terms 7
CHAPTER TWO 9
2 LITERATURE REVIEW 9
2.1 Research Gap 9
2.2 Fall Armyworm 10
2.2.1 History 10
2.2.2 Damages of FAW 11
2.2.3 FAW Haplotypes 11
2.2.4 Description and Lifecycle of FAW 11
2.3 Management of FAW 13
2.3.1 Chemical Control 13
2.3.2 Host Plant Resistance 14
2.3.3 Biological Control 14
2.3.4 Handpicking 15
2.3.5 Other Management Strategies 15
2.4 Beet Armyworm (*Spodoptera exigua*) 16
2.5 Visual Cues 17

2.6 Chemical Cues ... 17
2.7 Trap Cropping ... 18
2.8 Insects Identification ... 19
2.9 Poultry Feed ... 20
2.10 Nutritional Profile of Insects ... 20
CHAPTER THREE ... 22
3 MATERIALS AND METHODS ... 22
3.1 Introduction ... 22
3.2 Study Area ... 22
3.3 Experiment 1: Optimal Visual Cues of FAW for landing ... 24
3.3.1 Mass Rearing of BAW as a Model Insect of FAW ... 24
3.3.2 Visual Targets ... 25
3.4 Experiment 2: Effectiveness of Mass Trapping ... 28
3.4.1 Trap Capture ... 28
3.4.2 Infestation Level of FAW and Plant Damage ... 36
3.4.3 Insects' Identification ... 39
3.5 Experiment 3: Proximate Composition ... 39
3.5.1 Sample Collection ... 39
3.5.2 Sample Preparation ... 39
3.5.3 Proximate Analysis ... 40
3.5.4 Comparison of the Nutrient Content of *S, frugiperda* Larvae to other Chicken Feeds ... 41
CHAPTER FOUR ... 42
4 RESULTS AND DISCUSSIONS ... 42
4.1 Introduction ... 42
4.2 Assessment of the Optimal Visual Cues of FAW. ... 42
4.3 Effectiveness of Mass Trapping ... 47
4.3.1 Trap Capture ... 47
4.3.2 Infestation Level ... 56
4.3.3 Insects' Identification ... 59
4.4 Proximate Composition ... 60
4.4.1 Proximate Composition of FAW Larvae ... 60
4.4.2 Proximate Composition of BSF Larvae and FAW Larvae ... 62
4.4.3 Proximate Composition of HF larvae and FAW Larvae ... 63
4.4.4 Proximate Composition of Soya Bean and FAW Larvae ... 65

CHAPTER FIVE 69
5 CONCLUSIONS AND RECOMMENDATIONS 69
5.1 Conclusions 69
5.2 Recommendations 69
5.2.1 From the Current Study 69
5.2.2 Suggested for Further Study 70
6 References 71
Appendices 83

LIST OF TABLES

Table 1: Maize ratings based on foliar damage by FAW 37

Table 2: Maize ratings based on ear and kernel damage by FAW 38

Table 3: The number of insects that were morphologically identified in the short rain of 2020 59

Table 4: Proximate composition of FAW mean n=2 for *S. frugiperda* S1and mean standard deviation (SD±, n = 3) for *S. frugiperda* S2 and *S. frugiperda* S3 on dry matter basis (% DM)...61

Table 5: A Comparison of proximate composition of FAW larvae (n = 3) and BSF larvae from four studies BSF_1, BSF_2, BSF_3, and BSF_4 (n = 4) means, on dry matter basis(%DM)...63

Table 6: A Comparison of proximate composition of FAW Larvae (n = 3) and HF larvae from our studies HF_1, HF_2, HF_3, and HF_4 (n = 4) means, on dry matter basis(%DM) 64

Table 7: Comparison of proximate composition of FAW larvae (n=3) and Soya bean from four studies SB_1, SB_2, SB_3, and SB_4 (n=4) means, on dry matter basis(%DM) 66

LIST OF FIGURES

Figure 1: Areas affected by fall armyworm (in 2021) 10
Figure 2: A farmer in Kapsemwa village in Kaptagat, Uasin Gishu County- Kenya pours soil on his maize crop affected by the fall armyworm 16
Figure 3: Map of School of Agricultural and Food Sciences (SAFS), Jaramogi Oginga Odinga University of Science and Technology - Siaya Campus 23
Figure 4: Map of Onywera Primary School in Sindo, Suba South 24
Figure 5: Pupae in nasi box...25
Figure 6:Collection container 25
Figure 7: a =Petri dish, b=white glass, c = stand and bulb, d = complete water trap ..26
Figure 8 : Wind tunnel set up...27
Figure 9: Spectralon rooflight day condition (M1) for thrips 27
Figure 10: Spectralon moonlight condition (M3) for Spodoptera exigua...................27
Figure 11: Layout field 1 (long and short rains 2020) 30
Figure 12: a = LED light, b = Conical stand, c = Water container, d = Metallic stand, e = LED Water Trap (LWT), f = Delta trap (kb), g = Pheromone, h = Container with water and soap...31
Figure 13: Layout Field 2 (Control experiment short rains 2020)..............................33
Figure 14: Layout Field 3 trap selection data (Long rains 2021) 34
Figure 15: Trap designs, 14 a = Water trap with UV-A (385 nm) LED light, 14 b = Delta trap and 14 c = Bucket trap 35
Figure 16: Layout Field 4 for testing trap designs and lures (Long rains 2021) 36
Figure 17: Rating of maize plants based on foliar damage by FAW...........................37
Figure 18: Scores used to rate ear damage by FAW larvae..38
Figure 19: Box plot showing the catch of moths in various traps after 30 minutes 43
Figure 20: Box plot showing the catch of moths in various traps after 14 hours 43
Figure 21: Bar plot of mean percentage of moths caught per light wavelength of a trap, df = 6, p<0.01 44
Figure 22: Bar Plot of mean percentage of moths caught per light wavelength of a trap, df = 6, p <0.001 45
Figure 23: Field 1, Trap UV- A (385 nm) with pheromones and delta trap (kb) N=7, df = 3, week 1=p < 0.01, week 2 = p<0.001 and week 3= p<0.01 48
Figure 24: Plot of the total number of FAW moths captured by the traps per day in Long rains 2020 49

Figure 25: Field 1, Trap UV-A (385 nm) with pheromones and delta trap (kb), N = 7 50
Figure 26: Plot of the total number of FAW moths captured by the traps per day in short rains 2020..51
Figure 27: Field 3, Experiment on trap choice between water trap with UV-A (385 nm) LED light and white light (4500k), p value<0.01(**), N = 9..............................51
Figure 28: Field 4, Water trap with UV-A (385 nm) LED light, bucket trap and delta trap with promising pheromones 2003 and 4C from Pherobank. 52
Figure 29: Plot of the means of FAW captured (n=3) in Field 4 by water trap with UV-A (385 nm) LED light, bucket trap and delta trap with promising pheromones 2003 and 4C from Pherobank, P < 0.001 53
Figure 30: Level of FAW larvae infestations on maize foliage (long rains 2020) 56
Figure 31: Level of FAW larvae infestations on maize ear (long rains 2020) 57
Figure 32: Level of FAW larvae infestations on maize foliage (Short rains 2020).....57
Figure 33: Level of FAW larvae infestations on maize ear (Short rains 2020)...........58
Figure 34: Plot of proximate composition on Dry matter basis(%DM) of the means of Spodoptera frugiperda samples (S1, S2 and S3)..61
Figure 35: A plot for the Proximate analysis of BSF larvae and FAW larvae on Dry matter basis (%DM)...62
Figure 36: A plot for the Proximate analysis of HF larvae and FAW larvae on Dry matter basis (%DM)...64
Figure 37: A plot for the Proximate analysis of fall armyworm larvae (FAWL) and Soya bean on Dry matter basis (%DM) 65

LIST OF APPENDICES

Appendix I: Rotation plan for traps design and lures 83

Appendix II: ANOVA table for experiment 1: Trap captures after 30 minutes 85

Appendix III: ANOVA table for experiment 1: Trap captures after 14 hours............ 85

Appendix IV: Trap captures during the control experiment in field 2. 86

Appendix V: Trap captures in Rift Valley and Coastal regions November 2020 87

Appendix VI: Publications... 88

Appendix VII: Poster 89

Appendix VIII Ethical review certificate.. 90

Appendix IX National Commission for Science, technology and Innovation (NACOSTI) certificate.. 91

ABBREVIATIONS AND ACRONYMS

ACE	African Centre of Excellence
BAW	Beet armyworm
BSF	Black soldier fly
CABI	Centre for Agriculture and Biosciences
CV	Cultivar
HF	House fly
kb	Kenya biologics
kbp	Kenya biologics pheromone
LED	Light emitting diodes
LWT	LED water trap
FAO	Food and Agriculture Organization of the United Nations
FAW	Fall armyworm
FTC	Farmers Training Center
KALRO	Kenya Agricultural & Research Organization
KOH	Potassium hydroxide
MOA	Ministry of agriculture
SANBI	South African National Biodiversity Institute
WHO	World Health Organization
USD	US dollar
UV	Ultraviolet
ICIPE	International Centre for Insects Physiology and Ecology
INSEFOOD	Insects as Food and Feed
KNBS	Kanya National Bureau of Statistics
CIMMYT	International Maize and Wheat Improvement Center

SAFS	School of Agricultural and Food Sciences
UM	Upper Midland Zone
LM	Lower Midland Zone

CHAPTER ONE

1 GENERAL INTRODUCTION

1.1 Background

Fall armyworm (*Spodoptera frugiperda*) is a polyphagous pest that is widely accepted as the most damaging pest in the American continent (Abrahams *et al*., 2017; Goergen *et al*., 2016). This troublesome pest is currently in Africa and is causing serious damages to crops especially maize (Abrahams *et al*., 2017; Day *et al*., 2017; MOA, 2017) hence, solutions to reduce its population is critical. Therefore, a management strategy that uses optimal visual cues, trap cropping, and collecting the insects for feed could be a sustainable way to significantly lower its population in the field.

Globally, the growing population projected to be about 9.2 billion by 2050 is a threat to food security (Bongaarts, 2009; Godfray *et al*., 2019). As a result, there is pressure to produce more food to feed the population. Most people's diets are also changing from traditional foods to the consumption of more meat and cereals (Godfray *et al*., 2019). Intensification of agriculture which requires more land, pesticides, and fertilizers, is one of the ways to meet the food demand. However, it puts pressure on the already limited resources, thus leading to environmental degradation. Therefore, there is a need for more sustainable agriculture to address these issues (Dorper *et al*., 2021).

Insects are promising sources of alternative protein for food and feed (van Huis, 2016). They require less land for production, emit low greenhouse gases, have high feed conversion efficiency, and they also have the ability to transform low-value organic side streams into high-value protein products (Huis, 2016; Kouřimská & Adámková, 2016). Besides, entomophagy helps reduce the use of pesticides (Kouřimská & Adámková, 2016).

Several insects can be used as feedstock for pets, livestock, and fish (Ayieko, 2010; Shumo *et al*., 2019). These include, majorly, Black soldier fly *Hermetia illuscens* (Diptera: Stratiomyidae), and the Common housefly *Musca domestica* (Diptera: Muscidae) while mealworms, locusts, grasshoppers, crickets, and silkworms are less utilized (van Huis, 2016).

Insects considered as pests in agroecosystems can also be used as food or feed (Cerritos *et al*., 2015). An example is the Mexican grasshopper *Sphenarium purpurascens* Charpentier (Orthoptera: Pyrgomorphidae), a pest of corn, bean, pumpkin, and alfalfa in central and southern Mexico (Cerritos *et al*., 2015; van Huis, 2017). This insect has been exploited for human consumption since prehistoric times (van Huis, 2017). In Sub-Saharan Africa, most grasshopper species are crop pests (van Huis, 2016, 2017), but farmers prefer not to treat their crops using pesticides. Due to the fact that the insects' sales yield more revenue than some of the crops such as millet (van Huis, 2017).

Herbivorous insect species depend on plants for food; therefore, their collection depends on season. Nevertheless, in every season, certain edible insect species are available, which makes year round collection possible (van Huis, 2016). For these reasons, fall armyworm (FAW) (*Spodoptera frugiperda*) may be collected and utilized as feed when in season.

Fall armyworm has invaded Africa and is now causing significant yield losses to cereals crops, especially maize (Abrahams *et al*., 2017; Ministry of Agriculture (MOA), 2017). According to Abrahams *et al*., (2017), the potential impact of FAW on maize in Africa is between 8.3 and 20.6 million tonnes per year of the total expected production of 39m tonnes per year and with losses lying between USD 2,481m and USD 6,187m per year of the total expected value of USD 11,590.5m per year.

FAW has also been reported to cause damages to maize by feeding on peripheral foliage, making larger, ragged holes, and burrowing through the husk (Goergen *et al*., 2016; MOA, 2017). When FAW attacks at the vegetative stage, it is capable of causing up to 100% crop loss, where an attack on young maize can fully reduce plant density which calls for replanting (MOA, 2017).

Despite the losses and damages caused by FAW, it acts as a food source to some birds and grasshoppers, which are also sources of food to human beings (South African National Biodiversity Institute (SANBI), 2018). Furthermore, materials from the environment (insects, worms, snails, greens, seeds, among others) are possible feed sources for birds raised in traditional systems (FAO, 2013). For these reasons FAW larvae depicts a potential alternative source of protein for poultry feed.

According to van Huis, (2017), controlling insects pests considered edible in agroecosystems by harvesting for food or feed is beneficial. Edible insect pests are: (1) nutritional, contributing to food security; (2) economic because no pesticides are purchased; and (3) environmentally friendly, as there is no pesticide contamination, and pest resurgence or secondary outbreaks are prevented.

Currently, management of FAW is based on mass trapping using pheromones, mechanical and chemical control (Abrahams *et al*., 2017; Kenya Agricultural and Livestock Research Organization (KALRO), 2018; MOA, 2017). Some of the recommended chemicals could be effective and have less impact on the environment. However, their choice for use is based on the farmers' knowledge and ability to purchase, of which the majority go for cheaper products (Midega *et al*., 2018).

Furthermore, UN Food and Agricultural Organization (FAO), (2018a, 2018b) reports that mechanical method (hand picking) of this insect has significantly reduced the pest population in Embu County. This method is also cheap, especially for the small-scale farmers who cannot afford the pesticides. It has also reduced pest incidence and improved maize yields significantly. Moreover, collection of insects considered as pests can minimise the burden of pesticides to the environment (Kou & Adámková, 2016).

Cultural control practices that may be too labor intensive for commercial farmers such as hand picking of larvae could be sensible to smallholder farmers, more so if they do not have any other means of control and if labor is not an issue (Prasanna *et al*,, 2018). Therefore, enhancing the trap plant attraction using colours and pheromones could make the collection easier. Besides, farmers are already collecting the FAW larvae for chicken feed C. Midega (personal communication, April, 2019). However, edible insect species intended for production should be screened for risks to humans, animals, plants, and biodiversity (van Huis & Oonincx, 2017).

Even though insects are promising alternatives sources of protein for poultry feed, little is known about the potentiality of FAW larvae as poultry feed. Therefore, this project investigated the management strategy of FAW by assessing the optimal visual cues for landing and the effects of mass trapping for collecting FAW. Since FAW is a quarantine pest in Europe, the optimal visual cue of Beet armyworm (*Spodoptera exigua*) was assessed as a model insect of FAW. The study also conducted a proximate analysis to determine the nutritional profile of FAW larvae to be used as poultry feed.

This research came up with a management strategy of FAW that is capable of reducing the pest population especially in maize field with minimal damage to the environment. The strategy would improve maize yields thus a boost to food security. in addition to that, Utilization of FAW larvae as poultry feed would promote food security in its protein conversion into poultry products.

1.2 Statement of the Problem

Food security is threatened by the invasive FAW, which is causing serious damages to Maize and other cereals (Goergen, *et al*., 2016). Maize prices per kilogram have been relatively lower, for example, between 2013 to 2016, where maize was sold at 0.41 USD, 0.44 USD, 0.42 USD, and 0.42 USD, respectively compared to 2017 when the prices went up to 0.56 USD due to maize scarcity (Kenya National Bureau of Statistics (KNBS), 2018).

Moreover, invasion of fall armyworm (FAW) can contribute up to 100% maize yield losses, in case of severe attack resulting in maize scarcity (MOA, 2017). Furthermore, according to KNBS, (2018), maize production declined from 37.8 million bags in 2016 to 35.4 million in 2017 due to drought, pests such as FAW, and diseases. Consequently, the livelihoods of more than 3 million people are at risk due to food insecurity (FAO, 2018b).

The use of chemicals to control this pest have some detrimental effects on the environment (Prasanna *et al*., 2018). However, not many studies have sought to come up with a more sustainable and environmentally friendly management strategies to minimize the use of pesticides but this. Visual cues have also been utilized to monitor and control nocturnal insects (Meagher, 2001; Shimoda & Honda, 2013). Nevertheless, very few studies have documented the influence of visual cues in monitoring and mass trapping *Spodoptera* Spp. For these reasons this study assessed the response of Beet armyworm (BAW) as a model insect to FAW to specific light wavelengths for landing.

The use of trap crops is a strategy that has been used to reduce FAW populations in the main crop (Midega *et al*., 2018). It is noteworthy to mention that various studies have focused majorly on the attractiveness of the trap crop, but not much has been done on the dispersal of the insects from the crop (Holden *et al*., 2012). For this reason, this research aimed as well at reducing the pest population from the trap crop by picking the insects for feed.

In addition, no study has assessed FAW larvae as a potential poultry feed. Therefore, this study analyzed the nutritional profile of FAW larvae as an alternative source of protein.

General Objective

To assess the management strategy and the potentiality of fall armyworm (*spodoptera frugiperda*) larvae as poultry feed to boost food security.

1.2.1 Specific Objectives

1. To assess the optimal visual cues of FAW for landing.
2. To evaluate the effectiveness of mass trapping as a method of collecting FAW larvae.
3. To determine the potentiality of FAW larvae as poultry feed.

1.2.2 Hypotheses

1. Ho1. The response of FAW to various visual cues is the same.
2. Ho2. Mass trapping is not effective for collecting FAW larvae.
3. Ho3. FAW larvae is not a potential feed for poultry.

1.3 Justification

Management strategy of fall armyworm *Spodoptera frugiperda* (FAW) that would possibly lower the pest population in the field is vital. Currently, commercial traps which need reflection of sunlight to be visible are not attractive to nocturnal insects. The available light traps also appear to use unattractive light wavelengths. This study aimed at managing FAW through mass trapping using a Light Emitting Diode (LED) water trap with attractive light colours and trap crops.

In order to boost food security, sustainable agricultural practices that conserve the environment are required. Therefore, the management strategy in the current research would minimize pesticides residue in agroecosystems thus offering the solution in terms of the maximum residue level (MRLs) on agricultural products. It will also be able to boost food security by improving maize production.

The potentiality of FAW larvae as poultry feed would lead to global food security. This is because; there will be new business ventures, increased sources of income, availability of cheaper sources of protein for the poultry and reduced food-feed competition.

Significance of the Study

The study is significant to the researchers as it improved their knowledge on the fall armyworm *Spodoptera frugiperda*: the current distributions, biology, management strategies, and their nutritional profile. The researchers were able to contribute new ideas to science by identifying optimal visual cues for the insect.

The findings of this study are vital to the university's African Centre of Excellence in Sustainable Use of Insects as Food and Feed (ACE II INSEFOODS). It brings new knowledge on the potentiality of utilizing *S. frugiperda* larvae as poultry feed. The mass trapping strategy developed by this study could be used for harvesting other nocturnal insects for food and feed.

Since fall armyworm is a threat to food security in Kenya as mentioned by MOA (2017) this new insight could be used to develop a novel trap with improved trapping efficiency. The ability of the LED trap to capture both male and female *Spodoptera frugiperda* moths, different from a pheromone trap that catches male moths only, would significantly lower their populations. This would increase maize yield thus, boosting food security at the community level and the nation.

Mass trapping of FAW moths and harvesting of the larvae from the field would minimize the environmental risks that are posed by the use of chemicals. Using feed such as FAW larvae with low environmental impact for poultry production would also reduce greenhouse gas emissions (van Huis & Oonincx, 2017).

According to FAO (2021), about 811 people are malnourished, this is attributed to the climate change crisis, which has also led to poverty. Therefore, there is a need for a greener, more inclusive, resilient, and sustainable agri-food system. The findings of this study are in line with the FAO agenda, since the mass trapping strategy will be able to minimize pesticides application. Harvesting the insects for feed will help in nature conservation. Moreover, improved maize yields would alleviate poverty especially for small-scale farmers.

1.4 Scope of the Study

A preliminary study was conducted between 3rd November, 2019 to 31st January 2020 at Wageningen University and Research in The Netherlands to develop an efficient and effective strategy for mass trapping the FAW adults. The study aimed to investigate the optimal visual cues of FAW to develop an effective mass trapping strategy for the pest. It also evaluated the proximate composition of FAW larvae compared to other chicken feeds. A field study was then conducted between April 2020 and August, 2021 to test the effectiveness of the trap design and lures together with a trap crop (Brachiaria) in mass trapping FAW for poultry feed. Proximate analysis was performed for the collected larvae to determine their nutritional composition as chicken feed.

1.5 Limitations

Insufficient rainfall, especially during the short rains, which required irrigation and replanting. The research had limited funding which posed a challenge in data collection, thesis writing, and manuscript preparation.

1.6 Definition of Terms

1. Visual cue

According to Merriam-webster, (2022a) "Visual is defined as something (such as a graphic) that appeals to the sight and is used for effect or illustration" while, "cue is defined as a signal to a performer to begin a specific speech or action" Merriam-webster, (2022b). In this study, visual cue is used as sensory signal that is received by the eye in the form of light with the focus of the brain to everything that crosses the visual path.

2. Mass trapping

"Mass is a large quantity, amount, or number" while, "trapping means to catch or hold as if in a net" Merriam-Webster, (2022c); (2002d). This research defines mass trapping as a method of luring insects in large numbers to a trap that contains an attractant.

3. Trap cropping

"Trap is something that catches and holds" while cropping means "to look after or assist the growth of by labor and care" Merriam-webster, (2022e); (2022f). In the current study, trap cropping, is the use of other plants to attract agricultural pests especially insects from the main crop. They can be planted at the boarders of the field of a main crop or planted in various spots in the fields

4. Feed

Feed is defined as "food for livestock specifically**:** a mixture or preparation for feeding livestock" Merriam-webster, 2022g. in this research it was defined as food grown or developed for domestic animals especially livestock and poultry in animal production.

5. Polyphagous pest

Polyphagous means "feeding on or utilizing many kinds of food" while pest is "something resembling a pest in destructiveness especially**:** a plant or animal detrimental to humans or human concerns (such as agriculture or livestock production)" Merriam-Webster, (2022h); (2022i). Polyphagous pest is defined in this study as an insect that is capable of feeding on many plant species.

6. Entomophagy

Entomophagy is the practice of eating insects Merriam-webster, 2022j, in this research entomophagy is used to mean utilization on insects for feed.

CHAPTER TWO

2 LITERATURE REVIEW

2.1 Research Gap

Fall armyworm is a troublesome pest of maize in Africa (Goergen *et al*., 2016; MOA, 2017) hence there is need for a sustainable solution to manage it. The use of chemicals to control this pest have some detrimental effects on the environment (Prasanna *et al*., 2018). However, not many studies have sought to come up with a more sustainable and environmentally friendly management strategies to minimize the use of pesticides but this. Visual cues have also been utilized to monitor and control nocturnal insects (Meagher, 2001; Shimoda & Honda, 2013). Nevertheless, very few studies have documented the influence of visual cues on Spodoptera species.

The current sunlight reflected commercial traps may not be attractive to the FAW moths (Okello *et al*., 2020). Moreover, the available trap especially the funnel or bucket (Universal traps) use pheromone which only attract the male moths (FAO, 2018c.; Prasanna *et al*.,2018). Besides, no study has come up with a trap that can attract both male and female FAW moths. Therefore, there is need to study the response of FAW moths to specific light wavelength to develop a trap which is capable of attracting both the male and female moths.

In order to concentrate insect pest species for ease of elimination, highly attractive stimuli such as trap crop can be used to pull the insects (Finch & Collier, 2012). The use of trap crops is a strategy that has been used to reduce FAW populations in the main crop (Midega *et al*., 2018). It is noteworthy to mention that various studies have focused majorly on the attractiveness of the trap crop, but not much has been done on the dispersal of the insects from the crop (Holden *et al*., 2012). For this reason, there is need to reduce the pest population from the trap crop.

Several studies have documented the nutritional profile of most insects for feed (Abro *et al*., 2020; Ebeneezar *et al*., 2021; Nyakeri *et al*., 2017) however, no study has assessed FAW larvae as a potential poultry feed. Therefore, analyzing the nutritional profile of FAW larvae as an alternative source of protein would give information on the benefits of this insects as feed. Consequently, harvesting the pest in the field for feed would lower its population thus improving maize yields.

2.2 Fall Armyworm

2.2.1 History

The fall armyworm (FAW) *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera: Noctuidae) is a native of the tropical regions of the western hemisphere from the United States to Argentina (Feldmann *et al*., 2019; Goergen *et al*., 2016; Prasanna *et al*., 2018). The permanent reproduction area ends North of Mexico and South of Brazil and merges to certain area where only temporary reproduction occurs (Feldmann *et al*., 2019).

This pest spread very fast due to its ability to fly more than 100 km per night (Feldmann *et al*., 2019). It has been reported in nearly all parts of Sub Saharan Africa (Prasanna *et al*., 2018; FAO, 2019) as well as the Middle East and Asia (Figure (Fig. 1)) (CABI, 2021).

This troublesome invasive pest was first reported in West and Central Africa in 2016 (Goergen *et al*., 2016; International Centre for Insect Physiology and Ecology (ICIPE), 2017), and it is currently threatening food security in almost all Sub Saharan African Countries (Abrahams *et al*., 2017; FAO, 2019). In Kenya, the first reports were in the western part of Kenya around February/March 2017 (MOA, 2017).

Information on the current distribution of FAW

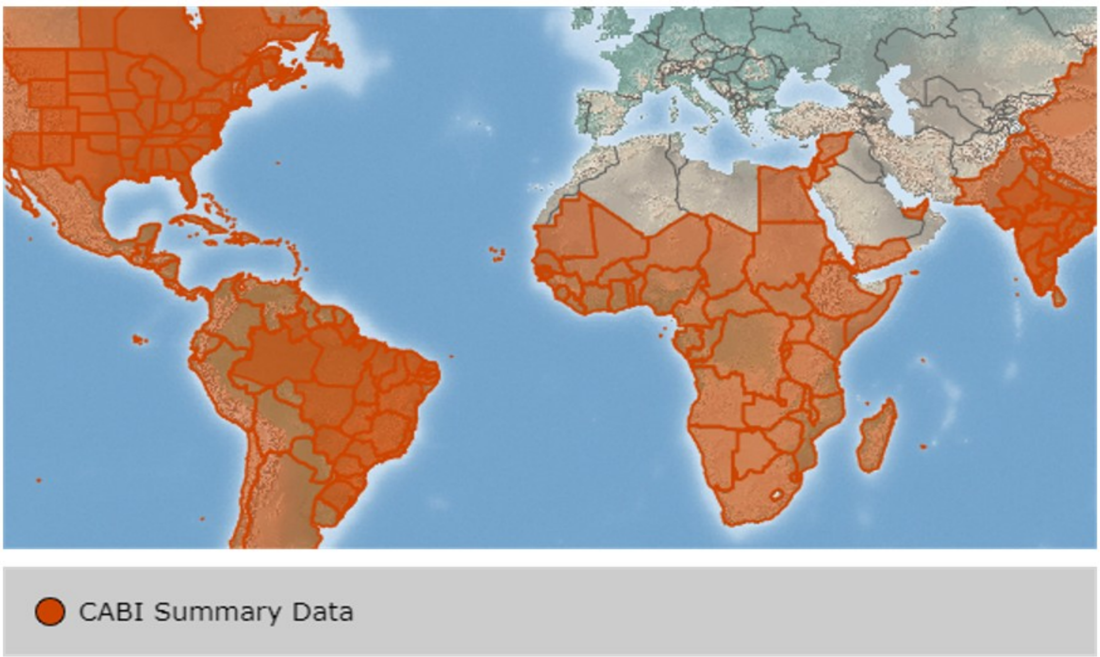


Figure 1: Areas affected by fall armyworm (in 2021)

Source: CABI, 2021

2.2.2 Damages of FAW

The incursion of FAW is severe when a new cropping season starts after a prolonged drought (Goergen *et al*., 2016). It attacks about 350 plant species (Montezano *et al*., 2018) with most preference to the grass family. The commonly, consumed plants are field maize and sweet maize, sorghum, Bermuda grass, and grass weeds such as crabgrass (*Digitaria* spp.). Under heavy infestation, they defoliate the preferred plants, acquire the typical "armyworm" habit, and disperse in large numbers, consuming nearly all vegetation in their path (Prasanna *et al*., 2018).

The damage to the plant depends on the development stage. For example, the neonate larvae usually bore the host plant and develop under protected conditions. Mature larvae cause cutworm damage by sectioning the base on the maize plantlet. At the vegetative phase, constant feeding results in skeletonized leaves and heavy windows on the whorls loaded with frass. Larvae also attack the reproductive parts of the grown maize plants (Goergen *et al*., 2016; MOA, 2017).

2.2.3 FAW Haplotypes

There are two strains, namely: maize strain and rice strain. The maize strain feeds mainly on maize, cotton, and sorghum, while the rice strain feeds primarily on pasture grasses (Ingber *et al*., 2021; Pashley *et al*., 1992). These two strains are identical morphologically but different in pheromone compositions (Prasanna *et al*, 2018; Heckel *et al*., 2009), mating, and host range (Prasanna *et al*., 2018; Heckel *et al*., 2009; Pashley *et al*., 1992).

In the Corn strain, mating was reported to occur in the early part of the night while in the rice strain it occurred in the last part of the night (Heckel et al., 2009; Pashley et al., 1992; Tessnow *et al*., 2022). Oviposition in the rice strain was reported to occurred throughout the night while for the corn strain majority oviposit during the first few hours of the scotophase (Heckel *et al*., 2009; Ingber *et al*., 2021). For these reasons, LED water trap would be a potential management strategy for FAW.

2.2.4 Description and Lifecycle of FAW

The FAW completes its life cycle in about 30 days in summer (at a daily temperature of around 28^{o}c). In cold moths it can take between 60 to 90 days to complete their life cycles (Prasanna *et al*., 2018). It does not have a diapause period (Prasanna *et al*., 2018; Goergen *et al*., 2016). Moreover, the pest occurs continuously through the year in case it is endemic. However, in areas where it is not endemic, migratory FAW invade when the environmental conditions are favorable (Prasanna *et al*., 2018).

The egg is about 0.4 mm in diameter and 0.3 mm in height as stated by Hardke *et al*., (2015) which further mentions that it has a dome shape. The base is flattened and the egg curves upward to a broadly rounded point at the apex. About 100 to 200 are laid per mass where approximately a total of 1500 eggs are produced per female moth. Most of the eggs are spread in a single layer attached to the foliage but sometimes they are produced in layers. Besides, the female also deposits a layer of grayish scales between the eggs and over the egg mass, imparting a furry or moldy appearance (Sharanabasappa *et al*., 2018). The eggs take 2 to 3 days period during the warm summer months to get to the larval stage (Prasanna *et al*., 2018).

The face of the mature larva may also be marked with a white inverted "Y" and on close examination of the epidermis of the larva it is rough and granular in texture (Prasanna *et al*, 2018; Hardke *et al*., 2015). Nevertheless, it does not feel rough to touch as does the earworm (*Helicoverpa zea* Boddie), since it lacks micropines. Sometimes the brownish larva could be green dorsally. The FAW would be identified best with a set of four large spots that form a square on the upper surface of the last segment of its body. The larval stage duration is about 14 days during the summer and 30 days during cooler weather (Prasanna *et al*., 2018; Sharanabasappa *et al*., 2018).

The FAW pupates typically in the soil at a depth of 2 to 8 cm. The larva constructs a loose cocoon by tying together soil particles with silk. The cocoon is oval and 20 to 30 mm in length. Sometimes the larvae web together leaf debris and other material to form a cocoon on the soil surface if the soil is too hard. The pupa is reddish-brown (Prasanna *et al*., 2018; Sharanabasappa *et al*., 2018)and measures 14 to 18 mm in length and about 4.5 mm in width. The duration of the pupal stage is about 8 to 9 days during the summer but reaches 20 to 30 days during cooler weather (Prasanna *et al.*, 2018).

Adult FAW moths have a wingspan of 32 to 40 mm (Prasanna *et al*., 2018; Hardke *et al*., 2015). In the male moth, the forewing generally is shaded gray and brown, with triangular white spots at the tip and near the center of the wing. The forewings of females are less distinctly marked, ranging from a uniform grayish brown to a fine mottling of gray and brown (Prasanna *et al*., 2018; Sharanabasappa *et al*., 2018). The hind wing is iridescent silver-white with a narrow dark border in both sexes. Adults are nocturnal and are most active during warm, humid evenings. After a preoviposition period of 3 to 4 days, the female moth normally deposits most of her eggs during the first 4 to 5 days of life, but some oviposition occurs for up to 3 weeks (Prasanna *et al.,* 2018).

Movement by the adults is initiated at dusk around early evening near host plants that are suitable for feeding, oviposition, and mating. The early evening movement is generally with the wind and extends from a few feet up to 30 feet above the canopy if a population is near corn fields(Cruz-Esteban *et al*., 2021; Sparks, 1979). Duration of adult life is estimated to average about 10 days, with a range of about 7-21 days (Prasanna *et al*., 2018; Sharanabasappa *et al*., 2018).

2.3 Management of FAW

2.3.1 Chemical Control

Fundamentally, chemicals have been used to respond to the incursion of the FAW in the maize fields in Africa (Prasanna *et al*., 2018). To manage the pest effectively, large quantities of insecticides and sometimes the use of multiple types and formulations of chemicals is required (Togola *et al*., 2018). The application of the chemicals leads to chemical residues in the environment that threaten humans, non-target organisms, and biodiversity (Prasanna *et al*., 2018; Togola *et al*., 2018). Furthermore, an ineffective application can reduce pests and increase pest population pressure, and more significant damage to crops (Prasanna *et al*., 2018).

FAO and World health organization (WHO) have set up permissible residue limits for pesticides and their derivatives. However, pesticides residues are still found in soil, foods, and other goods due to misuse, abuse, or overuse, making them stored in soil (Togola *et al*., 2018). This could be attributed to the choice of the chemical for use which is based on the farmers' knowledge and ability to purchase

Therefore, most smallholder farmers go for cheaper products (Midega *et al*., 2018). Besides, many farmers are unfamiliar with the pest and lack knowledge on pesticide safety and pre-harvest intervals associated with specific insecticides used for the pest. This is because FAW is a newly introduced pest in Africa (Feldmann *et al*., 2019; Goergen *et al*., 2016; Prasanna *et al*., 2018). FAW has also developed resistance to most chemicals, such as synthetic pyrethroids, which may be used extensively in Africa (Prasanna *et al*., 2018). For these reasons, there is a need for an alternative control strategy that is sustainable and environmentally friendly.

2.3.2 Host Plant Resistance

Host plant resistance is an essential Integrated Pest Management (IPM) strategy against fall armyworm. It is vital for the African context, where the majority are poor resource farmers with limited access to safe and affordable FAW control options (Feldmann *et al*., 2019). Validation and identification of new sources of resistance in the African context, germplasm with native resistance to FAW in the American continent and Africa-adapted maize inbred lines, pre-commercial and commercial hybrids are currently being evaluated by International Maize and Wheat Improvement Center (CIMMYT) against FAW populations in Africa (Prasanna *et al*., 2018).

2.3.3 Biological Control

The ability to regulate an organism's population naturally is referred to as natural control. It could result from biotic regulation for example food availability, parasites, predators and pathogens or abiotic factors such as climate and soil factors (Ordóñez-García *et al*., 2015). In case of disruption of the natural control systems due to anthropogenic activities in farm management such as monocropping, use of susceptible cultivars and poor use of broad spectrum pesticides then there would be outbreaks of pest and diseases (Prasanna *et al*., 2018).

Biological control mostly focusses on restoring the natural control, this is where living organisms (parasites, predators, or pathogens) are introduced by human to regulate the population of another organism at densities less than those that would occur in their absence (Prasanna *et al*., 2018). There are various natural antagonists of FAW available in North and South America (Feldmann *et al*., 2019; Sisay *et al.,* 2019) which could be used in Africa and Europe (Feldmann *et al*., 2019).

The use of entomopathogens have been exploited as one of the biocontrol strategies in the past for insect pests (Feldmann *et al*., 2019; Sisay *et al*., 2019). Insects' pathogenic viruses such as baculoviruses of the family baculoviridae are important sources of microbial control agents, especially for the control of lepidoptera pests (Feldmann *et al*., 2019; Lacey *et al*., 2015). According to (Feldmann *et al*., 2019) baculoviruses could be isolated from caterpillars of FAW and *Spodoptera littoralis*. It has been proven to be very effective against FAW hence it could be used in Africa. Other beneficial pathogens for FAW are fungi, bacteria (*Bacillus thuringiensis*) and nematodes (Hruska, 2019).

Botanical pesticides are potential biocontrol strategies for the FAW (Hruska, 2019; Stevenson *et al*., 2017). An aqueous seed extract from *Carica papaya* was reported to produce significant mortality of FAW larvae. In Colombia *Polygonum hydropiperoides* produced larval mortality as high as a commercial insecticides (Hruska, 2019).

2.3.4 Handpicking

One of the integrated approaches to least-toxic control of FAW by smallholder farmers is a low-cost control measure that is labour intensive but nonetheless effective (Prasanna *et al*., 2018; Tambo *et al*., 2020). These could be searching for egg clusters in the field and crushing them with fingers (MOA, 2017; Tambo *et al*., 2020). Searching maize plants to pick FAW has a cost (Prasanna *et al*., 2018; Tambo *et al*., 2020), for example searching a maize field of 50 plants at 5 seconds per plant would cost 70 hours in labour (Prasanna *et al*., 2018).

Nevertheless, Cultural control practices that may be too labor intensive for commercial farmers such as hand picking of larvae could be sensible to smallholder farmers (Harrison *et al*., 2019; Tambo *et al*., 2020), more so if they do not have any other means of control and if labor is not an issue (Prasanna *et al*, 2018). For these reasons collecting FAW larvae from the maize plant and feeding to the chicken would probably lower their populations.

2.3.5 Other Management Strategies

Other cultural practices such as, placement of ash/sand/soil (Harrison *et al*., 2019; Prasanna *et al*., 2018; Tambo *et al*., 2020)/chili powder in maize whorls, application of sugar water to maize foliage and deep tillage are being tried by some smallholders in Africa (Prasanna *et al*., 2018). According to (Chepngeno, 2019) farmers in the North Rift-Kenya are already using soil to kill FAW (Fig. 2). However, there is still need for further research to establish the efficacy, practicality at scale and cost of these practices.

Figure 2 is a picture of a farmer using soil to control FAW larvae.

Figure 2: A farmer in Kapsemwa village in Kaptagat, Uasin Gishu County-Kenya pours soil on his maize crop affected by the fall armyworm

Source: Daily Nation News Paper 18/07/2019

2.4 Beet Armyworm (*Spodoptera exigua*)

Beet armyworm, *Spodoptera exigua* (Hübner) (Lepidoptera: Noctuidae) whose origin is the Asian continent, is a serious polyphagous insect pest worldwide. The pest has over 50 host plants such as beet, broccoli, lettuce, tomato, turnip, cotton, soybean (Omagamre *et al*., 2020), and potatoes (Fu et al., 2017).

It is one of the important species in the genus Spodoptera. This is because it has strong capacity for long duration – flight, high fecundity, numerous host plants, rapid growth rate, and the rapid evolution of resistance to pesticides (Fu *et al*., 2017). Beet armyworm is capable of completing its life cycle within 24 days (Omagamre *et al*., 2020).

This pest has been used as a model insect for Plant – insect interaction studies (Omagamre *et al*., 2020) and also as the experimental model to investigate the mechanism of vision in nocturnal insects (Liu *et al*., 2018). For these reasons it was chosen as a model insect for *S. frugiperda* in the optimal visual cue experiment in this study.

2.5 Visual Cues

In insects, colour vision is vital (Westmore *et al*., 2019) when they search for food, mate, oviposition sites or homing (Liu *et al*., 2018; Prokopy & Owens, 1983; E. Warrant & Dacke, 2010, 2016). Many moths especially in the genus *Spodoptera* are nocturnal, meaning they are most active in the night. They have superposition eyes *(*Langer *et al*., 1979; Satoh *et al*., 2016) which are believed to be sensitive to light and are suitable for life in dim light (Land & Chittka, 2013; Satoh *et al*., 2016; E. Warrant & Dacke, 2010).

Vision in nocturnal insects allows them to orientate during flight and sometimes to locate food. These insects are capable of holding a straight-line course by using celestial patterns (Warrant, 2017) of polarized light as compass cue, orienting to constellations of stars and shoreline of a beach at night to enable stability and control over flight and landing. This is achieved by using the pattern of optic flows (movement of visual features a cross the retina induced by the animal's own movement) (Warrant & Dacke, 2010, 2016).

According to Shimoda & Honda, (2013) insects such as moths, beetles and stinkbugs are attracted to artificial light sources. Hawkmoths (*Macroglossum stellatarum*, *Manduca sexta*) prefer blue (440 nm) and yellow (540 nm) lights to lights of other wavelengths (Warrant *et al*., 2012).

Two approaches of visual stimuli have been explored in pest management. These are (a) incorporating visual cues in traps for population monitoring or direct control (Prokopy & Owens, 1983; Shimoda & Honda, 2013; van Tol *et al*., 2007), and (b) use of visual cues to disrupt host detection process (Prokopy & Owens, 1983; Shimoda & Honda, 2013). Therefore, knowledge of visual properties of moths especially in the genus *Spodoptera* would help to improve the attractiveness of moth traps.

2.6 Chemical Cues

Compounds released naturally by the insect to govern all aspects of their behaviour such as mating, aggregation, defense, host recognition, and resource allocations are known as Semiochemicals (Davidson *et al*., 2015; El-sayed *et al*., 2006). Volatiles from food and host plant sources have been used to attract male and female insects searching for food and females searching for oviposition sites (El-sayed *et al*., 2006; Knudsen & Tasin, 2015).

The female of a Lepidoptera insect typically releases a species-specific sex pheromone that only attracts males in moths. There is already a synthetic sex pheromone used to capture male moths and reduce mating in females (Cruz-Esteban *et al*., 2021; El-sayed *et al*., 2006; Sparks, 1979). Moreover, three compounds, namely: (Z)-9-tetradecenyl acetate (Z9-14: OAc), (Z)-11-hexadecenyl acetate (Z11-16: OAc), and (Z)-7-dodecenyl acetate (Z7-12: OAc) were reported in FAW females (Andrade *et al.*, 2000; Cruz-Esteban *et al*., 2018; Lima & McNeil, 2009).

The compounds were consistently released by FAW females from all populations (Cruz-Esteban *et al*.,2018) and evoked significant antennal responses (Andrade *et al*., 2000; Cruz-Esteban *et al*., 2018). Z7-12: OAc appeared in a minor concentration but elicited a higher antennal reaction. It is a very important component for *S. frugiperda* sex pheromone for attraction of the males in the field (Cruz-Esteban *et al*., 2018). This is because when it is combined with Z9-14: OAc it results in a highly attractive blend to males in the field (Cruz-Esteban *et al*., 2018; Unbehend *et al*., 2014). Therefore, it could probably play a role in stabilizing sexual selection (Cruz-Esteban *et al*., 2018).

S. frugiperda males were attracted to binary blends of Z7-12: OAc and Z9-14: OAc in the fields of different regions (Andrade *et al*., 2000; Unbehend *et al*., 2014). However, (Andrade *et al*., 2000) showed that numerically higher captures were consistently obtained to blends of Z9-14Ac, Z11-16Ac and Z7-12Ac than to the binary combination of Z9-14Ac and Z7-12Ac. Therefore, there is need to explore possible combinations to come up with effective pheromones.

2.7 Trap Cropping

Trap cropping involves luring insect pests away from the main crop to a more attractive host plant growing beside or around the crop (Cotes *et al*., 2018; Midega *et al*., 2018). It can be effective and sustainable pest management strategy, that involves manipulation and diversification of habitat(Cotes *et al*., 2018; Holden *et al*., 2012). Studies have shown that trap cropping in agroecosystem can potentially reduce crop damage by pests and minimizes the use of conventional pesticides, it has also been suggested to control invasive insects in natural ecosystems (El-sayed *et al*., 2006; Midega *et al*., 2018). Therefore, trap crop such as Brachiaria CV Mulato II could be used to trap FAW in maize farms (Midega *et al*., 2018).

Focus has been given majorly on the attractiveness of the trap crop (Cheruiyot *et al*., 2018; Cotes *et al*., 2018; Holden *et al*., 2012) but little has been done on the dispersal of the insects from the crop. For effective trap cropping designs, there is need for additional practices that prevent insects from dispersing back to the main crop. These techniques include trap harvesting, sticky traps, planting a high proportion of trap plants or applications of pesticides or natural enemies (Holden *et al*., 2012). The current study aimed at harvesting the FAW larvae from the trap plant in order to reduce its population thus preventing their dispersal into the main plot.

2.8 Insects Identification

Maximisation of the trapping efficiency (number of individuals caught) in traps is often important. several reports have been made on the efforts to achieve maximum trap capture through the use of attractive colours or semiochemicals, positioning of traps in optimal locations and increasing the size of the trap (Davidson *et al*., 2015; Taylor *et al*., 2014).

Besides ensuring maximum trap capture, accurate identification of the insects caught by a trap is critical (Augustin *et al*., 2012; Melanie M Davidson *et al*., 2015).During surveillance or eradication programs of new incursive species, it is necessary to accurately identify the invaders at low relative density with respect to similar looking related species (Davidson *et al*., 2015; Yousaf *et al*, 2022).

A reliable identification of moths in the genus Spodoptera is best carried out on adult stages. Identification of the adults is based on wing colour and wing pattern by comparing the specimens to the pictures as described by Van der Straten *et al*., (2015). For reliable identification, a dissection of the genitalia is needed (Amano & Nomura, 2021; Van der Straten *et al*., 2015) especially when the moths are captured in water which washes the scales off.

Molecular identification is one of the accurate methods of insect identification but it is advisable that it is performed along side morphological identification (Van der Straten *et al*., 2015). Some of the advantages associated with this method are: it can be applied to any life stage, efficient for multiple and bulk samples, and the uniformity of techniques (Amano & Nomura, 2021). Nevertheless, these methods normally need expensive equipment and reagents, and sometimes can be more time consuming than morphological identification by experienced entomologists (Amano & Nomura, 2021; Van der Straten *et al*., 2015).

2.9 Poultry Feed

Globally, there has been consistent production of poultry for meat and eggs over the years and the trend is likely to continue. The rise in poultry production is having a great effect on the demand for feed and raw materials (Allegretti *et al*, 2017; FAO, 2013). Fundamentally, feed is the most important input for poultry production in terms of cost. The availability of low-priced, high-quality feeds is important (Abro *et al*., 2020) if poultry production is to remain competitive and continue to grow to meet the demand for animal protein (FAO, 2013).

Poultry feed in most parts of the world consist of animal protein sources, such as fish meal, meat, and bone meal (Ochieng *et al*., 2021), while major plant protein sources include soybean meal (Allegretti *et al*., 2017; Ochieng *et al*., 2021), cotton seed, sunflower seed cake, and peanut products, with the main source of energy being maize (Ochieng *et al*., 2021).

Even though majority of poultry farmers depend on soybean meal as the main protein source for feed, there is competitive use of this legume in other animal diet. Therefore, there is need to search for viable alternatives (Allegretti *et al*., 2017). Moreover, Charlton *et al*., (2015), reported that invertebrates contribute to the natural diet of wild fish and `free range` monogastric livestock across the world offering the potential to be used effectively as alternatives to other animal and soy based proteins in animal feeds. Therefore, FAW would be a potential feed for the chickens in Kenya.

2.10 Nutritional Profile of Insects

Insects are sources of very high-quality feed (Abro *et al*., 2020; Duinkerken *et al*., 2012) that can be supplemented in poultry diets. Black soldier fly and the common housefly can be very good sources of protein for poultry. The black soldier fly larvae /BSFL) has been reported to contain 36.6% - 62.7% crude protein and 14.0%-40.7% fat (Abro *et al*., 2020; Ebeneezar *et al*., 2021; Ewald *et al*., 2020; G. Duinkerken *et al*., 2012; Mohammed *et al*., 2017; Shumo *et al*., 2019).

The common housefly (*Musca domestica*) which has been utilized mostly as poultry feed is reported to constitute between 43 – 68% crude protein and 4 – 32 % fat (Elahi *et al*., 2020; Fitches *et al*., 2019; G. Duinkerken *et al*., 2012; Hussein *et al*., 2017; Pieterse & Pretorius, 2014). According to Duinkerken *et al*., (2012), the crude protein content in common house fly is comparable to soybean meal which is a conventional poultry feed.

Previous studies have shown than fall armyworm fed on artificial diet had crude protein of 59% and fat of 20.6% while those fed on fresh plant materials had a crude protein of 59.3 % and fat of 11.7% (Williams *et al*., 2016). Therefore, FAW larvae could be a potential source of protein.

CHAPTER THREE

3 MATERIALS AND METHODS

3.1 Introduction

This chapter outlines the 3.2 study area, materials and methods used in 3.3 Optimal visual cues of FAW for landing, 3.3.1 Mass rearing of Beet armyworm (BAW) as a model insect for the FAW, and 3.3.2 Visual targets. 3.4 Effectiveness of mass trapping FAW, 3.4.1 Trap capture data 3.4.2 Infestation level of FAW and plant damage, 3.4.3 Insects' identification, and finally, 3.5 Proximate composition of FAW larvae.

3.2 Study Area

Experiment 1: Optimal visual cues of FAW for landing

The research was conducted between 3rd November 2019-31st January 2020, in the Netherlands at Wageningen University and Research in the Business unit Bio interactions and Plant Health Laboratories, 51°58'0.90" N 5°39'18.57" E (Latitude.to a, 2021).

Experiment 2: Effectiveness of mass trapping

This experiment was conducted at Jaramogi Onginga Odinga University of Science and technology -Siaya Campus, in the School of Agricultural and Food Sciences (SAFS). Siaya is dry near Lake Victoria and wet about 50km away from there. The annual average rainfall increases from 800 mm at the lake shore to 200 mm near the border of Kakamega (Fig. 3). The agro-ecological zones extend from a poor livestock millet zone to a good sugar cane zone. Annual average temperature is about 22.8°c near Lake Victoria and in the northeastern part of the district it is 21°C. The Humidity in this area is high with evaporation rate between 1800 – 2000 mm per year (Jaetzold *et al*., 2009).

Location of School of Agricultural and Food Sciences (SAFS) – Siaya Campus (Fig. 3)

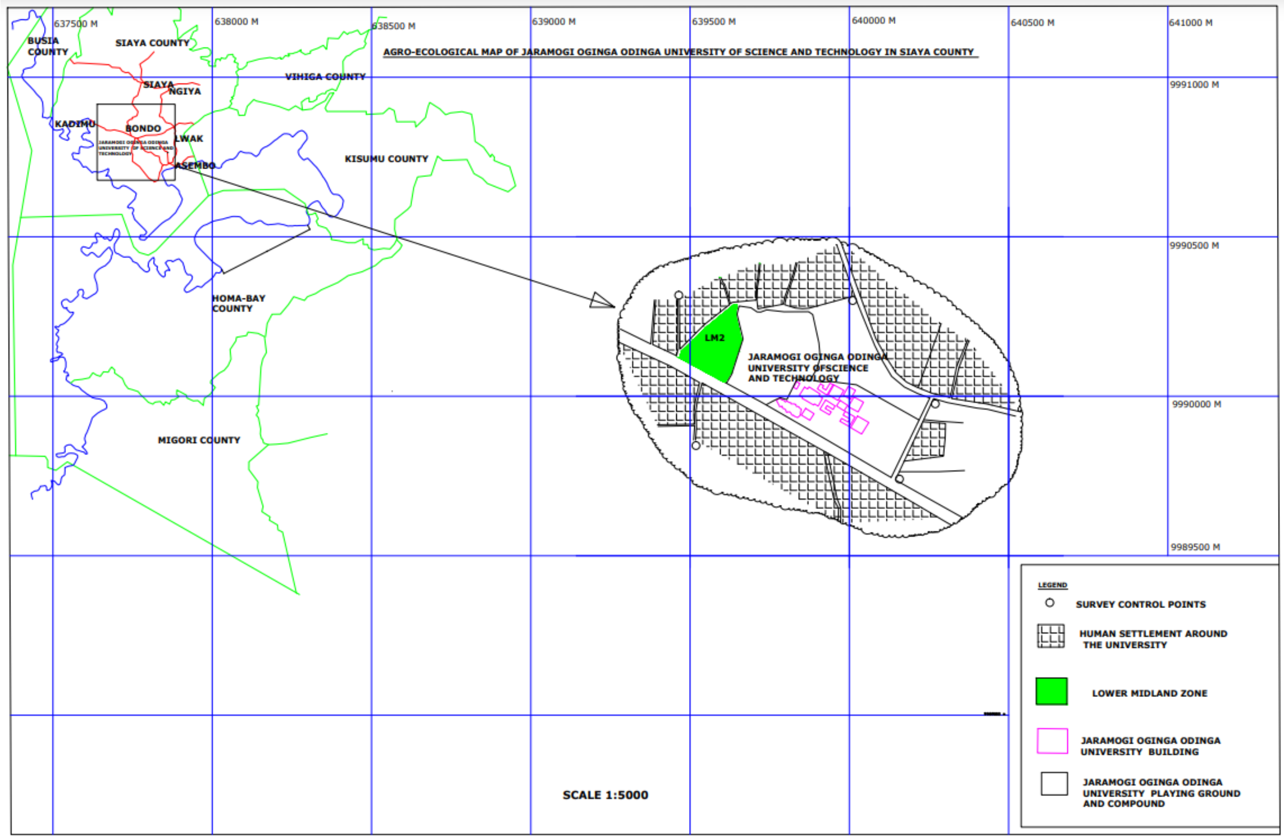


Figure 3: Map of School of Agricultural and Food Sciences (SAFS), Jaramogi Oginga Odinga University of Science and Technology - Siaya Campus

Source: Information obtained from (Jaetzold *et al*., 2009), the map drawn by Odero

Experiment 3: Potentiality of FAW larvae as poultry feed

Some of the samples were collected from the School of Agricultural and Food Sciences (SAFS) maize fields in Siaya (Fig. 3), while the rest of the samples were from Onywera Primary School in Sindo, Suba South – Homa-bay County (Fig.4). This region experiences annual average rainfall between 700 – 1800 mm. It has the sunflower maize zone with annual mean temperature of (20.5 – 19. 3)°C and Marginal cotton zone (22.7 – 20.4)°C (Jaetzold *et al*., 2009).

Location of Onywera Primary School in Sindo (Fig. 4)

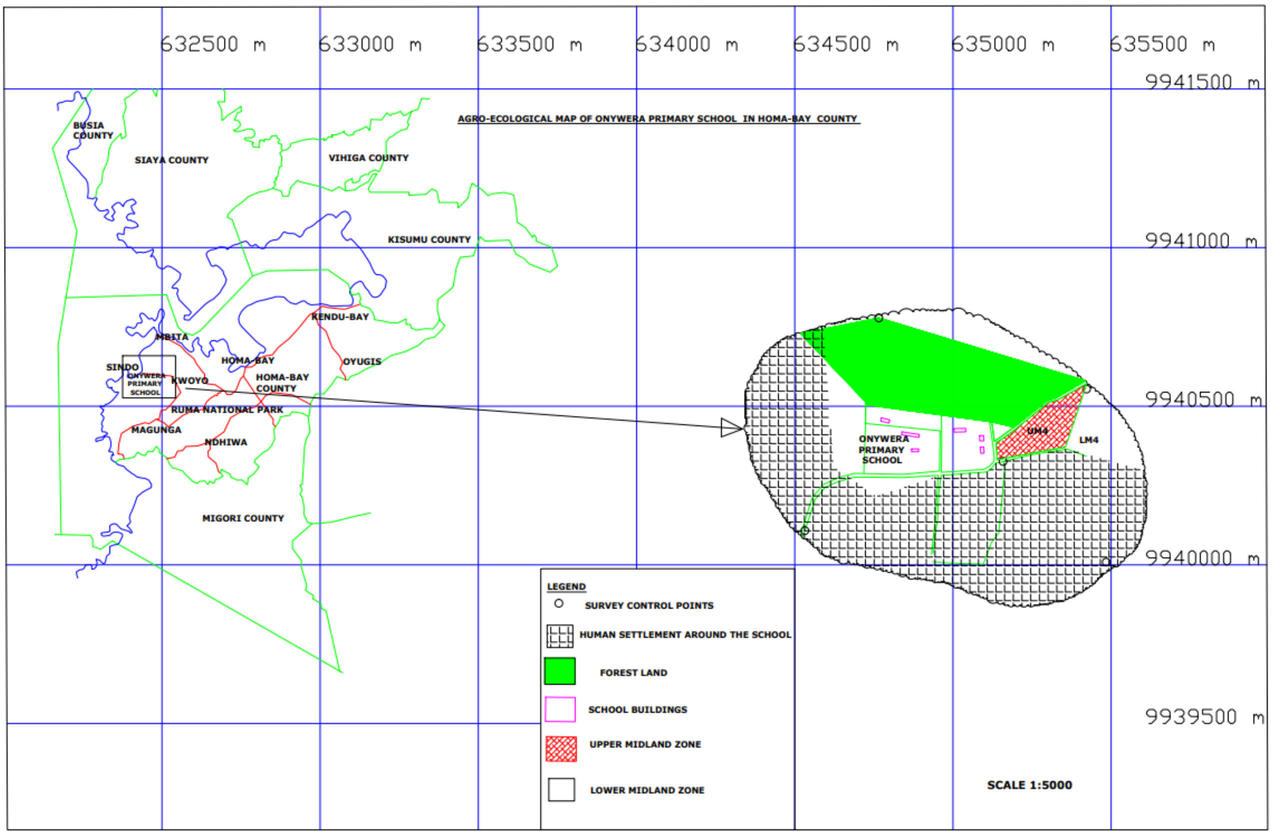


Figure 4: Map of Onywera Primary School in Sindo, Suba South

Source: Information obtained from (Jaetzold *et al*., 2009) the map dawn by Odero

3.3 Experiment 1: Optimal Visual Cues of FAW for landing

3.3.1 Mass Rearing of BAW as a Model Insect of FAW

The visual cue of *Spodoptera exigua* as a model insect for *Spodoptera frugiperda* was tested using freshly eclosed *Spodoptera exigua* moths. Ten days old L4/L5 larvae were put in 2 plastic nasi boxes (12.5 x 17 x 6.2) cm in a fridge at 28° C for three days. After that 100, one day old pupae were obtained from the Virology Laboratory in Wageningen University and Research every Monday morning.

The pupae were kept at 4° C in the entomology laboratory, where 20 pupae were taken daily and put in plastic nasi boxes on a thin film of vermiculite (2-3) mm from Sigma Aldrich (cas No: 1318-00-9). Water was then put in a small tube covered with oasis to provide humidity (Fig. 5) The boxes were covered with paper towels under the lids. Tiny pores were made on the lids, after which they were kept at 25° C. Therefore, 20 freshly eclosed adults were available for the experiment every day.

About 10 to 20 moths were collected from the nasi boxes by sedation using carbon dioxide at around 2.00 pm. They were then put in a cylindrical container (6 cm height and 7 cm diameter) covered with a net at the bottom and parafilm at the top (Fig. 6), which was left in the fridge until 5.00 pm.

Figure 5: Pupae in nasi box

Figure 6:Collection container

3.3.2 Visual Targets

The experiments began around 5.00 pm in the wind tunnel (Fig. 8), where moths starved for about 3 hours (Fig. 6) were released in the wind tunnel 90cm away from a water trap (illuminated with LED light of various colours from the bottom) (Fig. 8).

The water trap (Fig. 7d) is composed of a metal stand that is silver from inside and has a height of 10.5 cm and a diameter of 18 cm. It had a hole in the middle to hold the LED bulb (Fig. 7c). A diffused plate of diameter 18 cm to make the light diffuse (Fig. 5b) is put on the stand, followed by a large black painted petri dish on the sides, which is 5 cm high and the diameter is 19 cm (Fig. 7a). A small amount of Tween 20 from Schuchardt, Germany, was added to the petri dish to break the surface tension of the water. The total height of the trap was15.5 cm, while the release box was put on a stand 8 cm high (Fig. 7).

The spectralon was used to measure the dusk light with 99% purity for all colours. Spectral radiance was converted to photons since the photoreceptors in insects can count photons rather than energy (Cronin *et al*., 2014). The total number of photons of dusk light was 9.59E+16, and the photons for UV-A were 3.33E+15. The percentage spectralon of UV-A = (3.33E +15/9.59E+16) x 100 = 3.5%. While total spectralon of rooftop for the moths relative to the thrips was calculated to be (9.59E + 16/2.156+16) x 100. = 4.47% (Fig. 9) and (Fig. 10).

The wind speed was 2 cm/s, while humidity and temperature were 70% and 24° C, respectively. The number of the moths in the trap was recorded 30 minutes after the start of the experiment and then at the end of the experiment (after 14 hours). The treatments were seven light colours (365, 385, 400, 470, 530, 592 and 650) nm, where one colour was tested per day. Comparison of the colours was done using the same brightness (identical number of photons) of 3.50E+18 for each tested colour, N=7. The design of the experiment was Randomized Complete Block Design (RCBD) replicated 3 times using days as blocks.

Figure 7: a =Petri dish, b=white glass, c = stand and bulb, d = complete water trap

Figure 8 shows how the wind tunnel was set up.

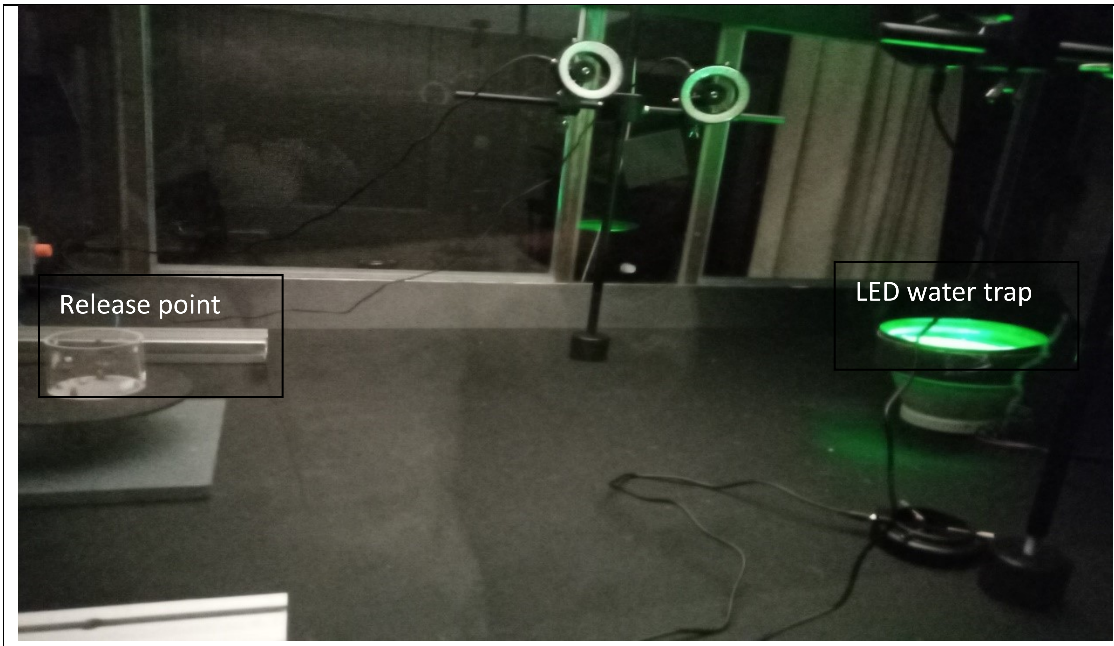


Figure 8 : Wind tunnel set up

Figure 9 and Figure 10 show the spectral reflectance of the wind tunnel roof top during the day condition and dusk condition.

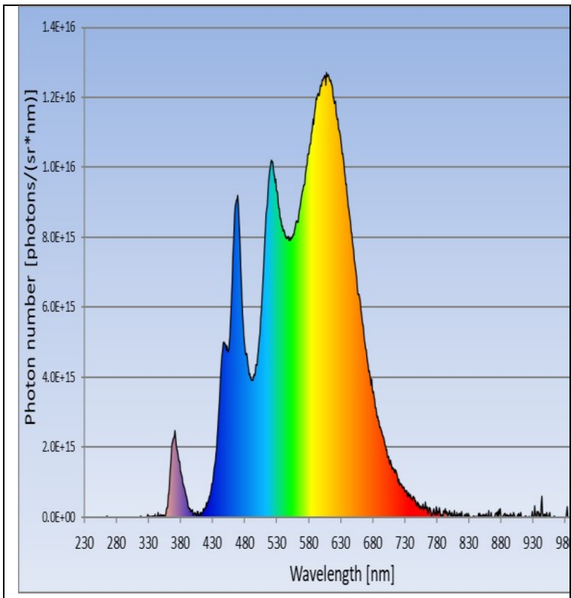


Figure 9: Spectralon rooflight day condition (M1) for thrips

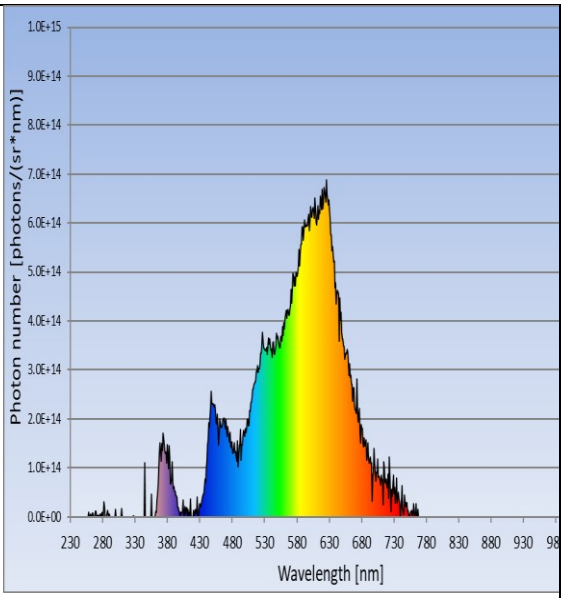


Figure 10: Spectralon moonlight condition (M3) for *Spodoptera exigua*

Source. van Tol

Data was visualized and analyzed using R software for statistical analysis R version 3.5.2 (2018-12-20). Normality and Homogeneity tests were performed using Shapiro-

Wilk normality Test and Levene's test, after which a one-way ANOVA was done. The outcome was presented in results.

3.4 Experiment 2: Effectiveness of Mass Trapping

The research was conducted over three seasons from April-July 2020 (long rains), September-December 2020 (short rains), and April-August 2021(long rains) at the School of Agricultural and Food Science (SAFS) in Siaya (Fig. 3), in order to test effectiveness of mass trapping FAW in the field. The experiments were conducted according to Midega *et al*., (2018) and modified to fit the research. In this experiment Three types of data were collected: 1. trap capture data, 2. infestation level of FAW and plant damage data, and Insects' identification data.

3.4.1 Trap Capture

Season 1: Long rains experiment (April-July 2020)

Water trap with UV-A (385 nm) LED light (Fig. 12e) and Delta trap (Fig. 12f) from Kenya biologics (control) were tested in Field 1(Fig. 10). The field was divided into plots of 6m x 6m with a path of 2m. It was then planted with DH04-Maize hybrid from Kenya Seed Company on 17/03/2020 at inter and intra- row spacing of 75cm and 30cm, respectively, for all the treatments. and splits of Brachiaria CV Mulato from the farmers Training Centre Siaya (FTC) farm in Siaya.

Diammonium phosphate (DAP) 18: 46:0 fertilizer was also applied at a rate of 60 kg/ha during planting. The brachiaria splits were then planted at a spacing of 50 cm x 50 cm and the innermost space of brachiaria was 1 m from maize. Thinning and 1st weeding was done on 20/04/2020 where thinning for maize was done to 1 plant per hill. Thereafter, 2nd weeding was done on 29/05/2020 and calcium ammonium nitrate (CAN) was used for top dressing at the rate of 60kg/ha.

The plots were subjected to four treatments namely; T0 = Maize Monocrop, T3 = Maize + Brachiaria, T4 = Maize + Brachiaria + Delta trap (kb) + Kenya Biologics pheromone (kbp) and T5 = Maize + Brachiaria + LWT with UV-A (385nm) + Pherobank pheromone, where they were replicated three times in a Randomized complete block design (RCBD) (Fig. 11). The traps were then placed at least 8m from one another.

The LED water trap (LWT) consisted of Light-emitting diode (LED) light (385 nm) (Fig. 12a) which illuminated the water trap from below. The light passed through a conical stand (Fig. 12b) wrapped with aluminium foil to help in reflecting the light into the water container (Fig. 12c). The container was covered all round with black insulating tape except the bottom part. The height of the plastic container was 5 cm and a diameter of 17.5 cm. A metallic stand (Fig. 12 d) measuring 33 cm x 28 cm x 22 cm was used to support the trap. Both the LWT (Fig. 12 e) and Delta trap (Fig. 12 f) were raised to a height of 1.5 m above the ground. Fresh water and soap were added into the container (Fig. 12 h) daily and then the LWT laid around 6.30 pm in the evening and removed in the morning around 7.00 am.

Five pheromones from Pherobank company The Netherlands, namely; *Spodoptera frugiperda* 2001, 2002, 2003, 2004/2005 and 2006 respectively, were tested together with the LWT. They were covered with a piece of net and suspended above the container using a wire (Fig. 12 g) which was attached to the metal stand. Three pheromones were chosen using simple random sampling with replacement method, where they were tested per week. The Delta trap (Fig. 12 f) from Kenya Biologics company was also tested along side a pheromone from the Kenya biologics company as a control experiment.

Data collection on trap captures started 49 days from planting for 5 weeks between May and June 2020. Three pheromones from Pherobank were tested together with Kenya Biologics pheromones for 7 days (N = 7).

Data was collected daily and only FAW moths which had clear morphological identification features were considered. The data was visualized and analysed using R software for statistical analysis R version 3.5.2 (2018-12-20). Where normality and homogeneity tests were performed using Shapiro-Wilk normality Test and Levene's test respectively. This was followed by Kruskal-Wallis H test and then Dunn's Kruskal – Wallis Multiple Comparisons (dunnTest) to separate the means. The relationship between the number of insects captured and time was analysed using the Mann-kendall test. A nonparametric loess curved was then fitted to the data to see the trend better.

Figure 11 is the design for the experiments in season 1 and season 2 in 2020.

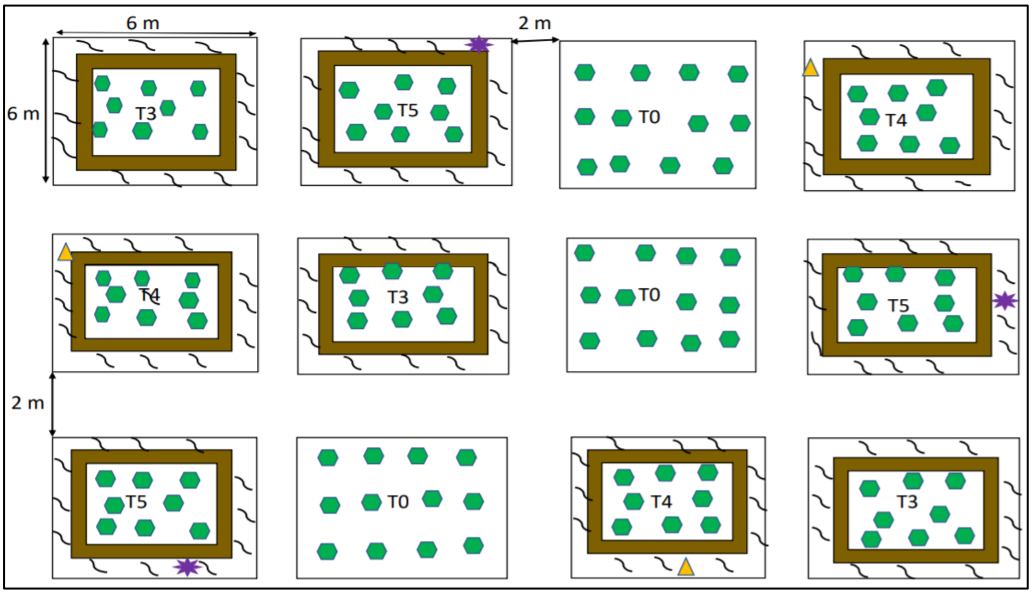


Figure 11: Layout field 1 (long and short rains 2020)

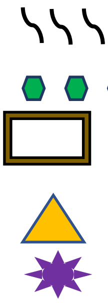
KEY

T0 = Maize Monocrop

T3 = Maize + Brachiaria,

T4 = Maize + Brachiaria + kb

T5 = Maize + Brachiaria + LWT



Brachiaria CV Mulato

Maize plants

1 m spacing between brachiaria and maize

Sticky delta trap (kb)

Water trap with UV-A (385 nm) LED light

Figure 12 is the LED water trap and the delta trap as was set in the field.

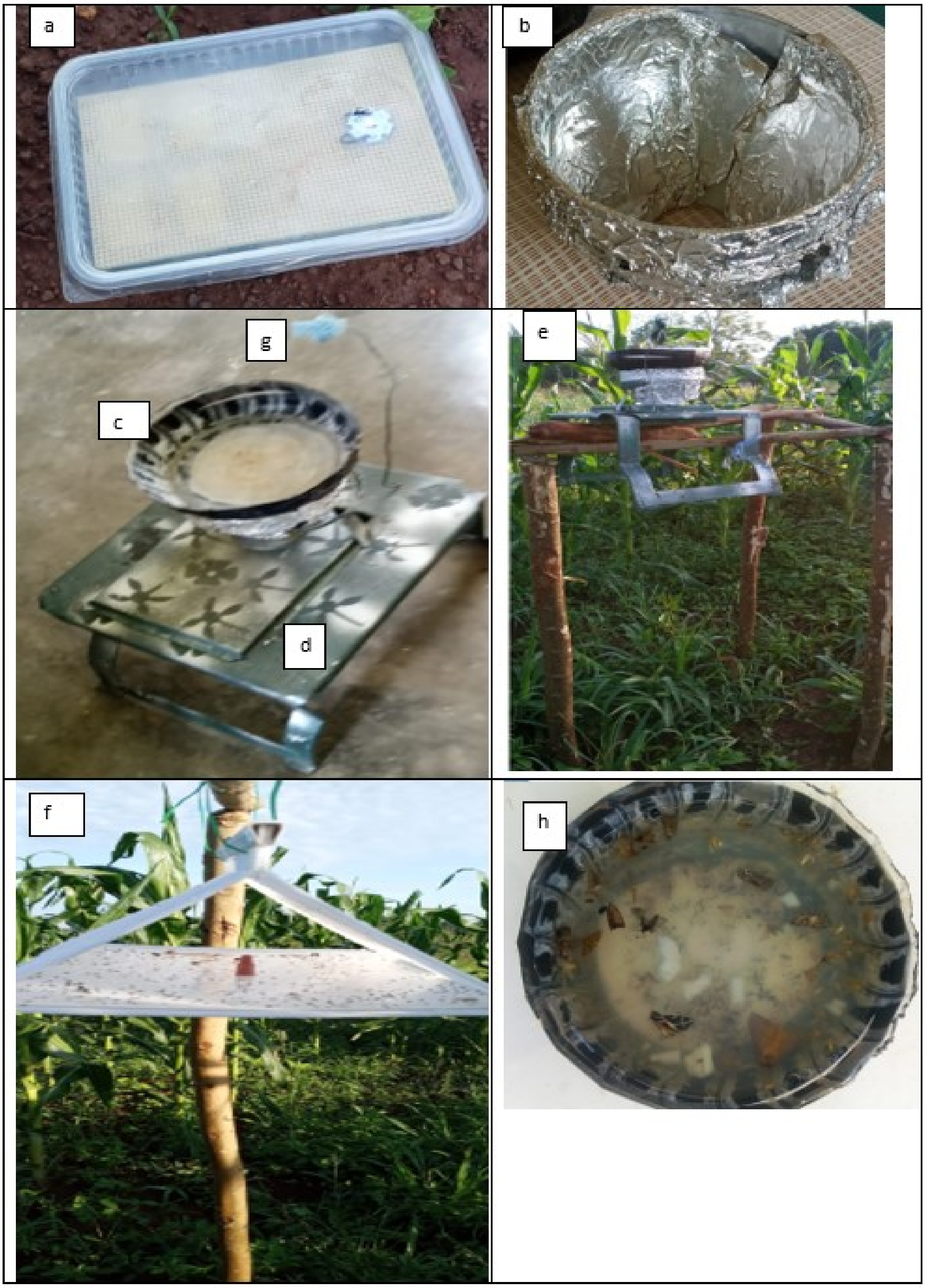


Figure 12: a = LED light, b = Conical stand, c = Water container, d = Metallic stand, e = LED Water Trap (LWT), f = Delta trap (kb), g = Pheromone, h = Container with water and soap

Season 2: Short rains experiment (September–December 2020)

In order to determine the appropriate time for FAW collection for poultry feed, the experiment was repeated in the short rains. Maize and brachiaria were planted in Field 1 (Fig. 11) in the short rains on 10/09/2020. The treatments and the procedure were the same as those in long rains April-July 2020. Data collection started two weeks after planting on 25/09/2020, where the trap captures data was collected daily for 7 days (N = 7).

To evaluate the effectiveness of LWT alone without pheromones, the study added more treatments. Therefore, another experiment was conducted in Field 2 in Siaya, at the School of Agricultural and Food Sciences (SAFS) experimental plots (Fig. 13) where maize and brachiaria were planted on 11/10/2020. The management practices remained the same as in Field 1. LWT with UV-A (385 nm) and LWT with white light (4500k) were tested with Pherobank pheromones (2001,2002,2003, 2004, and 2006) and the Kenya biologics pheromone. Six treatments were applied namely; T6 = LWT with UV-A only, T7 = LWT white light only, T8 = LWT with UV-A + Kenya Biologics pheromone (kbp), T9 = LWT white light + Kenya Biologics pheromone (kbp), T10 = LWT with UV-A + Pherobank pheromone and T11 = LWT with white light + Pherobank pheromone.

The data collection started on 2nd December 2020 for 7 days (N = 7) per a group of pheromones and went for 2 weeks. (Appendix. IV). The data was visualized and analysed using R software for statistical analysis R version 3.5.2 (2018-12-20). Where Shapiro-Wilk normality Test and a homogeneity test using Levene's test were used then followed by Kruskal-Wallis H test. The trend between number of insects captured and time was checked using the Mann-Kendall test for the data collected in field 1. In order to see the trend better, a nonparametric loess curved was then fitted to the data.

Figure 13 shows the experimental layout for the control experiment during the short rains of 2020.

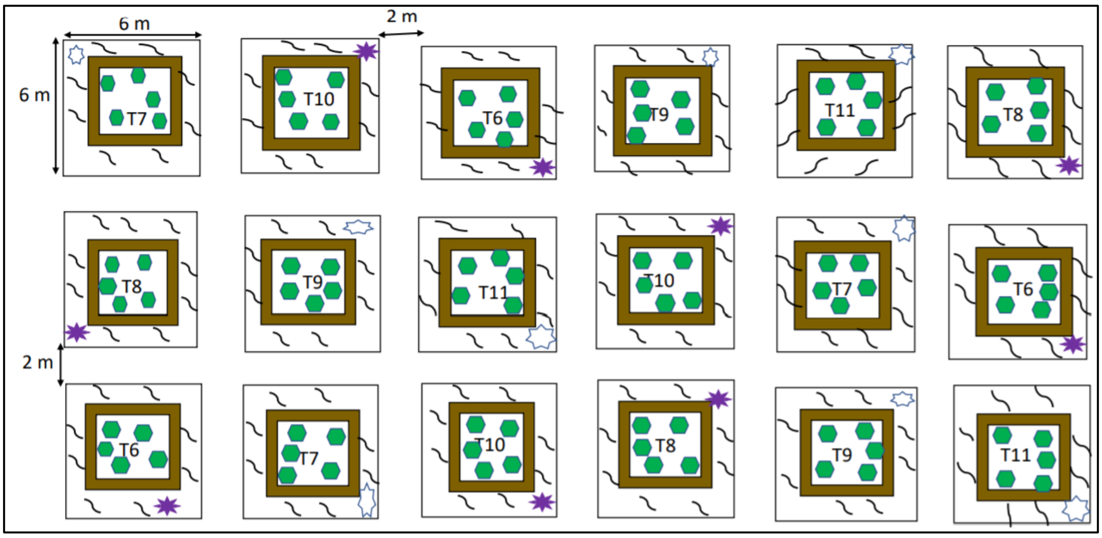


Figure 13: Layout Field 2 (Control experiment short rains 2020)

KEY

T6 = LWT with UV-A only

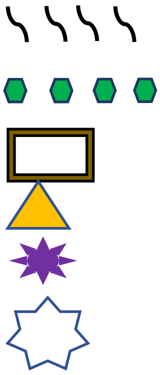
T7 = LWT white light only

T8 = LWT with UV- A+ Kenya Biologics pheromone (kbp)

T9 = LWT white light + Kenya Biologics pheromone (kbp)

T10 = LWT with UV-A + Pherobank pheromone

T11 = LWT with white light + Pherobank pheromone.



Brachiaria CV Mulato

Maize plants

1 m spacing between brachiaria and maize

Sticky delta trap (kb)

Water trap with UV-A (385 nm) LED light

Water trap with white LED light

Season 3: Long rains experiment (April – August 2021)

A repeat experiment was conducted in the long rains of 2021 (Fig. 14) since low data was recorded in the control experiment of 2020. Because some of the white lights were broken, only 5 UV-A and 5 white light traps were tested for the data to be comparable. Two pheromones, 2002 and 2004 from Pherobank were tested with the UV-A and white light. The data was collected for 9 days (N = 9) thereafter, it was visualized and analysed using R software for statistical analysis R version 3.5.2 (2018-12-20). Shapiro-Wilk normality Test and a homogeneity test using Levene's test was used for normality and homogeneity test. Thereafter, Mann Whitney U test was used to analyze the trap choice data.

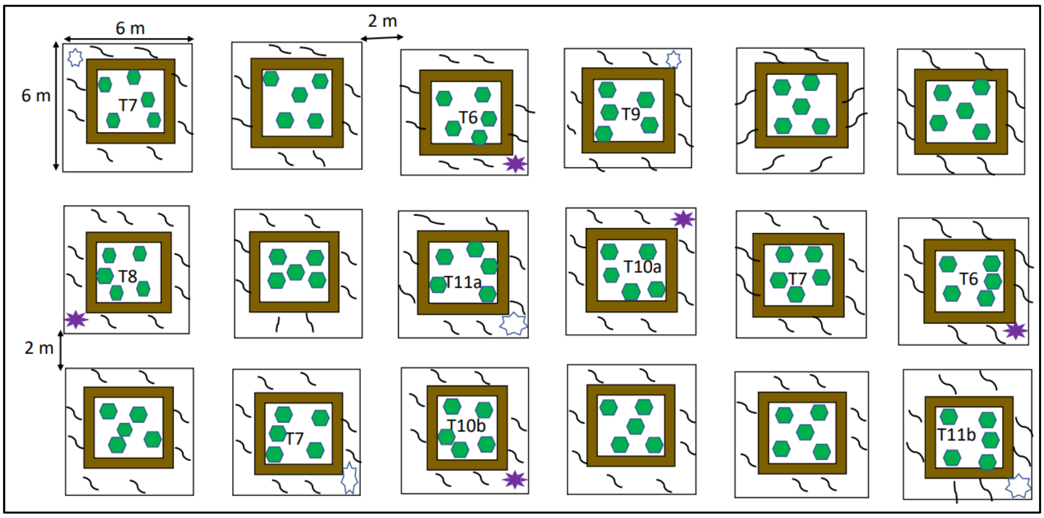


Figure 14: Layout Field 3 trap selection data (Long rains 2021)

KEY

T6 = LWT with UV-A only

T7 = LWT white light only

T8 = LWT with UV-A+ Kenya Biologics pheromone (kbp)

T9 = LWT white light + Kenya Biologics pheromone (kbp)

T10a = LWT with UV-A + Pherobank pheromone (2002)

T10b = LWT with UV-A + Pherobank pheromone (2004)

T11a = LWT with white light + Pherobank pheromone (2002)

T11b = LWT with white light + Pherobank pheromone (2004)

An experiment was also conducted between June and July 2021 in Field 4 in Siaya, School of Agricultural and Food Sciences (SAFS) experimental plots (Fig. 16) to include replicates since the data collected earlier was only temporal. Three traps design namely: water trap with UV-A (385 nm) LED light (Fig. 15 a), the delta trap (Fig. 15 b) and green bucket (funnel) trap (Fig. 14 b) together with lures: 2003 and 4 C from Pherobank, were tested in a maize field per plot measuring $12m^2$ and replicated 3 times.

The traps were laid 1 m from the ground level when the maize had attained at least 30 cm height. The spacing between the traps was at least 15m from each other. The study examined 8 treatments: T1 = Water trap +2003 only, T2 = Water trap with UV-A (385 nm) LED light only, T3 = Water trap with UV-A (385 nm) LED light + 2003, T4 = Water trap with UV-A (385 nm) LED light + 4C, T5 = Delta trap + 4C, T6 = Delta trap + Pherobank 2003, T7 = Bucket trap + Pherobank 2003 and T8 = Bucket trap + 4C, where rotation was done per replicate after 3 days according to a complete randomize design (Appendix I).

Data on trap capture were collected per day N= 24 and the data was visualized and analyzed using R software for statistical analysis R version 3.5.2 (2018-12-20). After a normality test using Shapiro-Wilk normality Test and a homogeneity test using Levene's test, Kruskal-Wallis H test performed. Dunn's Kruskal – Wallis Multiple Comparisons (dunnTest) was then used for the post hoc test where there were significance differences.

Figure 15: Trap designs, 14 a = Water trap with UV-A (385 nm) LED light, 14 b = Delta trap and 14 c = Bucket trap

Figure 16 shows the experimental layout for the trap designs and lures experiment.

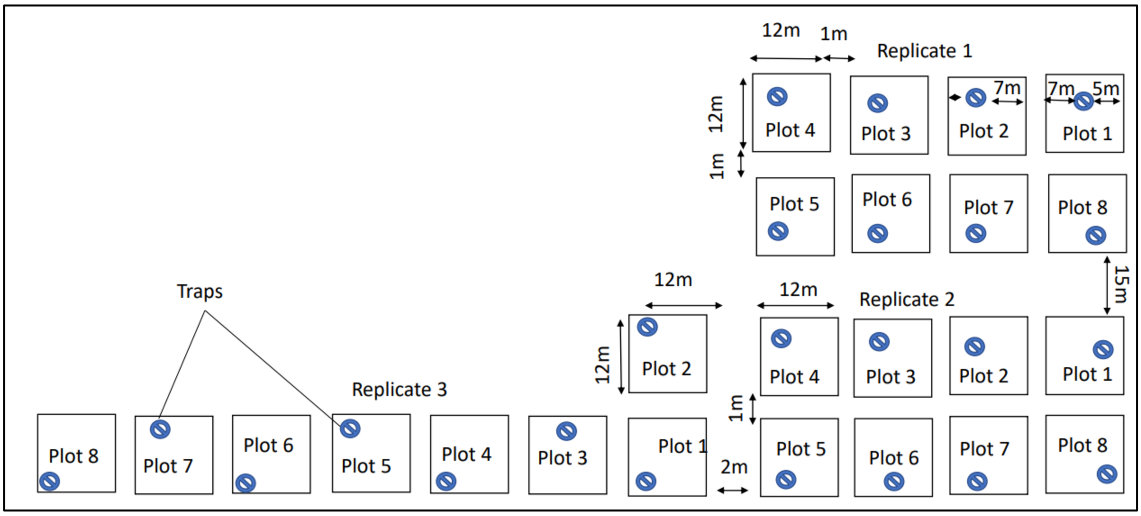


Figure 16: Layout Field 4 for testing trap designs and lures (Long rains 2021)

3.4.2 Infestation Level of FAW and Plant Damage

Infestation levels on maize were assessed regularly in Field 1(Fig. 11) in short and long rain 2020. The young leaves, leaf whorls, tassels, and cobs were examined by demarcating a 2 m transect line diagonally across the field, and 20 plants were randomly selected from within the transect line.

Each plant was visually checked for signs and symptoms of feeding such as cutting and tearing of plants, pinholes or small window panes, whorl feeding damage, fresh fecal matter (frass), damaged cob/ ears, and FAW larvae as described in Prasanna *et al*., (2018). Foliar, Kernel, and ear damage were examined and rated using the International Maize and Wheat Improvement Center (CIMMYT) unpublished protocol in (Prasanna *et al*., 2018) and modified to suit the project (Fig 17, Tab 1, Fig. 18, Tab. 2). Data collection was done on a ten-day interval and the number of infested plants were recorded where percent (%) infestation of the total plants per plot was calculated. The data was visualized and analysed using R software for statistical analysis R version 3.5.2 (2018-12-20). The treatments and experimental design were as per the field layout in figure 10.

Scores used to rate the foliar damage caused by FAW larvae are shown in Fig. 17.

Figure 17: Rating of maize plants based on foliar damage by FAW

Source: CIMMYT unpublished protocol in (Prasanna *et al*., 2018)

Table 1: Maize ratings based on foliar damage by FAW

Score	**Description**
1	No damage
2-4	Slightly damaged
5-7	Moderately damaged
8-9	Highly damaged

Source: CIMMYT unpublished protocol in (Prasanna *et al*., 2018)

Figure 18 shows the scores used for rating damages caused by FAW larvae to maize ear.

Figure 18: Scores used to rate ear damage by FAW larvae

Source: CIMMYT unpublished protocol in (Prasanna *et al*., 2018)

Table 2: Maize ratings based on ear and kernel damage by FAW

Score	Damage Symptoms/Description	Response
1	No damage to the ear	No damage
2	Damage to a few kernels (< 5) or less than 5% damage to an ear	Slightly damaged
3	Damage to a few kernels (6-15) or less than 10% damage to an ear	
4	Damage to (16-30) kernels or less than 15% damage to an ear	Moderately damaged
5	Damage to (31-50) kernels or less than 25% damage to an ear	
6	Damage to (51-75) kernels or more than 35% but less than 50% damage to an ear	
7	Damage to (76-100) kernels or more than 50% but less than 60% damage to an ear	Highly Damaged
8	Damage to (> 100) or more than 60% but less than 100% damage to an ear	
9	Almost 100% damage to an ear	

Source: CIMMYT unpublished protocol in (Prasanna *et al*., 2018)

3.4.3 Insects' Identification

The insects that were captured in season 2 in short rains of 2020 were morphologically identified by an expert at the International Centre of Insect Physiology and Ecology (ICIPE). The insects were identified up to species levels by looking at the insect's morphology and pinning after removing the genitalia, which were mounted on the slides.

3.5 Experiment 3: Proximate Composition

3.5.1 Sample Collection

The samples were collected from two sites. The first site was at the School of Agricultural and Food Sciences (SAFS) (Fig. 3). Since the study could not get enough FAW larvae for three samples during the short rains of 2020, more FAW larvae were collected in the long rains of 2020 from a maize field at Onywera Primary School in Sindo, Sub South of Homabay County (Fig.4).

S. frugiperda samples were collected by handpicking the larvae from the maize plants in the field (that is collected from the wild). The study observed the maize plants with signs of FAW infestations, and then the larvae were removed from the whorl of the plant carefully. The larvae were put together as one composite sample once the study was sure it was sufficient for a complete proximate analysis.

The samples were *Spodoptera frugiperda* (S1), *Spodoptera frugiperda* (S2), and *Spodoptera frugiperda* (S3), where S1(mature larvae 5th instar (L5) or 6th instar (L6)) were collected from maize fields in Siaya Campus – Siaya County during the short rains of 2020. The S2 and S3 were various stages of the larvae ranging from 2nd instar (L2) to 6th instar (L6), collected from a maize field in Homa bay County during the long rains of 2021.

3.5.2 Sample Preparation

Fresh samples were left for 24 hours to degut and then blanched in boiling water (Ayieko, *et al*., 2016) for about 5 minutes. After that, they were left in the sun to dry for at least 8 hours before being sent to the laboratories for nutritional analysis. *S. frugiperda* S1 was sent to Kenya Agricultural & Livestock Research Organization (KALRO) in Kakamega County, Kenya. The other two samples *S. frugiperda* S2 and *S. frugiperda* S3 were analysed at the Animal Sciences laboratory in Egerton

University -Njoro, Kenya. The samples were taken to Egerton University for analysis after the machines in KALRO broke down

3.5.3 Proximate Analysis

The samples at KALRO were analysed in duplicate, where crude protein analysis was done using a standard Kjeldahl method, and a neutral detergent fibre analysis (Zaklouta *et al*., 2011) was performed for crude fiber. At Egerton university laboratories, air dried samples were heated in an oven at 60° C for 2 hours. The samples were then ground through a 2 mm screen and kept in an air tight bottle until analysis. (Fombong *et al*., 2017). The analysis for moisture, crude protein, crude fiber, and ash were done in triplicate while that for fat was done in duplicate.

Moisture content was determined by oven drying at 105°C for 8 hours. The loss in weight was the moisture content and what was left was the dry matter of the sample. Crude ash was obtained through incineration of the sample in a furnace at 550°C for 4 hours, while the crude protein was determined by the micro Kjeldahl method, where the protein content = N x 6.25 (the conversion factor). The crude fats or ether extract (EE) were determined using the Soxhlet extractor method (Ayieko *et al*., 2016; Zaklouta *et al*., 2011).

The crude fibre was determined as described by Nduko *et al*., (2018) by weighing about 2.000g of air-dried sample into a 600ml glass beaker in triplicate, where 100ml of hot water was added before adding 2.04N H_2SO_4 and then the volume was increased to 200ml. The content of the beaker was boiled for 30 minutes, but the level of the solvent was kept at 200ml by adding hot water. Thereafter the beakers were removed and the content filtered using a filter stick packed with glass wool.

The residue was washed 3 times using hot water, then the residues were returned into the beakers into which 100 ml of hot water was added followed by 25ml of 1.78N KOH, then the volume was increased to 200ml using hot water in order to keep it constant. This was boiled for 30 minutes after which, it was filtered and washed 3 times using hot water. The residue was transferred into crucibles and then dried in an oven set at 105°C for 2 hours, cooled in a desiccator and weighed accurately. The contents were then bunt in a furnace at 550°C to ash for 4 hours and then left to cool to about 100°C. After which the samples were transferred to a desiccator for further cooling to room temperature and then their weights taken immediately.

Carbohydrate content (that is, Nitrogen free extracts) of the insects was determined by subtracting the sum of the weights of protein, fiber, lipid, and ash from the total dry matter weight (Fombong *et al*., 2017).

3.5.4 Comparison of the Nutrient Content of *S, frugiperda* Larvae to other Chicken Feeds

The primary data on the proximate analysis of *S. frugiperda* larvae from the current research was compared to secondary data of the Black soldier fly, the common housefly, and soya bean. The study chose to make a comparison to Black soldier fly (BSF) larvae and the common housefly (HF) larvae because they have been widely accepted as poultry feed. The study only considered BSFL that were fed on food waste, namely: Household waste, Kitchen waste, and departmental canteen waste. Soya bean data was also used in the study because: is highly used for feeding many livestock (Abro *et al*., 2020; Allegretti *et al*., 2017).

Statistical analysis

The data was visualized and analyzed using R software for statistical analysis R version 4.0.5 (2021-03-31) - "Shake and Throw". The distribution of the FAW samples data was checked using the Shapiro-Wilk normality Test while homogeneity of variance was performed using bartlett's Test for dry matter, moisture, fat, crude fibre, and carbohydrates. Levene's Test was used to check crude protein and ash. Kruskal-Wallis rank sum Test was used to analysed the FAW samples data for dry matter, moisture, ash, crude protein and fat and then Dunn's Kruskal – Wallis Multiple Comparisons (dunnTest) was used to perform the post hoc test where there was a significant difference.

Mann Whitney U Test (Wilcoxon Rank Sum Test) was then used to compare the differences between S2 and S3 FAW samples for crude fibre and carbohydrates. Mann Whitney U Test was also used to test the differences between: FAW larvae and BSF larvae, FAW larvae and HF larvae, and finally FAW larvae and Soya bean.

CHAPTER FOUR

4 RESULTS AND DISCUSSIONS

4.1 Introduction

First, the results on the optimum visual cues of the FAW (4.2) are presented and discussed. Second, results on the effectiveness of mass trapping as a method of collection of FAW for chicken feed (4.3) are shown. Finally, the results of proximate composition for the determination of the FAW larvae nutritional value are also covered (4.4).

4.2 Assessment of the Optimal Visual Cues of FAW.

Quick Visualization of the Data.

Data of moths' response to various light wavelengths after 30 minutes and 14 hours was explored using the figures 19 and 20. There are indications that less than 30% of the *Spodoptera exigua* moths were attracted to the traps after 30 minutes at the beginning of the experiment (Fig.19). Probably, the moths required a period of adaptation to take flight hence the low numbers.

These findings are consistent with the reports by Sponberg *et al*., (2015) that the moths likely require a period of adaptation to take flight, which explains the low numbers after 30 minutes. Nocturnal and twilight flying insects compensate for dim conditions by integrating light over longer times. Nevertheless, the results still show that *S. exigua* were more attracted to the light of (365, 385, and 400) nm wavelengths than the lights of (470, 530, 592, and 650) nm wavelengths.

The differences can be clearly seen in Fig. 20 where more than 75 % of the moths were attracted to the light of (365, 385, and 400) nm wavelengths than lights of (470, 530, 592, and 650) nm wavelengths.

Figures 19 and 20 are visualization of trap catches after 30 minutes and 14 hours respectively.

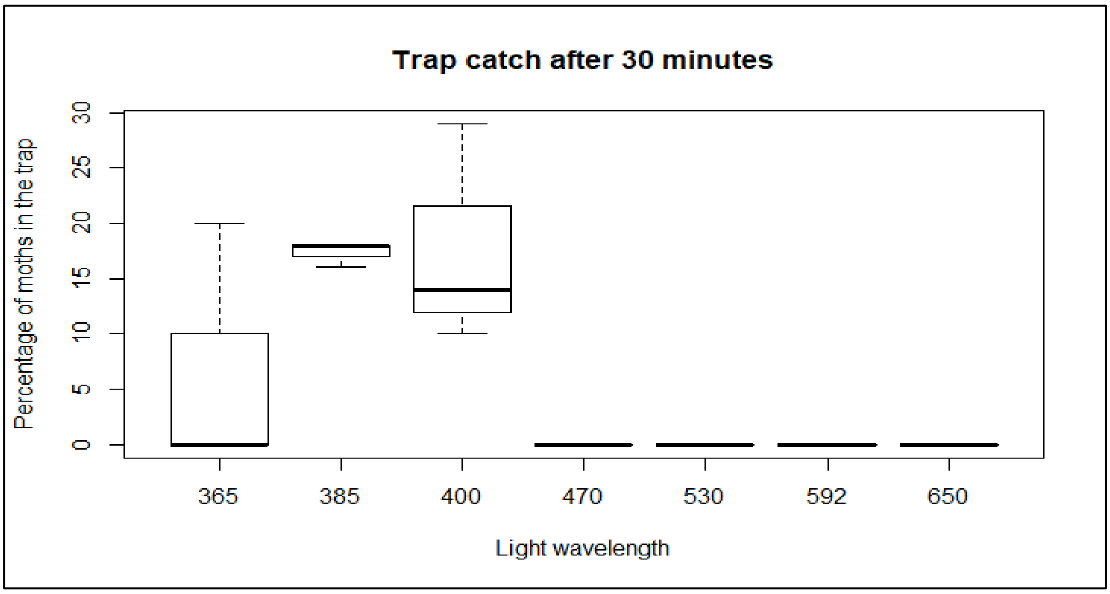


Figure 19: Box plot showing the catch of moths in various traps after 30 minutes

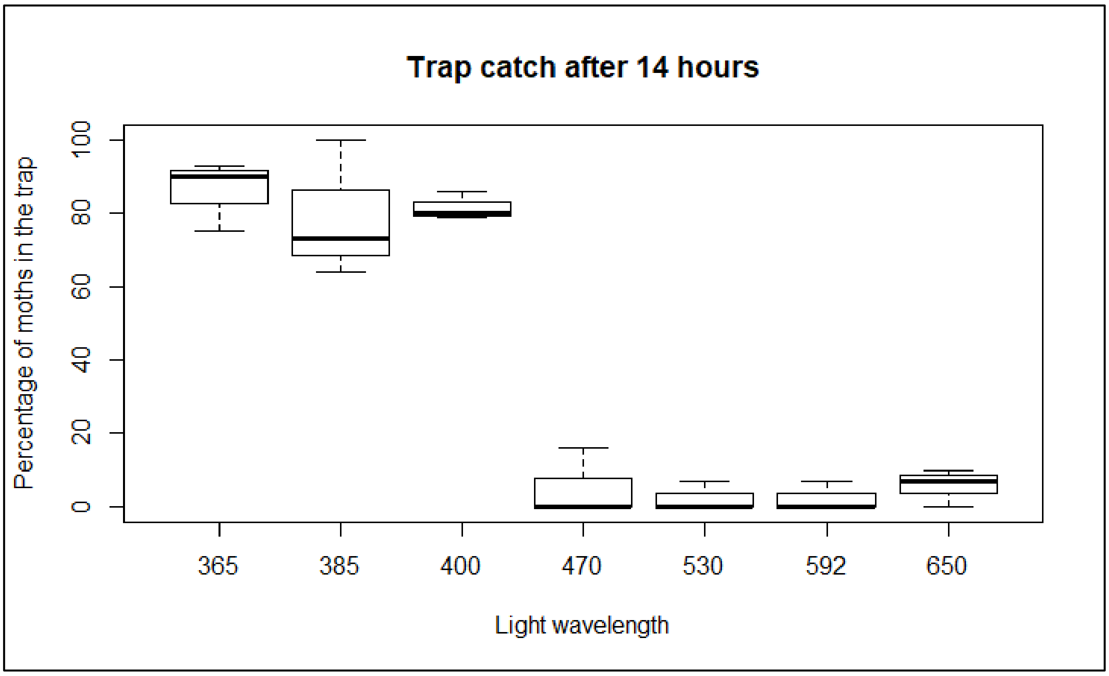


Figure 20: Box plot showing the catch of moths in various traps after 14 hours

Normality Test

A normality test was performed using the Shapiro test to check the distribution of the data for the traps catch after 30 minutes and 14 hours, respectively. The p values after 30 minutes and 14 hours were highly significant (***), $p < 0.001$. Therefore, the null hypothesis was rejected. The sample did not come from a normally distributed population.

Homogeneity Test

Levene's test was used to check for data homogeneity since it is less sensitive to departures from normality. Where p-values were 0.4373 and 0.6834 for trap catch after 30 minutes and 14 hours, respectively. Since the results show that all population variances are equal, a one-way ANOVA was performed for both data sets.

Analysis of the Optimal Visual Cues

The analysis of the trap captures after 30 minutes and 14 hours are shown by figures 20 and 21.

The null hypothesis that various light wavelengths attract the same number of moths after 30 minutes.

The results showed that the various light wavelengths had significant differences at df = 6, P = 0.00259** <0.01 (Appendix II). Mean separations further revealed the statistically significantly different trap light colours at 30 minutes. These results indicate that 365 nm, 385nm, and 400 nm wavelengths attracted more moths than the rest of the light wavelengths (Fig. 21).

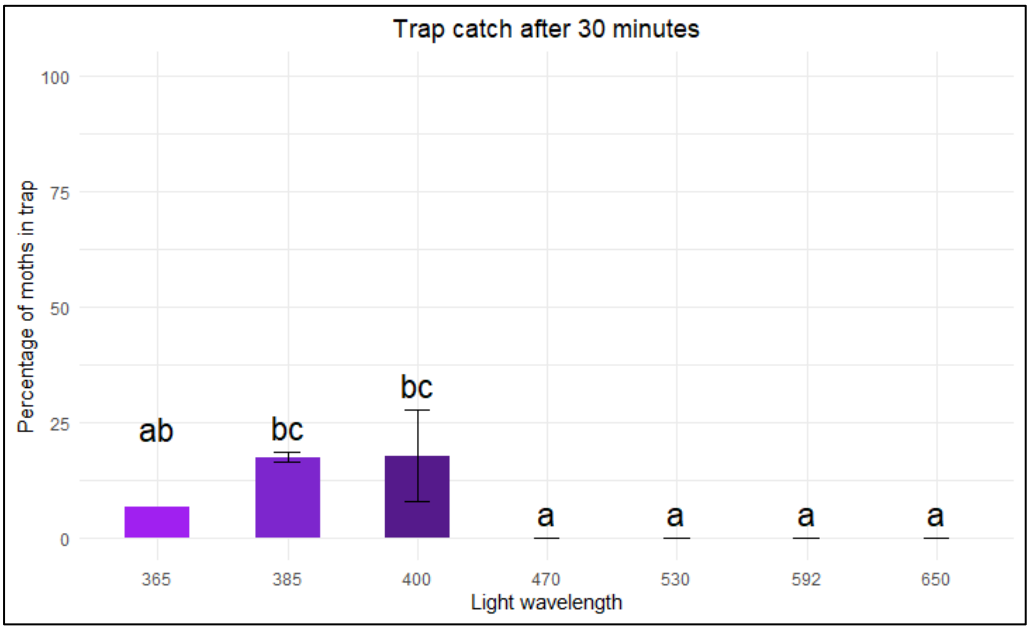


Figure 21: Bar plot of mean percentage of moths caught per light wavelength of a trap, df = 6, p<0.01

Means followed by the same letters are not significantly different from each other

The null hypothesis that various light wavelengths attract the same number of moths after 14 hours.

The one-way ANOVA test had a significant difference (***) at df = 6, p <0.001 (Appendix III). The results show that *Spodoptera exigua* were highly attracted to light colours of 365nm, 385 nm, and 400nm wavelengths than light colours of 470nm, 530nm, 592nm, and 650nm wavelengths (Fig. 22).

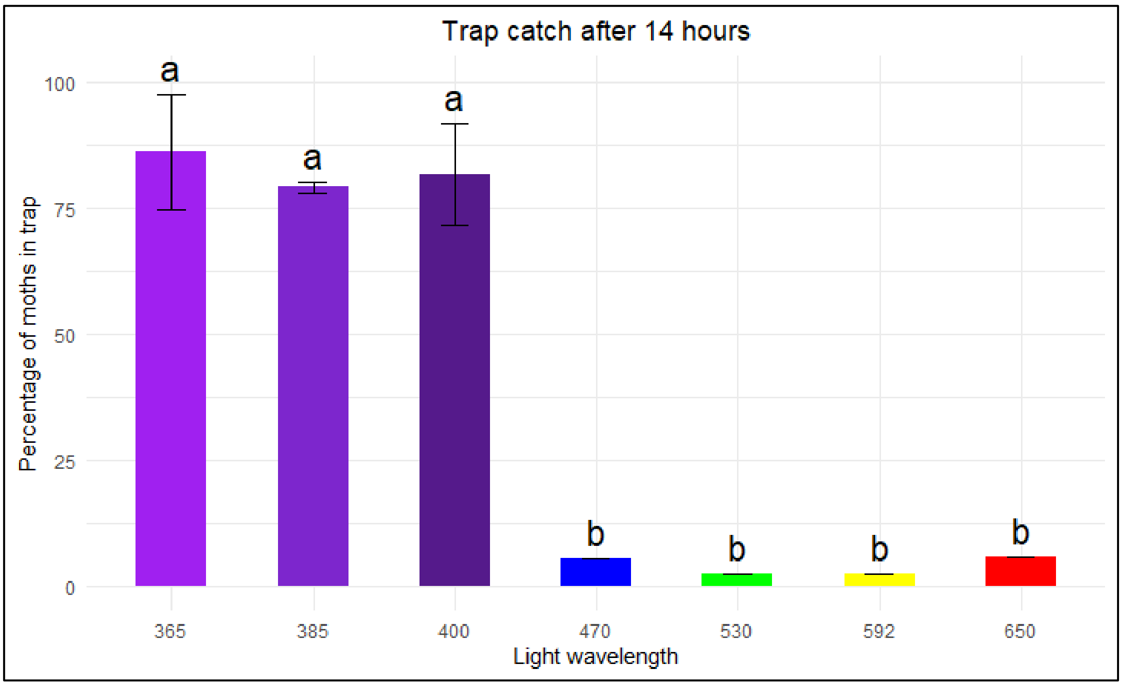


Figure 22: Bar Plot of mean percentage of moths caught per light wavelength of a trap, df = 6, p <0.001

Means followed by the same letters are not significantly different from each other

The results in (Fig. 21) and (Fig. 22) show that UV-A wavelength colours (365 to 400 nm) attracted more *Spodoptera exigua* adults. The moths were highly attracted to UV-A (365-400 nm) instead of other light colours (470,530,592 and 650 nm) (Fig. 22). These results are in line with reports by Mitchell & Agee, (1981); Ogino *et al*., (2016) that most insects are attracted to lights of lower wavelengths. The results are also consistent with van Tol *et al*., (2021) report, that insects can only see or respond to a limited number of light wavelengths.

Even though there are reports that noctuid's are only motivated to search for visual flower cues in the presence of flower odours Warrant *et al*., (2012), this study shows that *S. exigua* could rely on visual cues alone for landing. Land & Chittka, (2013) postulated that insect's preference for certain distinct colours while searching for food could still be modified by learning. However, this has only been shown for highly visual orientated insects like bees and bumblebees. The wind tunnel is a small space where insects are within visual range of the traps, so further research was conducted in the field using the UV-A and odours to see if the insects can still find and recognize the traps.

The study also observed that some moths could fly directly into the trap when provided with UV-A, especially 365 nm, after a short time. This was an indication that the insect's eye could easily detect light at short wavelengths (Ogino *et al*., 2016). Furthermore, Land and Chittka, (2013) also mentioned that superposition eyes are capable of functioning at very low light intensities. This is because their eyes are adapted in such a way that light leaving one lens system is not confined within a single ommatidium but can reach the rhabdoms of the neighboring unit.

It is evident from the results that the moths were not attracted by the lights of longer wavelengths (470, 530, 592, 650 nm). Nonetheless, the results contradict the report, which showed that over 60% of the moths were attracted to green, blue and yellow high-power light emitting diodes (HPLEDs) at 40 lux and 60 minutes exposure time (Oh *et al*., 2011). The difference could be because the moths were tested without roof light in complete darkness. In this case, the results could be biased as any light that the moths can see as even not attractive ones, but high enough brightness could evoke a signal that led to a response. There is a possibility that they used the visual cues for orientation to fly towards the light as noted in the paper of Warrant and Dacke (2010, 2016) rather than landing. Moreover, the dorsal eye region of the moth is specialized for the detection of polarized light (Warrant & Dacke, 2016).

The study could not presume that long light wavelengths suppressed nocturnal behaviours of moths, such as flying, sucking the juice, or mating (Shimoda & Honda, 2013). This is because these parameters were not tested. Nevertheless, flight activities could be observed even when long light wavelengths were provided, but they did not land in the traps. For these reasons, more research is required in order to determine whether these lights suppress the nocturnal behaviors of the moths or not.

It was also observed that some insects which missed to land directly into the water landed somewhere on the trap; hence they could escape. As a result, the study also proposes a lure and infect strategy, where the moths are attracted to UV-A trap and infected with entomopathogens. However, this mechanism has to be tested first to establish if the light can cause damage to the spores or reduce their germination and if the uptake of the spores is high enough to evoke infection and death of the moth before oviposition takes place.

4.3 Effectiveness of Mass Trapping

4.3.1 Trap Capture

Normality Test

Shapiro-Wilk normality test was used to check all the trap catches data. The results were highly significant at (***) $p< 0.001$, indicating that the sample did not come from a normally distributed population.

Homogeneity Test

Levene's test was used to check for homogeneity of variance in the data since it is less sensitive to departures from normality. May-June data for 2020 the results were significant at (*) $p < 0.05$ except for week 4 data which was not significant at $p = 0.243 > 0.05$. October-November 2020 data, there were no statistically significant differences at $p < 0.05$. The data on trap choice was also highly significant at (***) $p < 0.001$. Since most of the data violated the assumptions of ANOVA, the study used The Kruskal-Wallis H test to analyse more than two sample populations and a post hoc was done using dunn Test. Whitney-Wilcoxon Test was also used for two sample populations

Results for Season 1: Long Rains Experiment (April-July 2020)

Kruskal-Wallis H test revealed that catches between water trap with UV-A (385 nm) LED light (UV_1. UV_2, UV_3) and delta trap (kb) had statistically significant difference as in figure 23 at, $X^2 = 14.836$, df = 3, $p < 0.01$ in week 1. Catches in week 2 were significant at $X^2 = 23.17$, df = 3, $p < 0.001$ while week 3 also has significant catches $X^2 = 16.211$, df = 3, $p < 0.01$ (Fig. 23). Therefore, these results show that the

LWT+UV-A (UV_1. UV_2, UV_3) attracted more FAW moths than the delta trap (kb).

Figure 23 are the results of the trap capture data in season 1: long rains of 2020.

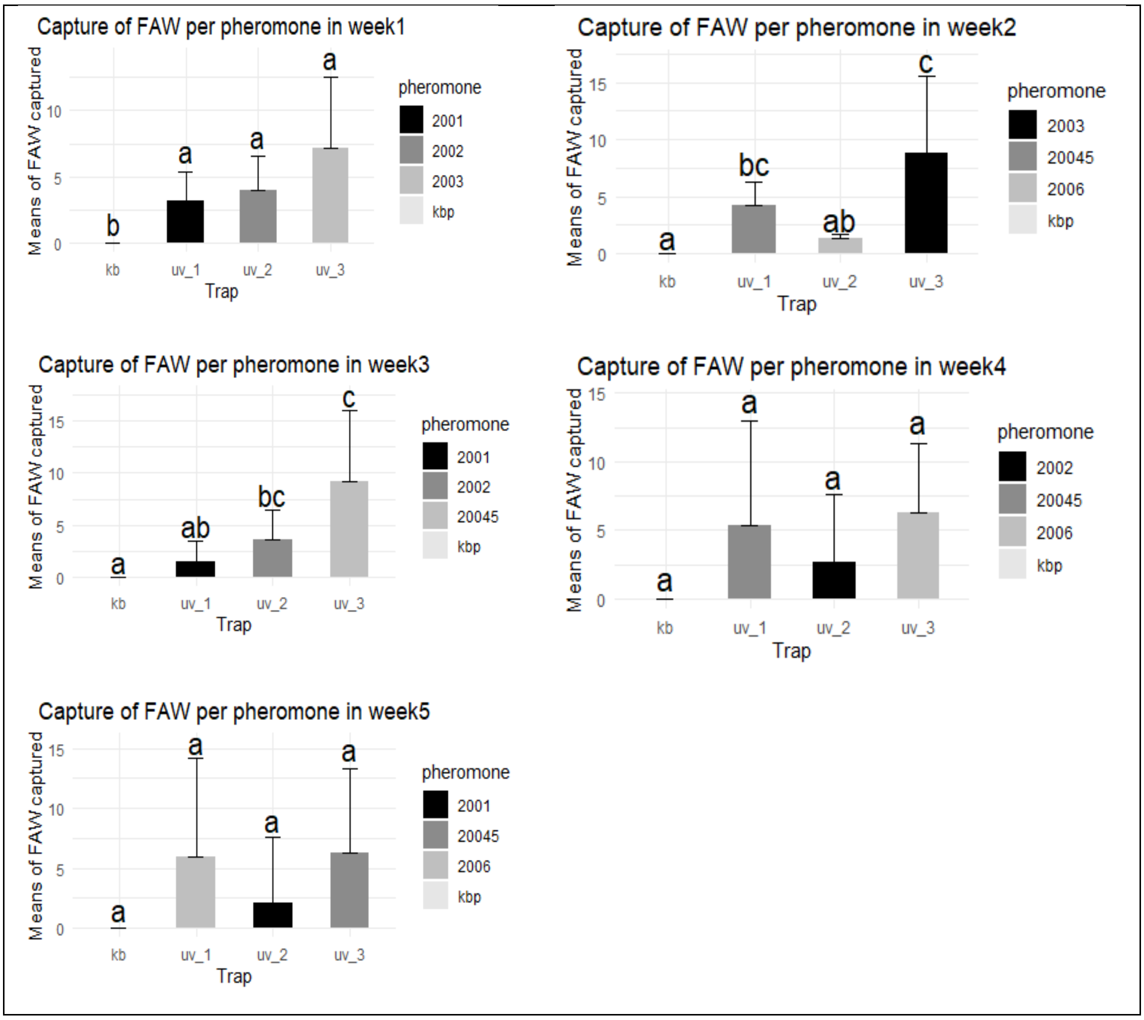


Figure 23: Field 1, Trap UV- A (385 nm) with pheromones and delta trap (kb) N=7, df = 3, week 1=p < 0.01, week 2 = p<0.001 and week 3= p<0.01

Means followed by the same letters are not statistically significantly different from each other

The analysis of the trend of trap captures and time using the Mann-Kendall trend test revealed P= 0.3671, S = -64.00, varS = 4879.33, and tau =-0.11while, the Sen's slope = -0.02. Figure 24 also revealed the downward trend however there were no significant differences in the pattern of trap captures with time.

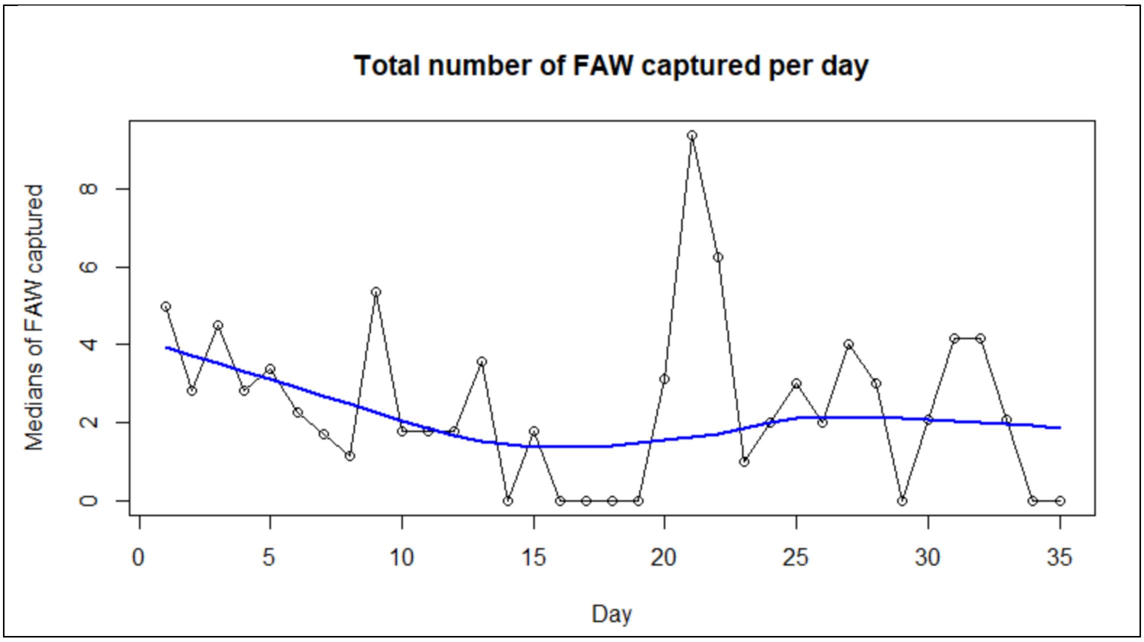


Figure 24: Plot of the total number of FAW moths captured by the traps per day in Long rains 2020

Results of trap captures in Season2: Short rains experiment (September-December 2020)

Kruskal-Wallis H test showed that there were no significant differences in the trap captures between LWT+UV-A (UV_1. UV_2, UV_3) and delta trap (kb) in week 1, week 2, week 3, week 4, and week 5 (Fig. 25).

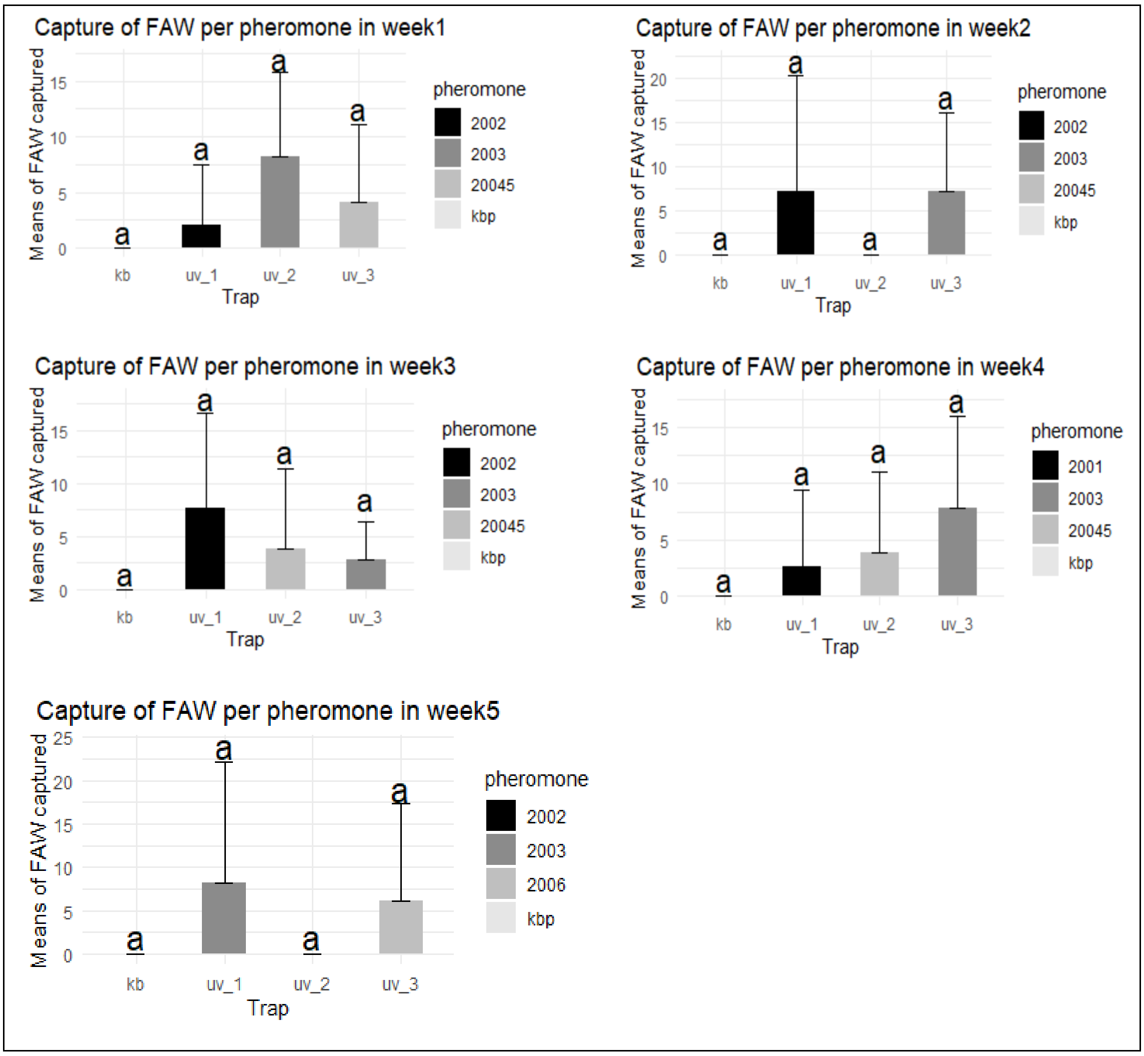


Figure 25: Field 1, Trap UV-A (385 nm) with pheromones and delta trap (kb), N = 7

Means followed by the same letters are not statistically significantly different from each other

Mann-Kendall trend test showed P – value = 0.51, S= - 33.00, varS = 2396.33, and tau = - 0.09. Sen's slope = 0. There was also insignificant downward trend in the pattern of trap captures and time (Fig. 26).

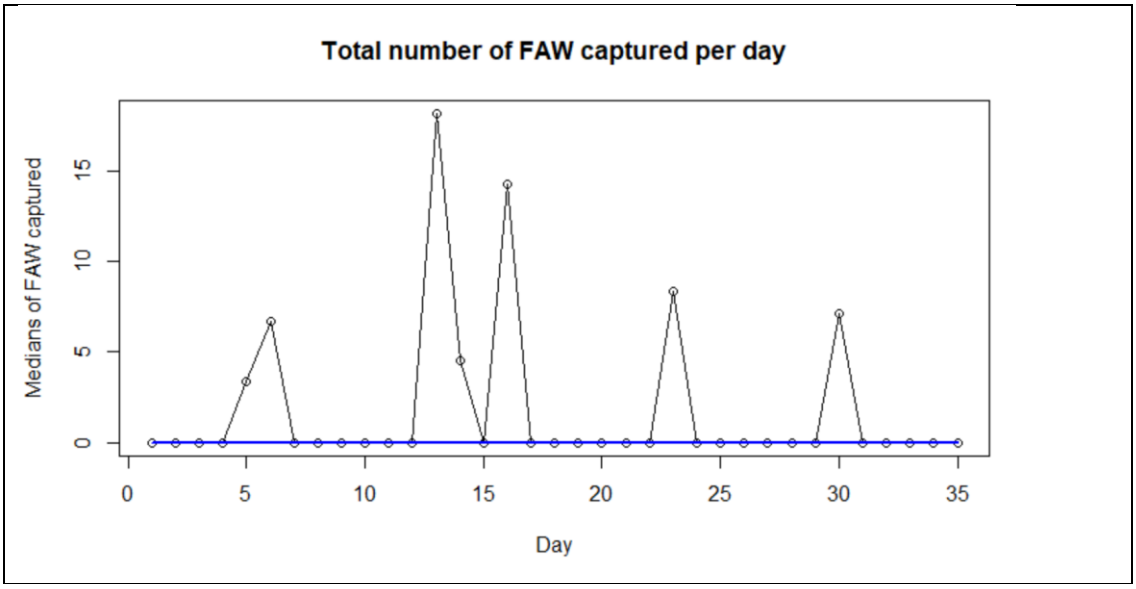


Figure 26: Plot of the total number of FAW moths captured by the traps per day in short rains 2020

Trap choice between LWT + UV-A and LWT + white light; Season 3 Long rains experiment (April-August 2021)

The results from the Wilcoxon rank sum test showed that there were statistically significant differences at W = 218.5, p-value < 0.01 between the captures of FAW moths by LWT + UV-A (385 nm) and LWT + white (4500k) (Fig. 27). These results indicate that FAW were more attracted to LWT + UV-A (385 nm) than LWT + white (4500k).

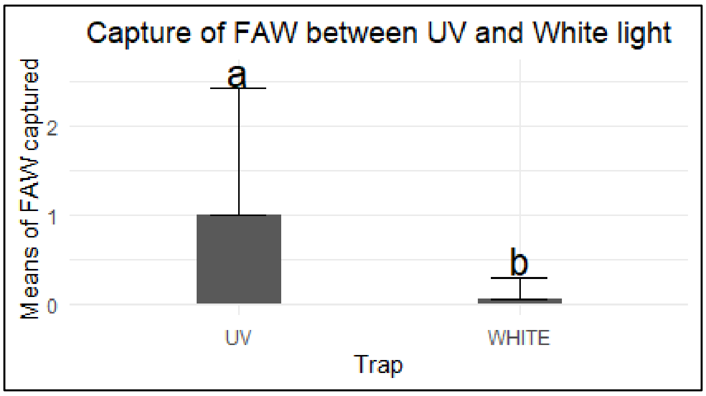


Figure 27: Field 3, Experiment on trap choice between water trap with UV-A (385 nm) LED light and white light (4500k), p value<0.01(**), N = 9

Means followed by the same letters are not statistically significantly different from each other

Visualization of trap design data; Season 3 Long rains experiment (April-August 2021)

Treatments (T1 = Water trap +2003 only, T2 = UV-A only, T3 = UV-A + 2003, T4 = UV + 4C, T5 = delta trap + (four- Component) 4C, T6 = delta trap + 2003, T7 = Bucket trap + 2003 and T8 = Bucket trap + 4C)

These results (Fig. 28) show that FAW moths were mostly attracted to LWT + UV-A trap than the bucket trap or the delta trap. There are indications that there were differences in the trap catches with the different pheromone treatments in combination with the LWT + UV-A trap. The study shows that LWT + UV-A tested together with 4C (T4) had more FAW moths than LWT + UV-A with 2003 pheromone (T3) and LWT + UV-A without a pheromone (T2).

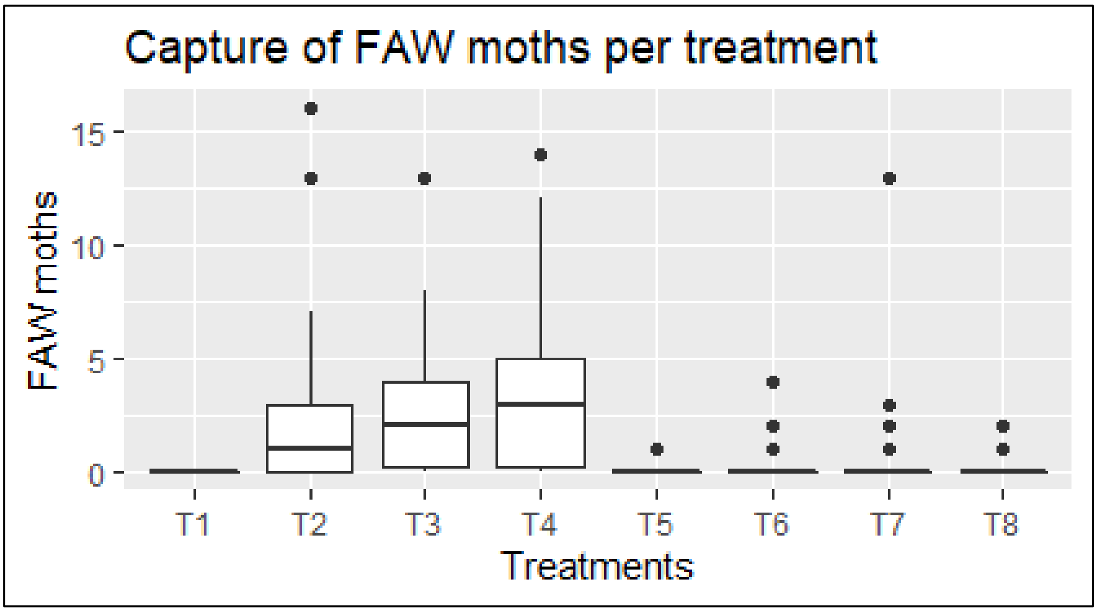


Figure 28: Field 4, Water trap with UV-A (385 nm) LED light, bucket trap and delta trap with promising pheromones 2003 and 4C from Pherobank.

Results of trap design data; Season 3 Long rains experiment (April-August 2021)

Kruskal-Wallis *H* test for the trap capture among the trap designs (Fig. 29) showed a statistically significant difference at $X^2 = 232.06$, df = 7, and $P < 0.001$. These results revealed that LWT + UV-A captured more moths than the bucket trap and the delta trap. The results also depicted that LWT + UV-A only (T2) without pheromone could capture FAW moths. The captures between T2 and T3 (UV-A + 2003) were not significantly different, but there were differences between T2 and T4 (UV-A + 4C).

Figure 29 show the analysis of the results of the number of moths caught by the various trap designs.

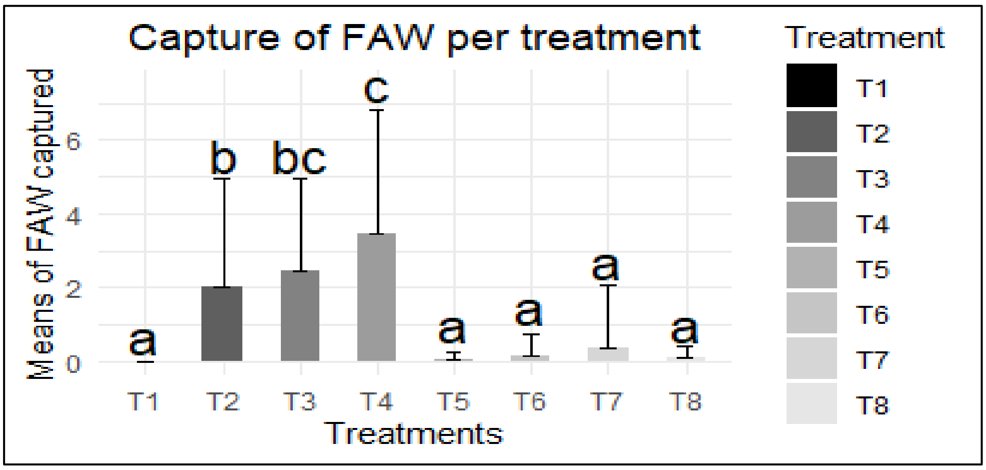


Figure 29: Plot of the means of FAW captured (n=3) in Field 4 by water trap with UV-A (385 nm) LED light, bucket trap and delta trap with promising pheromones 2003 and 4C from Pherobank, P < 0.001

Means followed by the same letters are not significantly different from each other.

Treatments (T1 = Water trap +2003 only, T2 = UV-A only, T3 = UV-A + 2003, T4 = UV + 4C, T5 = delta trap + 4C, T6 = delta trap + 2003, T7= Bucket trap + 2003, and T8 = Bucket trap + 4C).

The visual cues of fall armyworm were tested in the field of maize and brachiaria where Water trap with UV-A (385 nm) LED light and various pheromones from Pherobank were tested against a delta trap and Kenya Biologics pheromone (Fig. 23). The results indicate that there were significant differences between the water trap with UV-A LED light and the delta trap in Week 1 p value = 0.01(**), Week 2 p value = 0.001(***), Week 3 p value = 0.01. These results are in line with the reports of both Cruz-Esteban *et al*., (2021) and Meagher *et al*., (2019) that sticky delta traps did not perform well when it was compared to other traps. Time did not influence the number of moths captured by the traps even though there was a downward trend (Fig. 24)

A similar experiment in the short rains of 2020 (Fig.25) did not have any significant difference. However, there were indications that the Water trap with UV-A (385 nm) LED light had some catches compared to the delta trap. The non significance in the short rains could be a result of low populations of FAW, but still, the fact that the LWT with UV-A could capture some insects is a positive response. There was insignificant downward pattern in the trap captures and time (Fig. 26) and the slope = 0 which supports the idea that the population during this time was quite low.

The low numbers of FAW were also reported by R. Schaijk Personal communication, May (2021) in the Rift valley and Coastal regions of Kenya (Appendix V). According to Meagher *et al*., (2019) an effective trap is one that is able to capture insects even at very low populations. Therefore, the selection of an appropriate trap design could improve the monitoring and mass trapping efficiency of FAW.

To gather sufficient information on the efficacy of LED water trap in mass trapping FAW, another experiment was conducted with three trap designs: water trap with UV-A LED, delta trap, and bucket trap together with promising lures 2003 and 4C (Fig. 28 and 29). This experiment showed that the water trap with UV-A LED light captured more FAW moths than the delta and the bucket traps P value = 0.025 for T2 – T4. The rest were significant at p value = 0.001(***). The outcome is consistent with the report by Cruz-Esteban *et al*., (2021) that the bucket and delta traps captured fewer FAW than a plastic jug trap.

In the current study (Fig. 28 and Fig. 29), T1 (Water trap + 2003 pheromone) did not have any catches. This shows that without UV- A light, the water trap with a pheromone was not able to attract any moths. This indicates that the moths require a short-distance attractant to allow landing in or on the trap. These results are not comparable to those of Cruz-Esteban *et al*., (2021), who reported that a plastic jug trap that used soapy water as a drowning solution captured a larger number of FAW moths than the rest.

One of the reasons for the difference could be because our trap (Fig. 15 a) had a pheromone suspended just above the trap without a top. Therefore, some male moths that could have landed on the pheromone and did not find the female flew away. However, the ones that arrived on the pheromone in the plastic jug were probably hit by the top of the container and fell back into the drowning solution when they tried to fly away. Moreover, A. Groot personal communication, May (2021) also mentioned that the mechanism of hanging the pheromone on top of a delta trap from inside is to allow the insects to be hit by the top of the trap back to the sticky plate when they try to fly away. This could also be why the delta trap never performed well in the current research since the pheromone was just put somewhere on the sticky plate.

These observations were also reported by Cruz-Esteban *et al*., (2021) that the moths collided with either the pheromones or the ceiling of the trap and had a free fall in the solution. Furthermore, the moths could regain flight if they do not land in the centre of the funnel (sleeve trap, bucket trap, and water bottle). For these reasons, the current study proposes a modification on the water trap with UV-A (385 nm) LED light to have a top to avoid such incidences.

Even though Okello *et al*., (2020) reported that the available commercial sunlight reflected traps may not be attractive to nocturnal insects, Malo *et al*., (2018) reported that FAW captures were affected by trap colour. This could be because the nocturnal activities of FAW begin from 1800 h throughout the night (Ingber *et al*., 2021; Rojas *et al*., 2004). Therefore, there could have been a reflection of the traps by sunlight before sunset, which influences the visual cues.

Better performance of the white plastic jug than the other traps according to Cruz-Esteban *et al*., (2021) could be because it had a high spectral reflectance at 400 nm in the region of low light wavelength, as shown in (Malo *et al*., 2018). If the response was due to the spectral reflectance at the ultraviolet region, then it is in agreement with the study by Okello *et al*., (2020) that *Spodoptera exigua* were highly attracted to UV-A light at 400 nm wavelength. Marchioro and Faccoli (2021) also reported that ultraviolet was the best wavelength in attracting Lepidoptera moths, but the captures did not differ from white and red lights. For these reasons, the current study suggests that attractive UV-A light could have influenced the landing of FAW moths in the traps.

There was a significant difference between the captures of FAW in a water trap with UV-A LED only (T2) and a water trap with UV-A LED + 4C (T4), but there were no differences found between T4 and T3 (UV-A + 2003) (Fig. 29). Even though there was no statistically significant difference between T3 and T4, T4 had higher catches than T3 (Fig. 28 and Fig. 29). The current study revealed that various pheromone combinations influenced trap captures differently. The 4C pheromone caught more FAW moths than 2003 pheromone. These results are different from Meagher *et al*., (2019), who reported that a 3C pheromone captured more FAW moths than 4C and 2C.

A comparison of the response of the visual cue of FAW to two different types of lights, namely water trap with UV-A LED (385 nm) and water trap with white LED (4500 k), revealed a difference in the trap catches at p-value = 0.01(**) (Fig. 27). This is an indication that FAW is less attracted to white light. Nevertheless, Marchioro and Faccoli (2021) reported that white light showed the best results for catching Lepidoptera and Diptera, even though there were no significant differences between ultraviolent and red light.

The research did not collect data on the number of FAW larvae trapped in brachiaria since the numbers were low. The study thought that the low numbers could result from the height of the traps, which were 1.5m above ground. Initially, the project indicated that the traps would be hung closer to the brachiaria so that the moths that did not land in the traps could land on the trap crop and lay eggs. The project would later collect the FAW larvae from the brachiaria to be used as chicken feed. When LED water traps were hung closer to the ground level, many other insects were captured, including even the beneficial insects compared to the 1.5m Height catch.

4.3.2 Infestation Level

Infestation levels of FAW larvae on maize with treatments**:** T0 Maize monocrop, T3 = Maize + Brachiaria, T4 = Maize + Brachiaria + Delta trap (kb) + Kenya biologics pheromone (kbp), T5 = Maize + Brachiaria + LWT + UV-A (385nm) in the long and short rains of 2020 are presented in figures 30, 31, 32 and 33 respectively.

Figure 30 shows slight damages to the maize foliage by the FAW larvae across all the treatments T0, T3, T4, and T5. Very few plants were moderately damaged in T0, T3 and T5. This is an indication that the FAW population was low.

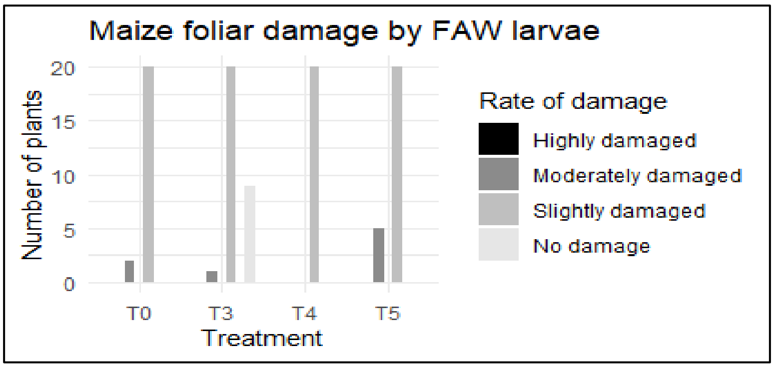


Figure 30: Level of FAW larvae infestations on maize foliage (long rains 2020)

The results in (Fig. 31) show that most of the maize ears were not damaged in T0, T3, T4, and T5, but some of them had slight damages. This is an indication that infestation level by FAW larvae were also low.

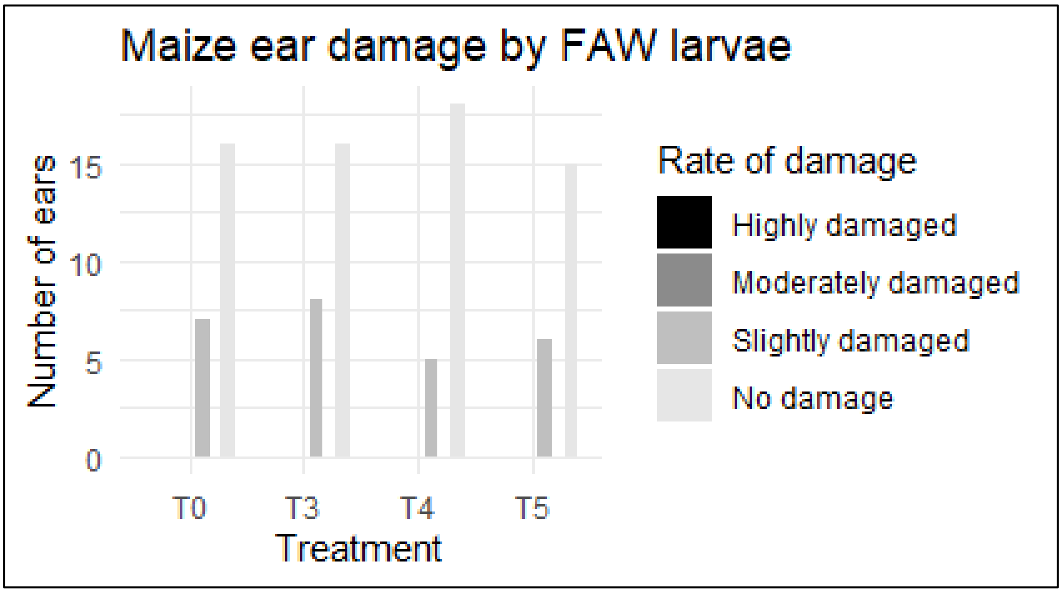


Figure 31: Level of FAW larvae infestations on maize ear (long rains 2020)

The information in figure 32 indicates both slight damages and no damages in similar measures with a few moderate damages in all the treatments. These findings suggests that FAW infestation was very low during the short rains of 2020.

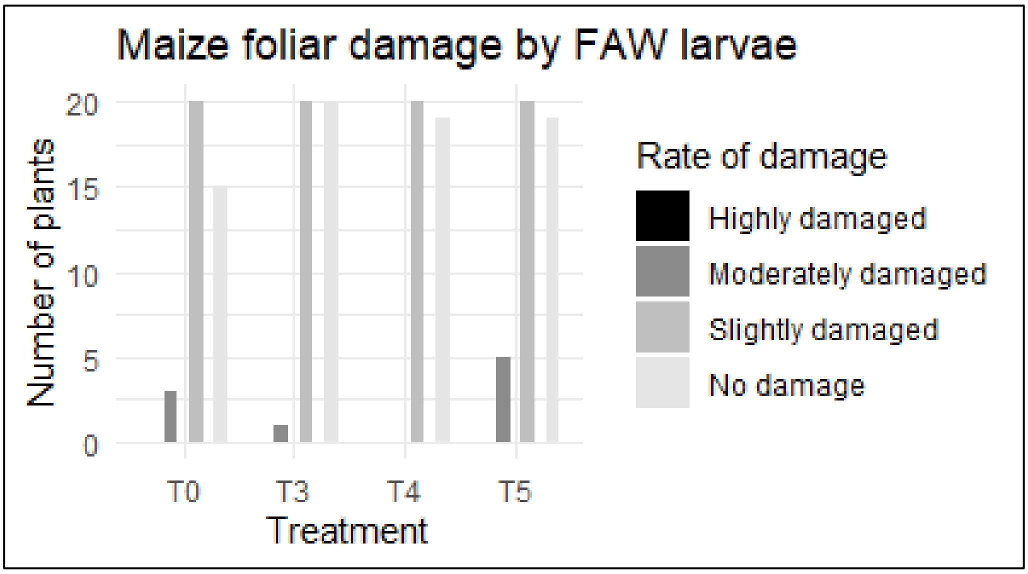


Figure 32: Level of FAW larvae infestations on maize foliage (Short rains 2020)

The infestation rating (Fig. 33) showed that FAW larvae did not damage most of the ears, with a few slightly damaged in all the treatments. These results could be possibly due to the low populations of the fall army during the short rains.

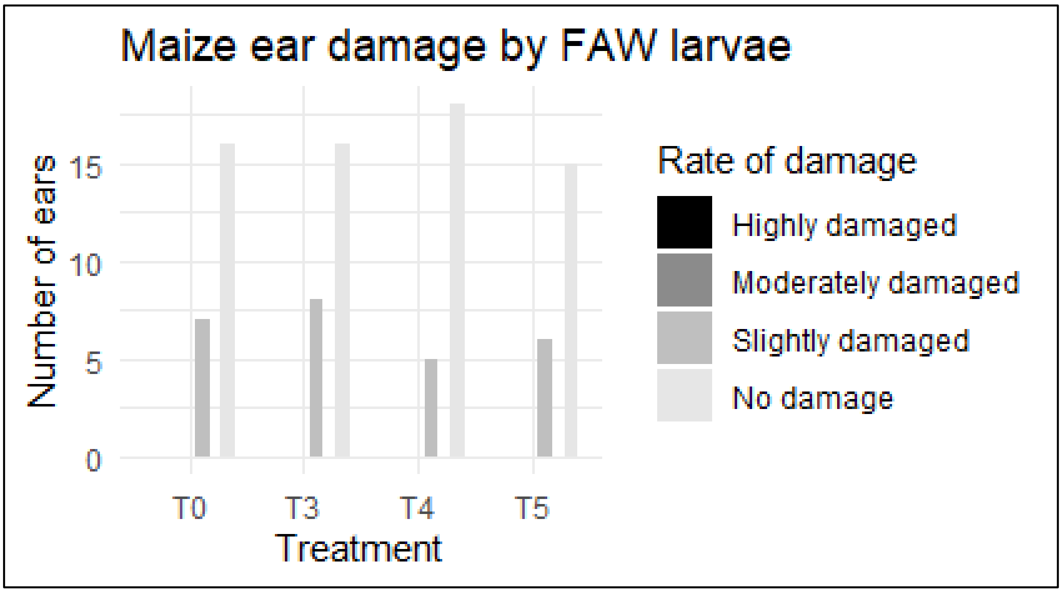


Figure 33: Level of FAW larvae infestations on maize ear (Short rains 2020)

Generally, there were slight or no damages to the maize foliage and ears both in the long and short rains of 2020 (Fig. 30, Fig. 31, Fig. 32, and Fig. 33). However, the study did not evaluate whether the low infestation levels observed were because of the influence of the trap or other factors such as early planting or variety. The research realized that the trap catches were not so good, especially in the short rains of 2020., which could be due to low numbers of FAW. A study by Midega *et al*., (2018) showed an effective reduction of infestation by fall armyworm with the climate–adapted push-pull system. Therefore, the fact that infestation levels did not increase per plant indicates that perhaps the water traps with UV-A LED had an influence on the plant damages. The traps could have lowered the FAW moths' population, thus preventing further infestations.

The project did not determine the effect of brachiaria on the infestation levels of the maize crop. Nonetheless, the study observed that more larvae could be found in the grass than maize. This could have possibly influenced the pest populations in the maize plants hence the low infestation levels. According to Midega *et al*., (2018) they were able to show that a combination of brachiaria as a trap crop and desmodium as a push crop reduced the populations of FAW Midega *et al*., (2018) and stemborer in maize crops (Cheruiyot *et al*., 2018; Midega *et al*., 2018).

4.3.3 Insects' Identification

Table 3 is the results of the morphological identification of the insects that were captured in the short rains of 2020. The results showed that the LWT + UV-A attracted several pests of economic importance that is pests that cause serious damages to agricultural crops. They are majority in Noctuidae family. *Spodoptera frugiperda* (44) was the highest caught, followed by *Thysanoplusia orichalcea* (22), and *Heliothis armigera* (11*)*: This indicates that these pests are attracted to UV-A (385nm).

Table 3: The number of insects that were morphologically identified in the short rain of 2020

Family	Genus	Species	Number of insects
Noctuidae	*Spodoptera*	*frugiperda*	44
Noctuidae	*Thysanoplusia*	*orichalcea*	22
Noctuidae	*Heliothis*	*armigera*	11
Pyralidae	*Ephestia*	*kuehniella*	1
Noctuidae	*Heliothis*	*zea*	3
Noctuidae	*Bohemannia*	*pulverosella*	1
Noctuidae	*Mythimna*	*separata*	2
Noctuidae	*Leucania*	*sp.*	1
Noctuidae	*Mythimna*	*unipucta*	2
Noctuidae	*Euplexia*	*stephen*	2
Gelechiidae	*Caryocolum*	*pullatella*	2
Noctuidae	*Mythimna*	*separata*	2
Noctuidae	*Mythimna*	*oxygala*	2
Pyralidae	*Ephesia*	*sp.*	1
Noctuidae	*Agrotis*	*ipsilon*	10

The study noticed that other nontarget pest were captured by the water trap with UV-A (385 nm) LED light. The highest capture was *Thysanoplusia orichalcea*, followed by *Heliothis armigera* and *Agrotis ipsilon* (Tab. 3). *Thysanoplusia orichalcea* is a polyphagous pest of vegetables, Stringer *et al*., (2008) suggested that successful trapping of female *T. orichalcea* in either a lure-and-kill or a mass trapping system may offer an effective way to manage its population size. Therefore, water trap with UV-A (385 nm) LED light could control this pest since it attracts both males and females.

Heliothis armigera is a polyphagous pest of economic and agronomic importance worldwide (Guerrero *et al*., 2014; Pan *et al*., 2020). One of the management strategies that has been used before for this pest is the use of the Universal (Unitraps) moth "bucket" traps baited with pheromone (Guerrero *et al*., 2014). According to Pan *et al*., (2020), *H. armigera* captures were the same among (four) wavelengths (375 nm, 385 nm, 395 nm, and 405 nm). These results are in agreement with the current research which captured the moths at 385 nm wavelengths.

4.4 Proximate Composition

4.4.1 Proximate Composition of FAW Larvae

The data on the proximate composition of FAW larvae samples *S. frugiperda* (S1, S2, and S3) were explored using visualization in figure 34 while the summary of the analysis is in table 4. The following parameters were measured: CF= Crude fibre, CP= Crude protein, DM = Dry matter, EE = Ether extract, M = moisture and NFE = Nitrogen free extract.

These results (Fig. 34) show that among the *S. frugiperda* samples, S1 had a lower amount of crude protein (36.9) % compared to S2(63.54) % and S3 (61.84) %. The crude protein (CP) content in S2 and S3 agrees with the study of Williams *et al*., (2016), which reported similar amounts. The same plot indicates the availability of a similar quantity of crude fibre (CF) that is S2(9.6) and S3(9.1) whereas crude fat (EE) was depicted to be S1(22.9) %, S2(17.8) %, and S3(21.1) %.

Kruskal-Wallis rank sum test (Tab. 4) showed that there were statistically significant differences in the amount of crude protein between S1 and S2 but there was a non significance between S1 and S3, and also between S2 and S3. However, there were no significant differences in the crude fibre, crude fat, carbohydrates, and ash among the three samples**.**

Figure 34 and Table 4 are the visualization and analysis on the nutrient composition of FAW larvae.

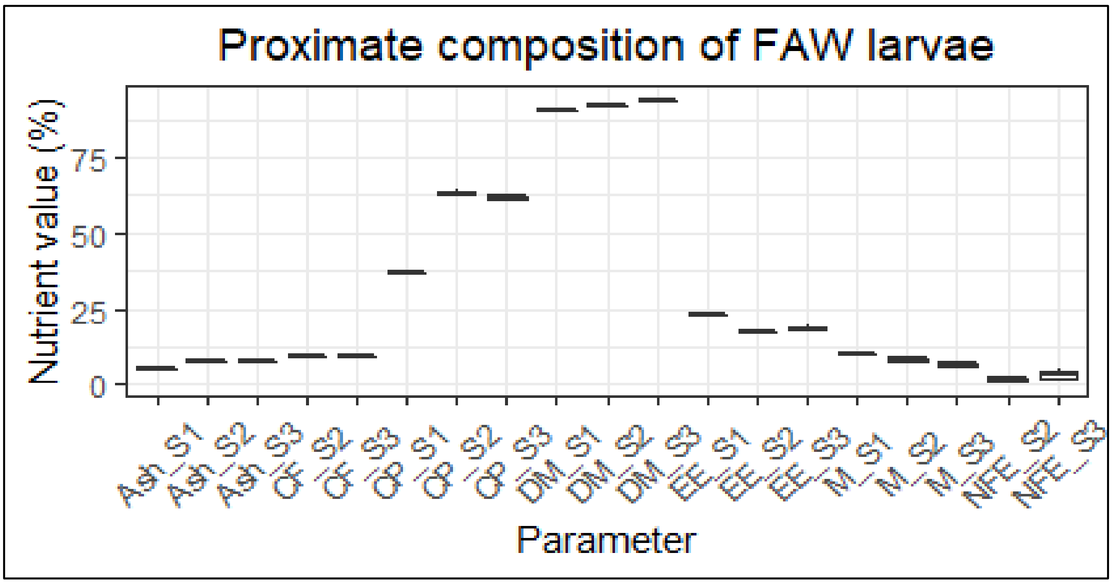


Figure 34: Plot of proximate composition on Dry matter basis(%DM) of the means of *Spodoptera frugiperda* samples (S1, S2 and S3)

Table 4: Proximate composition of FAW mean n=2 for *S. frugiperda* S1and mean standard deviation (SD±, n = 3) for *S. frugiperda* S2 and *S. frugiperda* S3 on dry matter basis (% DM)

Sample	***S. frugiperda S1***	***S. frugiperda* S2**	***S. frugiperda* S3**	**P value**
Feed	Wild	Wild	wild	
Moisture	10^{a}	8.218 ± 0.2^{ab}	6.469 ± 0.3^{b}	0.04
Dry matter	90 ^{a}	91.782 ± 0.4 ^{ab}	93.531 ± 0.3 ^{b}	0.04
Ash	5.6^{a}	7.4 ± 0.1^{a}	7.4 ± 0.2^{a}	0.13
Crude fibre		9.6 ± 0.4^{a}	9.1 ± 0.3^{a}	0.12
NDF	17.8			
Crude protein	36.9^{a}	63.54 ± 1^{b}	61.84 ± 0.7^{ab}	0.04
Fat	22.9^{a}	17.8 ± 0.4^{a}	21.1 ± 1.6^{a}	0.17
Carbohydrates		1.65 ± 0.9^{a}	3.3 ± 2.7^{a}	0.44

Means followed by the same letter across a row are not statistically significant from each other at $p< 0.05$

4.4.2 Proximate Composition of BSF Larvae and FAW Larvae

Data on the comparison between BSF larvae and FAW larvae was visualized in Fig. 35, while the analysis of the comparison between BSF larvae and FAW larvae is presented in Tab. 5. The following parameters were analysed ASH_BSF = ASH for BSF larvae, CF_BSF = Crude fibre for BSF larvae, CP_BSF = Crude protein for BSF larvae, EE_BSF = Ether extract for BSF larvae, NDF_BSF = Nutrient detergent fibre for BSF larvae, ASH_FAW = ASH for FAW larvae, CF_FAW = Crude fibre for FAW larvae, CP_FAW = Crude protein for FAW larvae, EE_FAW = Ether extract for FAW larvae, NDF_ FAW = Nutrient detergent fibre for FAW larvae.

Figure 35 revealed that FAW larvae has a higher amount of crude protein (56.22) % compared to BSF larvae (38.41) %. The amount of fat was lower in FAW larvae (19.7) % compared to BSF larvae (37.3) %. However, the results in table 5 indicate no statistically significant difference at p = 0.05 between the crude protein (%) of FAW larvae and BSF larvae. This shows that FAW larvae is rich in protein. The fat content had a significant difference at p = 0.04 for FAW larvae and BSF larvae.

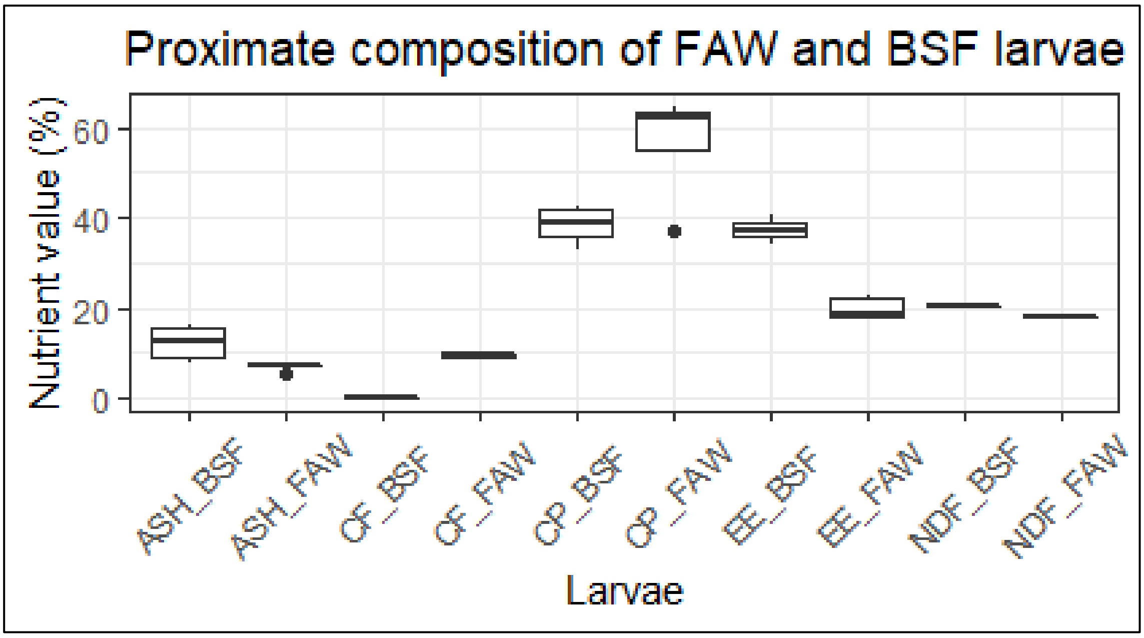


Figure 35: A plot for the Proximate analysis of BSF larvae and FAW larvae on Dry matter basis (%DM)

The analysis of the nutrient contents of FAW larvae and BSF larvae are presented in table 5.

Table 5: A Comparison of proximate composition of FAW larvae (n = 3) and BSF larvae from four studies BSF_1, BSF_2, BSF_3, and BSF_4 (n = 4) means, on dry matter basis(%DM)

	Sample				**Mean**		
Parameter	**BSF_1**	**BSF_2**	**BSF_3**	**BSF_4**	**BSF**	**FAW**	**p value**
Feed	KW	KW	HW	DC			
CP	42.6	33	36.6	41.44	38.41[a]	56.222[a]	0.05
CF	NA	NA	NA	0.08	0.08 [a]	9.333 [a]	0.21
NDF	NA	20.4	NA	NA	20.4 [a]	17.8 [a]	0.48
EE	36.9	34.3	40.7	35.69	37.3 [a]	19.655 [b]	0.04
ASH	15.3	9.6	16.3	7.87	12.27 [a]	7 [b]	0.01
Reference	(Mohammed *et al*., 2017)	(Shumo *et al*., 2019)	(Ewald *et al*., 2020)	(Ebeneezar *et al*., 2021)		Current study	

Means followed by the same letter in a row are not statistically significantly different from each other.

HW = Household waste, KW = Kitchen waste, and DC = Departmental Canteen waste

4.4.3 Proximate Composition of HF larvae and FAW Larvae

A comparison of the proximate composition of common housefly larvae and FAW larvae is presented in the figure 36. The summary of the analysis of their comparison is presented Table 6. The following parameters were tested ASH_HF = ASH for HF larvae, CF_HF = Crude fibre for HF larvae, CP_HF = Crude protein for HF larvae, EE_HSF = Ether extract for HF larvae, ASH_FAW larvae, CF_FAW larvae, CP_FAW larvae and EE_FAW larvae.

Figure 36 and table 6 show that FAW larvae and the common housefly (HF) larvae have similar amount of nutrients content. CP_FAW (60.94) % and CP_HF (56.22) % indicate that they are rich in crude protein and also fat that is EE_FAW = 19.66% and EE_HF = 15.33.

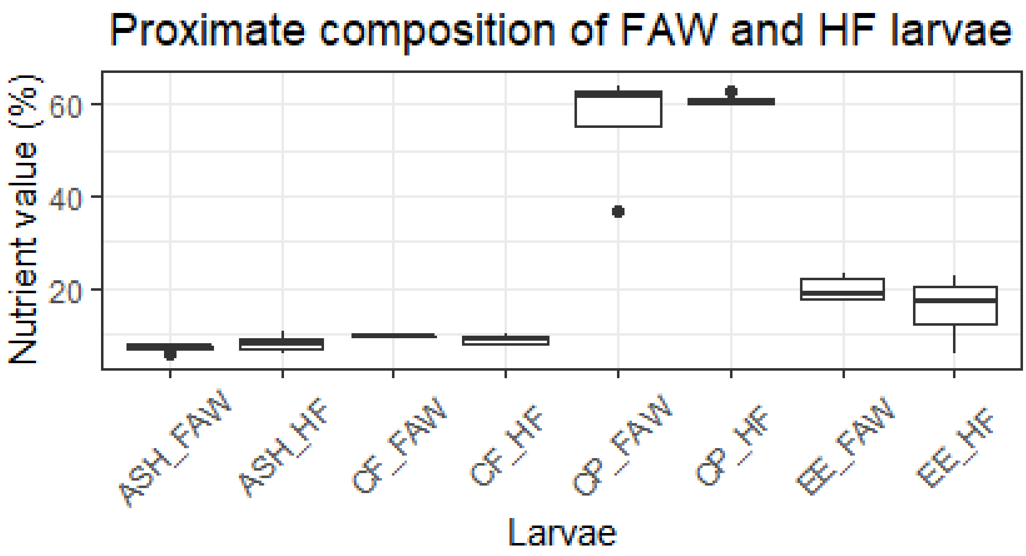


Figure 36: A plot for the Proximate analysis of HF larvae and FAW larvae on Dry matter basis (%DM)

Table 6: A Comparison of proximate composition of FAW Larvae (n = 3) and HF larvae from our studies HF_1, HF_2, HF_3, and HF_4 (n = 4) means, on dry matter basis(%DM)

	Samples				**Mean**		
Parameter	**HF_1**	**HF_2**	**HF_3**	**HF_4**	**HF**	**FAW**	**p value**
CP	60.38	59.87	60.51	62.98	60.94 [a]	56.22[a]	0.44
CF	8.59	7.11		9.64	8.45 [a]	9.33 [a]	0.36
EE	14.08	19.64	22.21	5.58	15.33 [a]	19.66 [a]	0.34
ASH	10.68	7.06	5.27	8,15	7.79 [a]	7 [a]	0.26
Reference	(Pieterse & Pretorius, 2014)	(Hussein *et al*., 2017)	(Fitches *et al*., 2019)	(Elahi *et al*., 2020)			

Means followed by the same letter in a row are not statistically significant different from each other at p <0.05.

4.4.4 Proximate Composition of Soya Bean and FAW Larvae

The data on proximate composition of FAW larvae and Soya bean is visualized in figure 37. The summary of their analysis is presented in table 7. The study tested: ASH_SB = ASH for Soya bean, CF_SB = Crude fibre for Soya bean, CP_SB = Crude protein for Soya bean, EE_SB = Ether extract for Soya bean, ASH_FAW = ASH for FAW larvae, CF_FAW = Crude fibre for FAW larvae, CP_FAW = Crude protein for FAW larvae, EE_FAW = Ether extract for FAW larvae.

The current research revealed in figure 37 that FAW was rich in protein given that it had a higher crude protein value CP_FAW (56.22) % when compared to soya bean, CP_SB (41.12) %. It also had the same mount of fat (EE_FAW) = (19.66) % when compared to soya bean (EE_SB) =20.33%.

Comparison of FAW larvae and soya bean means did not reveal any statistically significant difference as indicated in the table 7. Even though, there were no significant differences, figure 37 showed that FAW larvae had a higher amount of CP compared to soya bean.

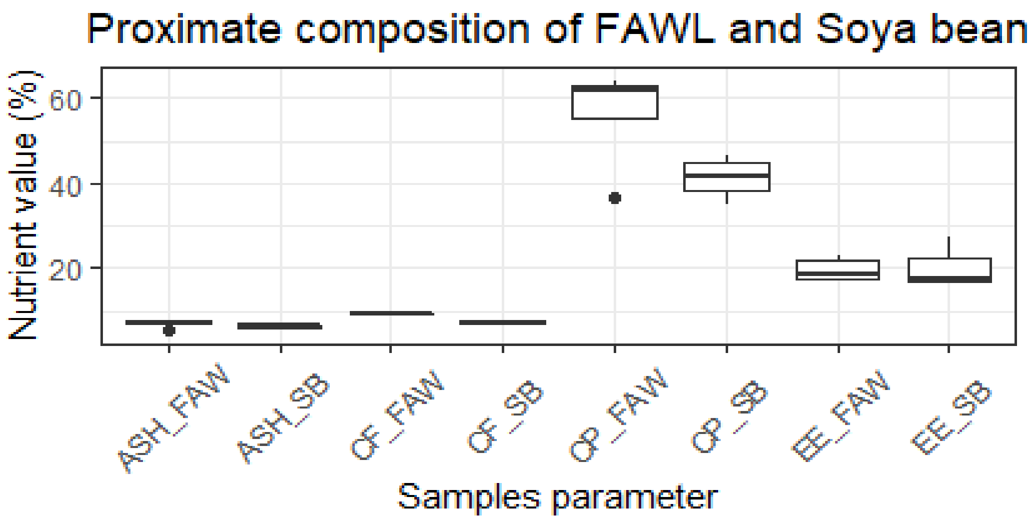


Figure 37: A plot for the Proximate analysis of fall armyworm larvae (FAWL) and Soya bean on Dry matter basis (%DM)

The results of the analysis of nutrient content of FAW larvae and Soya bean is shown in table 7.

Table 7: Comparison of proximate composition of FAW larvae (n=3) and Soya bean from four studies SB_1, SB_2, SB_3, and SB_4 (n=4) means, on dry matter basis(%DM)

	Samples				**Mean**		
Parameter	**SB_1**	**SB_2**	**SB_3**	**SB_4**	**SB**	**FAW**	**p value**
CP	39.28	46.4	44	34.8	41.12 [a]	56.22[a]	0.16
CF		6.75	7.3	7.5	7.18 [B]	9.33 [a]	0.03
EE	16.37	27.18		17.5	20.35 [a]	19.66 [a]	0.7
ASH	6.61	6.65		5.2	6.15 [a]	7 [a]	0.12
Reference	(Kwikiriza, *et al*., 2016)	(Khan, *et al*., 2018)	(Sayed *et al.,* 2019)	(Świątkiewicz *et al*., 2021)			

Means followed by the same letter in a row are not statistically significantly different from each other.

In the current study, there was a significant difference in the crude protein between *S. frugiperda* (S1) and *S. frugiperda* (S2) at p = 0.04 (Tab. 4). This is consistent with the report by Rumpold & Schl, (2013) that there are differences in the results of the nutritional composition of edible insects. In this study, the difference could have resulted from the method that was used for the analysis. *S. frugiperda* (S1) was analyzed at KALRO, while *S. frugiperda* (S2) and *S. frugiperda* (S3) were analysed at Egerton University. The difference could also result from the stage of the larvae that was harvested, for *S. frugiperda* (S1) it was L5/L6, while the larval stages of *S. frugiperda* (S2) and *S. frugiperda* (S3) ranged from L2 to L6. Therefore, the study suggests that further research be conducted on the nutritional profile of different larval stages.

The % crude protein of *S. frugiperda* was comparable to that of *Spodoptera littoralis* 51.2% (Sayed *et al*., 2019). Our findings are in agreement with those reported by Williams *et al*., (2016) that the % crude protein of *S. frugiperda* fed on artificial diet and *S. frugiperda* fed on fresh plant materials were 59. 0 % and 59.3 % respectively. When the crude protein of FAW larvae was compared to BSF larvae (Tab. 5) and house fly (HF) larvae (Tab. 6) and Soya bean (Tab. 7) there were no statistical differences in their means. These results indicate that FAW larvae is rich in protein. Besides, caterpillars in the order Lepidoptera are rich in protein (Braide *et al*., 2010; Sayed *et al*., 2019; Williams *et al*., 2016).

There were no statistically significant differences in the amount of crude fibre available in *S. frugiperda* (S2) and *S. frugiperda* (S3) (Fig. 33). A comparison of the crude fibre of FAW larvae, BSF larvae, HF larvae, and Soya bean indicated that the amount of crude fibre was the same (Tab. 5, Tab 6 and Tab. 7). Crude fibre of < 10% for *S. frugiperda* in the current study is inline with the report of Williams *et al*., (2016), which is an indication that their bodies were not hardened.

The average ash content did not have any significant differences among the *S. frugiperda* samples in this study (Tab. 4). This was similar to the report by Williams *et al*., (2016) of 5.7 % for *S. frugiperda* fed on an artificial diet. Still, they also reported a slightly higher value of 11.6 % for *S. frugiperda* larvae fed on fresh plant products. According to Braide *et al*., (2010), an ash content of 6.42% indicates high mineral content. Therefore, this research also found the ash content of 5.6 %and 7.4 %; hence *S. frugiperda* is rich in minerals.

FAW larvae ash content compared to HF larvae (Tab. 7) and Soya bean (Tab. 4) did not have statistically significant differences. Therefore, this shows that FAW larvae possibly have the same mineral content as HF larvae and Soya bean. Nevertheless, there was a statistically significant difference when compared to BSF larvae (Tab. 5). This indicates that BSF larvae could have a higher amount of minerals than FAW larvae.

There was no significant difference in the fat content of *S. frugiperda* S1 (22.9) %, S2 (17.8) %, and S3(21.1%) (Tab. 4). The results are consistent with the reports by Williams *et al*., (2016) that *S. frugiperda* fed on artificial diets had 20.6% fat but lower in *S. frugiperda* fed on fresh plants 11.7 %. A comparison of FAW larvae fat content (19.66 %) to HF larvae (15.33) % (Tab. 6) and Soya bean (20.33) % (Tab. 7) showed that the fat content was the same, but there was a statistically significant difference when the fat content of FAW larvae was compared to BSF larvae (37.3) (Tab. 5) ($p = 0.04$) which can also be seen in (Fig. 34). These findings are in agreement with the report by Kou & Adámková, (2016) that averagely edible insects contain about 10 to 60% of fat in dry matter.

Insects have been reported to have very low carbohydrates levels (Fombong *et al*., 2017). This study reports carbohydrates of (1.65 – 3.39) % for *S. frugiperda* S2 and *S. frugiperda* S3 (Tab. 4), which are close to 5.2 for *Spodoptera littoralis* (Sayed *et al*., 2019). Since FAW larvae are comparable to BSF Larvae, HF larvae, and Soya bean in terms of crude protein and crude fiber except for fat and ash content with BSF larvae. There is sufficient evidence that FAW larvae could be a potential source of poultry feed. However, there is a need to study if regions could affect their nutrient content.

Utilizing FAW larvae as a source of protein could contribute to improved global food security through feed, new business ventures, creating new jobs, enhancing income by providing a cheaper source of poultry feed, and reducing food-feed competition (Abro *et al*., 2020; Veldkamp & Bosch, 2015).

CHAPTER FIVE

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The current study suggests that the optimal visual cue of *S. exigua* in a wind tunnel experiment functions well as a model insect for *S. frugiperda*, which is attracted to UV-A (365-400) nm in the field experiments. Therefore, these light wavelengths have the potential to be incorporated in the trapping of *Spodoptera* Spp. A water trap with UV-A LED light (385nm) together with attractive pheromones was able to capture FAW moths in maize fields. The findings of this study suggest that an effective pheromone could increase FAW captures by a water trap with LED light. For these reasons, the current study suggests that a combination of optimal visual and olfaction cues could be a game-changer in insect pest management. Based on the findings of this study, it is evident that *S. frugiperda* has sufficient nutrients for chicken feed. Therefore, there is a possibility that FAW larvae could be utilized as an alternative source of protein for chicken, since FAW is rich in crude protein at (36.9 – 63.54) %, crude fibre (9.1 – 9.6) %., and crude fat (17.8 – 22.9) %. Utilization of FAW larvae as poultry feed would promote food security in its protein conversion into poultry products

5.2 Recommendations

5.2.1 From the Current Study

In order to avoid the environmental degradation through the use of pesticides, this study recommends that the government of Kenya through the Ministry of Agriculture and FAO to adopt the use of a combination of water trap + UV-A LED and an attractive pheromone in mass trapping of *S. frugiperda* and *S. exigua* in the field. Manufacturing and usage of the traps would lower the pest population subsequently increasing maize production hence boosting food security. The research also recommends that poultry farmers and livestock feed companies to incorporate FAW larvae in the poultry diets since it is rich in protein.

5.2.2 Suggested for Further Study

The study recommends the further studies to be carried out with the LED water trap to make it more effective such as modification of the trap, test it in a lure and kill strategy, and the impact of longer light wavelengths on the nocturnal behaviours of *S. frugiperda* and *S. exigua*. Even though *S. frugiperda* has depicted a potential to be utilized as poultry feed due to its rich nutrients, the research recommends further analysis to determine its safety as food or feed and also to evaluate the performance of chicken reared on FAW larvae.

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Appendices

Appendix I: Rotation plan for traps design and lures

Set up field experiment

lures

Each trap with 1 lure is at least 15 meter distance from each other

Each rotation is rotated after 3 nights depending on the catches

Rotation 1 (of 8)				Rotation 2 (of 8)				Rotation 3 (of 8)				Rotation 4 (of 8)			
	Rep1	Rep 2	Rep 3		Repl 1	Rep 2	Rep 3		Rep 1	Rep 2	Rep 3		Rep 1	Rep 2	Rep 3
1	T2	T8	T1	1	T6	T5	T3	1	T5	T7	T6	1	T1	T6	T7
2	T8	T6	T3	2	T4	T7	T2	2	T7	T1	T4	2	T3	T4	T1
3	T1	T5	T7	3	T2	T8	T6	3	T8	T4	T2	3	T7	T2	T4
4	T5	T7	T8	4	T3	T6	T4	4	T6	T2	T3	4	T8	T3	T2
5	T4	T2	T5	5	T7	T1	T8	5	T1	T3	T7	5	T5	T7	T3
6	T7	T3	T4	6	T5	T2	T1	6	T2	T6	T5	6	T4	T5	T6
7	T3	T1	T6	7	T8	T4	T7	7	T4	T5	T8	7	T6	T8	T5
8	T6	T4	T2	8	T1	T3	T5	8	T3	T8	T1	8	T2	T1	T8

Rotation 5 (of 8) Rotation 6 (of 8) Rotation 7 (of 8) Rotation 8 (of 8)

	Rep 1	Rep 2	Rep 3
1	T3	T2	T4
2	T2	T8	T5
3	T6	T1	T3
4	T4	T5	T1
5	T8	T4	T6
6	T1	T7	T8
7	T7	T3	T2
8	T5	T6	T7

	Rep 1	Rep 2	Rep 3
1	T8	T1	T5
2	T6	T3	T7
3	T5	T7	T8
4	T7	T8	T6
5	T2	T5	T1
6	T3	T4	T2
7	T1	T6	T4
8	T4	T2	T3

	Rep 1	Rep 2	Rep 3
1	T4	T3	T2
2	T5	T2	T8
3	T3	T6	T1
4	T1	T4	T5
5	T6	T8	T4
6	T8	T1	T7
7	T2	T7	T3
8	T7	T5	T6

	Rep 1	Rep 2	Rep 3
1	T7	T4	T8
2	T1	T5	T6
3	T4	T3	T5
4	T2	T1	T7
5	T3	T6	T2
6	T6	T8	T3
7	T5	T2	T1
8	T8	T7	T4

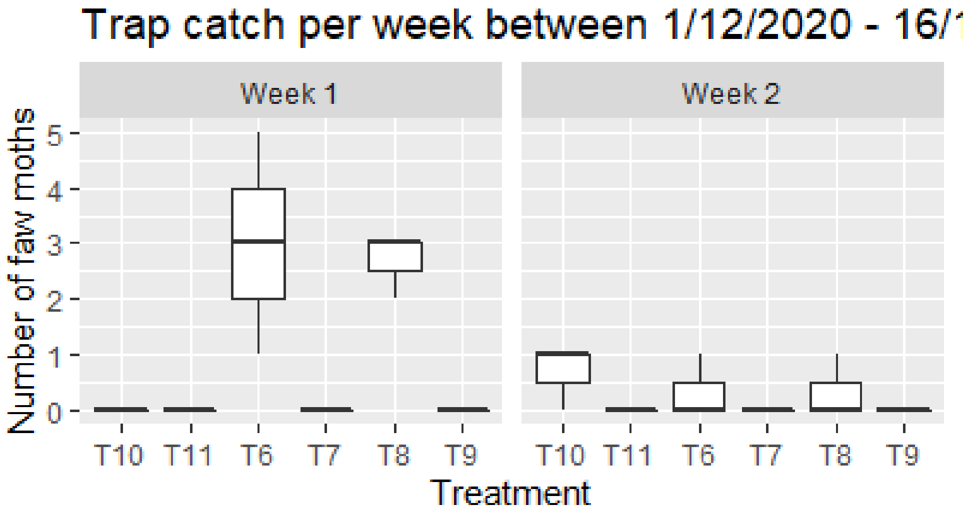
Appendix II: ANOVA table for experiment 1: Trap captures after 30 minutes

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Wavelength	6	1227	204.49	6.091	0.00259 **
Residuals	14	470	33.57		

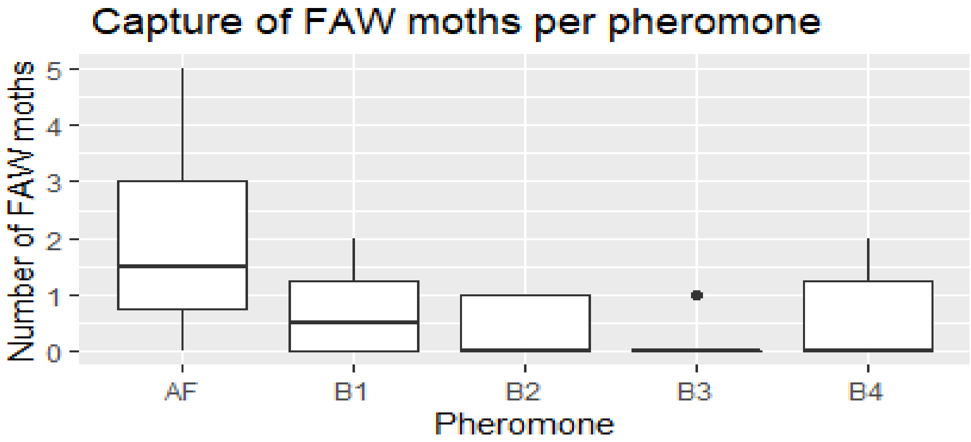
Appendix III: ANOVA table for experiment 1: Trap captures after 14 hours

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Wavelength	6	31640	5273	61.25	3.02e-09 ***
Residuals	14				

Appendix IV: Trap captures during the control experiment in field 2.



Appendix V: Trap captures in Rift Valley and Coastal regions November 2020



Appendix VI: Publications

1. Okello, E. A., Watako, A., van Tol, R. W., & Ariga, E. S. (2020). Evaluation of optimal light wavelength for the attraction of *Spodoptera exigua* as a model insect for mass trapping and control of *Spodoptera frugiperda*. International Journal of Entomology Research, *5*(3), 27–32. http://www.entomologyjournals.com/search/5-2-43

2. Okello, E. A., Watako, A., Ochia, C. O., & Muok, B. (2022). A comparative evaluation of nutrient content of fall armyworm (Spodoptera frugiperda) larvae to other chicken feeds. African Journal of Agricultural Research, 18(1), 27-34. Okello, E. A., Watako, A., Ochia, C. O., & Muok, B. (2022). A comparative evaluation of nutrient content of fall armyworm (Spodoptera frugiperda) larvae to other chicken feeds. African Journal of Agricultural Research, 18(1), 27-34. DOI: https://doi.org/10.5897/AJAR2021.15882

Appendix VII: Poster

Light-Emitting Diodes (LED) with UV-A light: a game changer in the phytosanitary systems?

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Abstract:. The fall armyworm *Spodoptera frugiperda* (FAW) is an invasive pest from the American continent. The devastating pest is ravaging plants causing serious damages thus posing a threat to food security in Africa. Insect's vision has been used in Integrated Pest Management (IPM) to monitor and control insect pests, such as the FAW and Beet armyworm (*Spodoptera exigua*) (BAW). However, current commercial traps which need reflection of sunlight to be visible are not attractive to nocturnal insects. The available light traps appear to use unattractive light wavelengths. This study aims at managing FAW through mass trapping using a Light Emitting Diode (LED) water trap with attractive UV- A light and pheromones. Field results indicate that the trap has the potential of lowering the population of FAW in the field thus minimising the amount of pesticides residue in agricultural produce. This trap could offer the solution in terms of the maximum residue level (MRLs) on agricultural products, consequently, LED water trap with UV-A light could be a game changer in the phytosanitary systems

Introduction

Fall armyworm (FAW) is an invasive pest from the American continent which is causing serious damages to maize (Fig 1) in Africa. Most of the nocturnal insects especially the ones in the genus Spodoptera have superposition eyes, which are believed to be sensitive to light. This allows them to orientate during flight and sometimes locate food (Satoh *et al.* 2016).

Insect's vision is one of the management strategies used in Integrated Pest Management (IPM) to monitor and control insects pests, in maize fields. However, current commercial traps which need reflection of sunlight to be visible are not attractive to nocturnal insects such as FAW and BAW. The available light traps appear to use unattractive light wavelengths as shown by Okello *et al.* (2020). Therefore, the study aims at managing FAW through mass trapping using a Light Emitting Diode (LED) water trap with attractive UV- A light and pheromones

Fig. 1 Damages by FAW larvae on maize

Materials and methods

Efficacy of mass trapping FAW using visual cues and lures were tested using various trap designs and lures in a maize field on daily basis. The trap designs were a LED water trap with UV-A light (Fig 2a.), Bucket (funnel) trap (Fig 2b) and Delta trap (Fig 2c).

Fig.2a = LED water trap, 2b = Bucket (funnel) trap, 2c= Delta trap

Results

The results from the field show that LED water trap with UV-A + pheromones (Fig. 3 & 4) depicts a positive response in capturing FAW and other moths as compared to the bucket (Fig. 5) and the delta traps (Fig. 3).

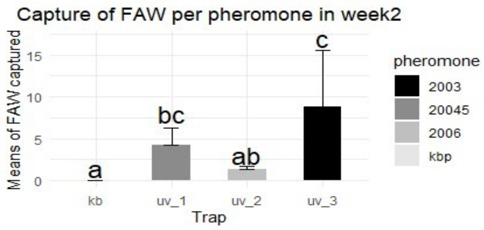

Fig. 3 Capture of FAW by LED water traps; UV_1, UV_2, UV_3 and Delta trap (kb) in season 1, N = 7, p value= 0.001(***)

Fig. 4 Capture of FAW by LED water trap in season 3

Fig. 5 Capture of FAW by Bucket (funnel) trap in season 3

Conclusion

LED water trap with UV-A has the potential of lowering the population of FAW in the field and thus minimising the amount of pesticides residue in agricultural produce. This trap could offer the solution in terms of the maximum residue level (MRLs) on agricultural products. For these reasons, LED water trap with UV-A light could be a game changer in the phytosanitary systems

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•Okello, E. A, Watako, A., van Tol, R. W M., & Ariga, E. S. (2020). Evaluation of optimal light wavelength for the attraction of *Spodoptera exigua* as a model insect for mass trapping and control of *Spodoptera frugiperda*. *International Journal of Entomology Research*, *5*(3), 27–32

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Theme: *Enhancing Phytosanitary Systems for Health Plants, Safe and Sustainable Trade"*
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Appendix VIII Ethical review certificate

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JOOUST-ETHICS REVIEW OFFICE

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P.O. BOX 210 - 40601
BONDO

OUR REF: JOOUST/DVC-RIO/ERC/E2

16th December, 2019

Emily Awuor Akelo
SAFS
JOOUST

Dear Ms. Akelo,

RE: APPROVAL TO CONDUCT RESEARCH TITLED *"MANAGEMENT STRATEGY AND POTENTINAL UTILIZING FALL ARMYWORM (SPODOPTERA FRUGIPERDA) LARVAE AS POULTRY FEED"*

This is to inform you that JOOUST ERC has reviewed and approved your above research proposal. Your application approval number is **7/15/ERC/12/19-3.** The approval period is from 16th December, 2019 – 15th December, 2020.

This approval is subject to compliance with the following requirements:

i. Only approved documents including (informed consents, study instruments, MTA) will be used.
ii. All changes including (amendments, deviations and violations) are submitted for review and approval by JOOUST IERC.
iii. Death and life threatening problems and serious adverse events or unexpected adverse events whether related or unrelated to the study must be reported to NACOSTI IERC within 72 hours of notification.
iv. Any changes, anticipated or otherwise that may increase the risks of affected safety or welfare of study participants and others or affect the integrity of the research must be reported to NACOSTI IERC within 72 hours.
v. Clearance for export of biological specimens must be obtained from relevant institutions.
vi. Submission of a request for renewal of approval at least 60 days prior to expiry of the approval period. Attach a comprehensive progress report to support the renewal.
vii. Submission of an executive summary report within 90 days upon completion of the study to JOOUST IERC.

Prior to commencing your study, you will be expected to obtain a research permit from National Commission for Science, Technology and Innovation (NACOSTI) https:oris.nacosti.go.ke and also obtain other clearances needed.

Yours sincerely,

Prof. Francis Angiawa
Chairman, JOOUST ERC

Copy to: Deputy Vice-Chancellor, RIO Director, BPS Dean, SAFS

Appendix IX National Commission for Science, technology and Innovation (NACOSTI) certificate

REPUBLIC OF KENYA

NATIONAL COMMISSION FOR SCIENCE, TECHNOLOGY & INNOVATION

Ref No: **752072**

Date of Issue: **14/January/2021**

RESEARCH LICENSE

This is to Certify that Ms.. EMILLY AWUOR OKELLO of Jaramogi Oginga Odinga University of Science and Technology, has been licensed to conduct research in Siaya on the topic: MANAGEMENT STRATEGY AND POTENTIAL OF UTILIZING FALL ARMYWORM (Spodoptera frugiperda) LARVAE AS POULTRY FEED for the period ending : 14/January/2022.

License No: **NACOSTI/P/21/8313**

752072

Applicant Identification Number

Director General

NATIONAL COMMISSION FOR SCIENCE, TECHNOLOGY & INNOVATION

Verification QR Code

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