INSECT DIVERSITY AND THEIR SUITABLE MANAGEMENT ON AFRICAN INDIGENOUS VEGETABLES IN WESTERN KENYA

BY

MNENE ANJELINE WAWUDA

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF MASTER OF SCIENCE IN PLANT PROTECTION OF THE UNIVERSITY OF ELDORET, KENYA.

2021

DECLARATION

Declaration by the Student

This thesis is my original work and has not been submitted for any academic award in any institution; and shall not be reproduced in part or full, or in any format without the prior written permission from the author and/or the University of Eldoret.

Mnene Anjeline Wawuda

(AGR/PGC/011/14) Date

Declaration by Supervisors

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

Prof. Linnet Sarange Gohole **Date**
University of Eldoret, Kenya

Prof. John Stephen Yaninek **Date**
Purdue University, USA

DEDICATION

I dedicate this work to my lovely parents Mr. Cornelius C. Mnene and Mrs. Ephigenia M. Mnene who have always been there to encourage and support me throughout this journey.

ABSTRACT

Insect pests, especially aphids (Hemiptera) and flea beetles (Coleoptera), have been documented to lower the yield and quality of common African indigenous vegetables (AIVs) in western Kenya. Their persistence and severity is one of the major reasons for low yields in this region. This study was therefore done to establish the insect pests of AIVs in western Kenya and evaluated a selection of aphid pest management intervention technologies. A field survey was conducted in Homa Bay, Siaya, Kisumu, Busia, Kakamega, Uasin Gishu and Kisii counties where amaranth (*Amaranthus sp*), spider plant (*Cleome gynandra*) and nightshade (*Solanum nigrum*) are commonly produced and consumed. This was to develop an inventory of the AIV common insect pests. The counties were sub-divided into agro-ecological zones. From the survey, 84.6% of total insect species collected were pests. Hemipterans were most numerous, while coleopterans were most diverse. AIV insect species diversity was higher in spider plant, then amaranth and least in nightshade. Aphids were the most important common pest with *Aphis fabae* and *Myzus persicae* found on all three AIV among the six aphid species identified. The highest insect diversity was found in the lower highland agro-ecological zone where annual polyculture is practiced, while the lowest diversity was found in lower midland agro-ecological zone where perennial monoculture (sugar-cane farming) is practiced. Additionally, a three replicate split-plot in RCBD experiment was laid in Mwamba-Lugari sub-county during rainy and dry seasons to evaluate a selection of aphid pest management technologies. They included traditional wood ash, botanical neem (azadirachtin 0.03% ai) and synthetic chemical Karate (lambda-cyhalothrin ai) on amaranth (*Amaranthus sp*) and nightshade (*Solanum nigrum*). Aphid density and yields data was subjected to analysis using SAS 9.4 and means separated by Turkey-Kramer’s test at 95% confidence level. In both seasons, amaranth and nightshade treated with plain water (control) had significantly ($p<0.05$) greater aphid densities compared to all other pest management strategies (ash, neem, Karate). Yields of both amaranth and nightshade from dry and wet season were significantly ($p<0.05$) higher on plots treated with Karate and least on plots treated with plain water. Generally across all seasons and AIV varieties, aphid density was lower in AIVs treated with Karate followed by neem then ash and finally plain water (control). Aphid pressure (density) influences overall yields (higher aphid pressure leads to lower yields). AIV farmers should monitor insect pest densities before treatment application and consider using synthetic pesticides when pest densities are high in order to minimize losses.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS AND ACRONYMS

ABI	Applied Bio systems
ai	Active ingredient
BLAST	Basic Local Alignment Search Tool
COI	Cytochrome oxidase subunit I
DNA	Deoxyribonucleic Acid
HIV/AIDS	Human Immuno deficiency Virus/Acquired Immunodeficiency Syndrome
NCBI	National Centre for Biotechnology Information
PCR	Polymerase chain reaction

ACKNOWLEDGMENT

First, I would like to thank Almighty God for life, health and strength to finish my master’s degree. I also want to thank the Hort Nutrition project of the USAID-funded Horticulture Innovation Lab for funding my project and the tuition fee. This enabled me to finish my Master of Science degree. My gratitude is also extended to the University of Eldoret for giving me this opportunity to build my career as an entomologist. I would also like to thank Dr. Steve Weller of Purdue University for his invaluable support and guidance. To my family Mr. and Mrs. Mnene, sisters Agnes Mchape, Teresia Riziki, brother Richard Ndoloi, my husband Mr. Frankline Ngatia, thank you for his constant encouragement prayers and support. Finally, to my friends Mr. Boniface Alkamoi, Mrs. Norah Kiptoo and Mr. Naman Nyabinda thank you.

CHAPTER ONE

INTRODUCTION

1.1 Background information

Agriculture is the largest employer in Africa with a majority of Sub-Saharan Africa (SSA) inhabitants depending on it (Diao *et al.*, 2010). Be that as it may, Africa has one of the highest levels of malnutrition globally, accounting for 45% of deaths among children less than 5 years (Akombi *et al.*, 2017). Africa's staple food is mostly comprised of cereals and tubers like maize, cassava, sweet potatoes and plantain (green bananas) which are full of energy but low in other essential vitamin and mineral nutrients (Omasaja, 2016; Oniang'o *et al.*, 2003), thus contributing to "hidden hunger" (Abukutsa-Onyango, 2010). 300 million people in SSA are deficient in these minerals and this could get worse in the near future; the International Food Policy Research Institute predicted an 18% rise in malnourished children by the year 2020 (Kamga *et al.*, 2013).

African indigenous vegetables (AIVs) are an important source of nutrients in local diets. Sub Saharan Africa has up to 1000 traditional African leafy vegetables (Wemali, 2014) that are a rich source of calcium (Ca), magnesium (Mg), Potassium (K), phosphorous (P), zinc (Zn), iron (Fe), protein and carotenoids (Kamga *et al.*, 2013). These nutrients are particularly important to breastfeeding mothers, children, and people with potentially terminal diseases like HIV/AIDS (Bua & Onang, 2017). Apart from nutritional benefits, AIVs also have medicinal advantages. For instance they are said to cure colds, diarrhea, diabetes, high blood pressure and boost the immune system of HIV/AIDS patients among other illnesses (Tumwet, 2013). Consumption of AIVs could therefore greatly contribute to alleviation of malnutrition (Okello *et al.*, 2015). However, these vegetables and their nutritional attributes have not been fully understood, appreciated and exploited (Gido *et al.*, 2015).

AIVs have a long history of cultivation, production and utilization in Africa. Adaptations to local environmental conditions helped them become part of local food cultures in Sub Saharan Africa (Abukutsa-Onyango, 2010). They provide vegetables derived from leaves, roots or fruits of plants collected in the wild or grown either for family consumption, commercial purposes or both (Muhanji *et al.*, 2011; Omasaja, 2016). They are often used as relish to accompany starchy staples (Mavengahama, 2013). Production, processing and marketing of these vegetables especially in western Kenya is done by women at subsistence level in home gardens for consumption where little remains for the market. Land preparation, planting and weeding is done manually using hoes and machetes or seeds broadcasted by hand. Wood ash is then often used to manage insect pests (Abukutsa-Onyango, 2007). Planting is done twice a year and harvesting goes for up to three months (Abukutsa-Onyango, 2007).

Consumption of AIVs is influenced by culture, gender, age, availability, taste, shelf life, preparation method and time among others. For instance, men are reported to prefer less vegetables compared to women, while youth consider AIVs consumption backward due to their monotonous preparation method which makes them less tasty and appealing compared to exotic vegetables and leaves them stigmatized as poor man’s food (Muhanji *et al.*, 2011; Wemali, 2014). Introduction and promotion of exotic vegetables like cabbage, which are lower in nutrients compared to AIVs during the colonial period, suppressed use of AIVs and contributed to “hidden hunger” due to inadequate consumption of micronutrients (Abukutsa-Onyango, 2010). Vegetables consumption rate in SSA is still low (Bua & Onang, 2017; Kamga *et al.,* 2013) at (30-50kg/person/year) at 43% of the recommended rate of 73kg/person/year (Kouamé *et al.,* 2014; Ntawuruhunga, 2016). This explains why fifty percent of Kenyans are deficient in iron (Fe) and other nutrients like zinc (Zn), calcium (Ca), magnesium (Mg), vitamin A and iodine (I) (Kamga *et al.,* 2013; Lingunya *et al.,* 2015; Oniang'o *et al.,* 2003) nutrients which are readily available in many AIVs (Kamga *et al.,* 2013). The low consumption of AIVs reflects their limited supply which has been attributed to several production constraints including both abiotic, i.e., drought and soil acidity, and biotic, i.e., insect pests and pathogens (Onyango *et al.,* 2013; Wemali, 2014). Additionally, poor marketing channels, access to markets and poor seed quality are some of the other factors responsible for low production, limited availability and low profitability (Abukutsa-Onyango, 2007).

Recently, an awakening to the benefits of these ‘super vegetables’ has significantly increased demand. AIVs are now being sought after all over, from back street food joints to five star hotels and now even the Kenyan parliament. This rising demand has made growing and selling AIVs a potential profitable venture and no longer just a women’s affair (Shiundu & Oniang'o, 2007).

Research has been done to increase yields with improved varieties but little has been done to address their pests. Common insect pests of AIVs include hemipterans, dipterans, coleopterans and lepidopterans (Keatinge *et al.,* 2015; Omasaja, 2016). Farmers use different interventions like wood ash and synthetic pesticides to manage insect pests on various crops, but little has been documented for AIVs (Kariuki, 1999; Okutu *et al.,* 2014; Olubayo *et al.,* 2008). There is also inadequate documentation on pest diagnosis, economic and action thresholds, suitable and manageable pest management strategies that

AIV farmers can use to manage their common insect pests (Abang *et al.,* 2012). The insufficient information recorded about the influence of agro-ecological climatic zones on insect pests of AIVs can also not be ignored. It is, therefore, in view of these gaps, that this study aimed to improve AIVs production by 1) developing sustainable integrated pest management IPM for the most important insect pests of popular AIV crops based on 2) an inventory of the common AIV insect pests found in the different agroecological zones of western Kenya.

1.2 Statement of the problem

Consumer demand has created an opportunity to produce AIVs all year round, but practices that intensify production have increased pest problems (Unger, 2014). Flea beetles are documented to cause more than 25% loss on spider plant (Kirigia *et al.,* 2017). On nightshade they have also been documented to cause immense damage although the extent has not been properly documented. Yield losses by aphids have been reported to be 80% on cotton in Zambia although losses on AIVs in Kenya are yet to be quantified (Mureithi *et al.,* 2017). In western Kenya, insect pests are reported as one of the major challenges in AIVs production. Through their mode of feeding (chewing, sucking or burrowing), they affect both quality and quantity of AIVs by reducing yield and market value leading to economic loss and loss of crop diversity since farmers will not plant what is highly susceptible (Omasaja, 2016). Their persistence and severity is one of the major reasons for low yields and reduced profits (Abukutsa-Onyango, 2007; Lingunya *et al.,* 2015; Onyango *et al.,* 2013). Farmers use chemicals and wood ash to manage vegetable insect pests (Abukutsa-Onyango, 2007; Omasaja, 2016; Sithanantham, 2004) but the ability of these interventions to suppress insect pest pressure (densities) on AIVs is not substantiated with research.

1.3 Justification

Among the biotic factors affecting the production of indigenous vegetables, insect pests are often mentioned as a production constraint (Liburd *et al.*, 2015; Lingunya *et al.*, 2015; Omasaja, 2016). To achieve sustainable production, appropriate insect pest management must be adopted (Kebede & Bokelmann, 2017; Omasaja, 2016). Therefore, apart from lack of knowledge on economically viable and environmentally friendly approaches for managing AIV pests, little has been documented about the AIV insect pests and their importance (Omasaja, 2016; Pasquini *et al.,* 2009). In as much as improved AIV varieties are high yielding, many are often more susceptible with almost minimal resistance and tolerance to insect pest infestations compared to local varieties (Omasaja, 2016).

Farmers want simple, manageable and effective pest intervention strategies to manage key pests and minimize losses in yield and product quality. Integrated pest management is a potential answer to these concerns. IPM is a strategy that seeks to involve a combination of several compatible crop protection strategies in order to avoid pest infestations from reaching economically damaging levels (Braima *et al.,* 2010).

It is, therefore, in view of this gap that this research attempted to identify common insects including pests of AIVs found in the western Kenya region where AIVs have been produced and consumed for long. This study also sought to evaluate effective, manageable and sustainable insect pest management strategies on AIVs in collaboration with other cultural management practices in order to reduce insect pest losses.

1.4 Objectives

1.4.1 General objective

To improve AIVs production in western Kenya through management of common insect pests.

1.4.2 Specific objectives

- To establish an insect pest diversity inventory for selected AIVs from different agro-ecological zones of western Kenya.
- To evaluate commonly used insect pest management strategies for their suitability in management of AIV insect pests.

1.5 Research hypotheses

H_1: There is insect pest diversity in the different agro-ecological zones of western Kenya.

H_2: Establishing a sustainable insect pest management will reduce AIV pest losses in western Kenya.

CHAPTER TWO

LITERATURE REVIEW

2.1 African indigenous vegetables

African indigenous vegetables (AIVs) are made up of a wide range of vegetable species whose natural original habitat is Africa (Gido *et al.,* 2016). Although there are more than 7,000 species that are edible, only a few are being utilized (Shackleton *et al.,* 2009). Their production is suitable, especially for the "resource-limited" persons since they are easy to grow and do not require inputs similar to their exotic counterparts (Pichop & Weinberger, 2009). AIVs are preferred because of their high nutritive, mineral, economic and medicinal values. They also produce their own seeds in tropical conditions, respond well to organic fertilizers, flourish well when intercropped, are ready for harvesting 3 to 4 weeks after planting and are a source of income providing employment opportunities, especially to rural communities (Abukutsa-Onyango, 2010; Gido *et al.,* 2016). Kenya has about 200 wild weedy species of edible leafy vegetables consumed across the coastal, western, lake regions and highlands of Kenya (Wemali, 2014). While some researchers believe consumption of AIVs has declined because of a perception that AIVs are inferior in taste and nutritional value compared to exotic vegetables like spinach and cabbage (Mwaura *et al.,* 2013), others report a steady growth in AIV consumption with increasing appearance and availability in formal markets in the past 15 years (Mwaura *et al.,* 2013). Production area and value of AIV grew by 6 % and 10%, respectively in 2014 because of a growing awareness of their nutritional and health benefits (Chepkoech *et al.,* 2018). Before 2000, AIVs were regarded as back street and open air vegetables, but since then

AIVs have increasingly become important in both formal and informal markets (Mwaura *et al.*, 2013).

Many studies have been done on the production and the importance of AIVs but little has been done on their consumption (Gido *et al.,* 2016; Yang & Keding, 2009). Consumption of AIVs depends on the community in question, local perception, availability, geographic location and cultural background (Wemali, 2014). In western Kenya women gather these vegetables to supplement cultivated vegetables that are typically consumed with Ugali (a stiff maize meal porridge) as stew (Wemali, 2014). Rural dwellers consume AIVs four times a week on average compared to urban dwellers who consume AIVs twice a week on average (Gido *et al.*, 2017).

2.1.1 Poor man's food?

During the colonial era, entrepreneurs brought many exotic vegetables to Africa (Muhanji *et al.,* 2011). Their introduction led to changes in food habits. Exotic vegetables were favored and fetched higher prices in the market over indigenous vegetables. This was because AIVs were considered outdated compared to exotic vegetable that were associated with affluence. Since AIVs grew wild, were easily accessible and had boring methods of preparation, they were primarily consumed by rural communities who could not afford the expensive exotic vegetables. This led to AIVs being referred to as "poor man's food" thus affecting their consumption. Branding AIVs as weeds and promoting their eradication instead of conserving them did not help the situation (Abukutsa-Onyango, 2010; Oladele, 2011; Wemali, 2014).

2.1.2 Production in western Kenya

There is a rich diversity of AIVs produced and consumed in Kenya and especially in western Kenya. These include slender leaf (*Crotalaria oschroleuca* and *C. brevidens*), cowpea (*Vigna unguiculata*), pumpkin (*Cucurbita pepo*) and jute mallow (*Corchorus spp*) among others. However, commonly consumed AIVs are spider plant (*Cleome gynandra*), amaranth (*Amaranthus spp*), and night shade (*Solanum nigrum*) (Gido *et al.,* 2016; Mwaura *et al.,* 2013; Omasaja, 2016).

Traditionally, these AIVs were gathered from the local countryside as wild plants and formed part of daily diets in many rural households. During cultivation, some were intentionally left to grow for later harvest instead of being uprooted. (Gido *et al.,* 2016)

2.1.3 Crop specific information

Nightshade

Sharing its family with potatoes, tomatoes, chilies, red and green peppers, nightshade is a dicot annual herb 30-100 cm high. The stem is angular with opposite leaves. Flowers are white sometimes with purple veins 8-10 mm long, grouped in groups of 3-5 along the stem. Fruits are dull black when mature, round and 8-10 mm wide. Nightshade is widely distributed in various habitats. Its success is attributed to its ability to tolerate different habitats, flower while still young and produce a high number of seeds. It reproduces by seed or shoot cuttings during the rainy season though yield may be reduced (Albouchi *et al.,* 2018; Edmonds & Chweya, 1997).

In Kenya, nightshade is a widely distributed and consumed AIV (Ontita *et al.*, 2016). Known as "mnavu" in Swahili, nightshade has several species belonging to the genus Solanum in the family Solanaceae. However, only 5 species are regularly consumed in

Kenya. These include *Solanum nigrum* L., *Solanum villosum* Miller, *Solanum americanum* Miller, *Solanum scabrum* Miller and *Solanum physalifolium* Rusby (Odongo et al., 2018; Ondieki *et al.,* 2011). In Kenya, farmers record yields of up to 1.5-3.0 tons/ha, which is well below their potential yield of 30-50 tonnes/ha (Wesonga *et al.*, 2016). This explains in part why increases in demand and consumption have not been fully met in Kenya (Abukutsa-Onyango, 2010).

Traditionally, Kenyans are believed to rely on nightshade for their nutritional and medicinal needs. The leaves are high in proteins, amino acids, minerals like calcium, iron and phosphorous, fibre and vitamins A and C. Unripe fruits are applied to aching teeth especially on teething babies to ease the pain. The leaves are pounded and used to treat tonsillitis while roots are boiled in milk and used as tonic for children. Leaves boiled in milk are also used to cure stomach ailments and boost health of pregnant and breastfeeding mothers (Jagatheeswari *et al.,* 2013).

Spider plant

Spider plant, also known as "mwangani" in Swahili, is an erect herbaceous plant belonging to the family Capparaceae and subfamily Cleomoideae (Chweya *et al.,* 1997; Van den Heever & Venture, 2007). It is regularly consumed in east and southern Africa. In east Africa, spider plant is native in Kenya, Ethiopia, Sudan, Tanzania, Uganda and Somalia (Mishra *et al.,* 2011). Traditionally, spider plant was not cultivated. It was collected in the wild (Chweya & Mnzava, 1997). Spider plant thrives in both pure stands and mixtures. Seeds from previous crops are broadcasted or drilled when planting and germinate within 5 days. The seedlings are then thinned out 3 weeks later. Thinned seedlings are used as vegetables. Removing the inflorescence regularly as it appears lengthens the vegetative stage. Once fully mature at the end of rainy season, any remaining plant produces seeds for the next season (Chweya & Mnzava, 1997).

Spider plant is rich in proteins, vitamins, carbohydrates and minerals that are mostly lacking in other vegetables (Kujeke *et al.,* 2017). Apart from nutritional benefits, consumption of spider plant is reported to cure diseases like asthma, diabetes, cardio-vascular diseases and even cancer (Kujeke *et al.,* 2017). Apparently, spider plant also has insecticidal properties. It has anti-tick properties and anti-feedant action against tobacco caterpillar. Extract from mature seeds of spider plant are reported to be toxic to aphids (e.g., *Aphid gossypii* Glov.) and bollworm larvae (*Heliothis armigera* Hubner). Ethanol extracts of spider plant are also toxic to pests like painted bug (*Bagrada cruciferarum* Kirk) and diamondback moth (*Plutella xylostella* L.). Volatile oils of spider plant repel diamond-back moth larvae on cabbages (Chweya & Mnzava, 1997).

Amaranth

Belonging to the genus Amaranthus of the family Amaranthaceae, amaranth is one of the oldest domesticated vegetables (Andreas *et al.,* 2011). “Mchicha” in Swahili, amaranth consists of approximately 70 species. Among the 70 species, 17 are consumed as vegetables and 3 are consumed as grain amaranth (Andreas *et al.,* 2011). In Kenya, amaranth is grown in open fields. It is distinguishable by its chaffy inflorescence, which is dense and either green or red in colour. Being a C4 plant, amaranth maximizes on the use of sunlight and soil nutrients at high temperature and low moisture, which makes it drought tolerant (Muriuki, 2015). It is propagated by either seed or transplants, which can be harvested 4-6 weeks after planting (Tubene & Myers, 2008).

Amaranth is a multi-purpose crop whose grains and leaves are high in nutritional content (Muriuki, 2015). Historically, its utilization in Kenya was low, however, consumption has increased in recent years because consumers realized its high nutritive value (Chege, 2012; Muriuki, 2015). It is rich in proteins, antioxidants, vitamins and minerals like calcium and iron (Bhat *et al.*, 2015; Kaufui, 2017). Medicinal benefits are several including using it as a laxative and for improving appetite among others.

2.2 AIV production constraints

Abukutsa-Onyango, (2010) reports that in as much as AIVs are easy to produce, they actually do face challenges. Researchers and practitioners have classified AIVs as “hard core survivor plants” and often recommended them for marginalized areas. This is because they are perceived to adapt well to harsh environments and various stresses, which contributed to the scarcity of evidence on how climate change, water stress, pests and weeds affects small holder production of AIVs (Chepkoech *et al.*, 2018). Optimizing yields of AIVs requires soil management to enhance fertility and soil structure just like you might expect for any leafy vegetable. Even though farmers generally adopt different strategies to keep their soils fertile like applying both organic and inorganic fertilizers, labour and financial constraints often hinder these efforts resulting in applications that are less than the recommended levels (Oluoch *et al.*, 2009).

Insect pests that feed on harvestable AIV parts (i.e., leaves) are reported to be most destructive with the biggest impact on yield (Oluoch *et al.*, 2009). They either suck cell sap and sometimes vector plant diseases (Oluoch *et al.*, 2009) or chew leaves leaving damaged edges and numerous holes in the foliage. Common pests include defoliators like beetles and caterpillars, tissue suckers like aphids, spider mites, thrips, bugs, stem borers, leafminers and webbers like spider mites (Sithanantham *et al.,* 2005). According to research done by Omasaja, (2016) in Kitale-Trans Nzoia County, AIV insect pests include hemipterans, coleopterans, dipterans and lepidopterans. However, aphids and flea beetles were the most devastating to AIVs in this region.

Insect pests vary from season to season, climate, agroecological zones, diversity, abundance, population dynamics, distribution and damage (Fajinmi *et al.*, 2011; Omasaja, 2016; Owusu *et al.*, 2014). Yield losses due to insect pests on AIVs in Kenya are estimated at 17.0% for spider plant and 20% for amaranth (Sithanantham *et al.*, 2005). Weeds have also been reported to be a challenge in AIV production causing yield losses up to 34% (Chepkoech *et al.*, 2018). Weeds grow and spread more during the rainy season than the dry season. High weed populations can bring competition while increasing pests and disease incidences (Chepkoech *et al.*, 2018). In as much as AIVs do well in weed free plots, farmers report weeding to be labour intensive (Chepkoech *et al.*, 2018).

2.2.1 Pest specific information

Aphids

Aphids are regarded as one of the most economically important insect pest in agriculture. They are tiny pear shaped soft bodied insects (Guerrieri & Digilio, 2008; Liburd *et al.*, 2015) that cause damage through their mode of feeding by causing leaf curl or transmitting phytoviruses with their toxic salivary secretions (Albouchi *et al.*, 2018; Kinyanjui *et al.*, 2016; Skaljac & Vilcinskas, 2016). Aphids also secrete honey dew, which encourages growth of sooty mold fungus that reduces photosynthetic activity and lower harvest quality by reducing the aesthetic and marketability value of the crop

(Kinyanjui *et al.,* 2016). Aphid species of economic importance found in Kenya include *Aphis gossypii* Glover,1877, *Aphis craccivora* Koch, 1854, *Aphis fabae* Scopoli, 1763 , *Brevicoryne brassicae* Linnaeus, 1758, *Lipaphis pseudobrassicae* Davis, 1914, and *Myzus persicae* Sulzer, 1776 (Kinyanjui *et al.*, 2016). Black aphids (*Aphis fabae solanella* Theobald, 1914) mostly infest the underside of AIV leaves affecting plant development leading to yield losses (Ashilenje *et al.,* 2011).

Aphids feed passively by using a stylet that pierces plant tissue to reach the phloem (Guerrieri & Digilio, 2008). Being “r- strategists,” aphids can reproduce multiple generations in a season. Most aphids reproduce asexually during significant periods of their life cycle and give birth to numerous live young (nymphs) that can rapidly increase a population. In conducive environments, nymphs can develop to adults within a week and double a population every two days. When crowded, aphids develop wings and migrate in search of new hosts to build fresh colonies (Barbercheck, 2014; De Conti *et al.,* 2010).

2.3 Pest management

2.3.1 AIV pest management

Research has shown that pests and diseases are a major constraint to AIV production (Okolle *et al.,* 2016). Despite this fact, AIV farmers are unable to identify these pests, therefore lack knowledge on suitable pest management practices (Kouamé *et al.,* 2014). Although detailed information on traditional pest management practices is lacking, traditionally, cultural practices like inter-cropping, weeding, physical killing of insect pest among others helped prevent pest outbreaks (Abate *et al.,* 2000). Other methods included use of abrasives like wood ash and botanicals made from plant extracts to repel or kill arthropod pests. Synthetic chemicals are rarely used (Onyango *et al.,* 2016).

Cultural practices

Agriculture in Africa has been largely traditional and pest management is an internal step between local practice in the general crop production process rather than a stand-alone well-defined activity (Nyirenda *et al.,* 2011). Farmers manipulate local practice and resources by integrating different crop production practices to reduce the likelihood of pest damage (Nyirenda *et al.,* 2011; Oluoch *et al.,* 2009).

Intercropping

Intercropping has been used for centuries to increase production per unit of land but has also demonstrated an advantage of reduction in pest populations (Braima *et al.,* 2010; Risch, 1983). It is a cultural practice that involves growing different crops in the same field resulting in an increase in the number and diversity of natural enemies through creation of micro climates, natural pest barriers, pest repellants, pest traps through trap cropping or provision of supplementary food and refuge (Atanu, 2018). In Kenya, intercropping of AIVs is a wide spread practice especially in western Kenya (Abukutsa-Onyango, 2007; Pasquini *et al.,* 2009).

Weeding

In as much as weeds provide refuge for beneficial insects, they can also provide refuge to insect pests that can restore pesticide sensitivity when they interbreed with resistant individuals (Hillocks, 1998). Weeds also can be a reservoir for polyphagous insect pests that can reproduce, oviposit and grow in populations that may move from weeds to crops where they can causing crop damage (Capinera, 2005). They can also serve as alternate hosts that insect pests inhabit between cropping seasons (Hillocks, 1998), therefore, the disastrous effects of weeds on insect pest populations cannot be overlooked. Farmers weed to lower nutrient and water competition in order to increase yield (Hillocks, 1998), but at the same time this helps to suppress insect pest economic damage (Braima *et al.*, 2010).

Physical killing of insect pest

Physical killing involves mechanical removal and destruction of insect pest and/or pest egg masses. It is labour intensive and time consuming compared to other pest management practices therefore not regularly practiced in pest management. It also needs to be repeated every few days to control emerging insect pests, therefore consequently of limited success (Braima *et al.,* 2010).

Abrasives

A survey conducted in Kisii and Kakamega counties found that 53% and 65% of the farmers growing nightshade respectively, use wood ash for pest management (Onyango *et al.,* 2016). This traditional practice is a promising insect pest management strategy as shown with tests on aphids attacking Irish potatoes and paw-paw (Kariuki, 1999; Okutu *et al.,* 2014; Olubayo *et al.,* 2008). Farmers however do blanket application on the foliage regardless of the insect pest densities or location which makes wood ash less effective compared to other management strategies. Wood ash needs to be applied directly on the insect pest and not just on the leaf to be effective. Wood ash also poses a risk of scorching the plants if applied excessively as well as raising soil pH (Fuzesi *et al.,* 2015; Onwuka *et al.,* 2016; Wiklund, 2017).

Botanicals

For a very long time, botanical pesticides have been perceived to be better than synthetic pesticides because of their low risk to both human and the environment. Use of neem and pyrethrum extracts are well established as antifeedants, repellants and toxicants to insect pests (El-Wakeil, 2013). However, less that 10% of AIV farmers in western Kenya (Kakamega County) use botanicals for pest management (Onyango *et al.*, 2016).

Synthetic Chemicals

Synthetic chemical management strategies have been used widely in vegetable production including for AIVs, but generally with a focus on pesticide applications rather than integration with other management approaches. Pesticides are intended to quickly kill unwanted organisms by interrupting their normal biochemical and physiological processes. Although this has proven effective, in terms or reliability, this approach is short lived and can lead to development of resistant biotypes while causing environmental pollution and health risks to both humans, animals and beneficial natural enemies (Bayissa *et al.*, 2016; Pretty & Bharucha, 2015). In Kisii County, 14% of AIV farmers use chemicals, while in Kakamega County synthetic chemicals are not commonly applied on AIVs due to costs and lack of knowledge on their use (Onyango *et al.*, 2016).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Survey of common insects of AIVs in western Kenya

The survey of common insects including pests of AIVs was done in western Kenya in two parts between November and December 2016. The first part was done in Uasin Gishu, Busia and Kakamega counties on 3rd, 4th and 7th November 2016 while the second part was in Siaya, Homa Bay, Kisumu and Kisii counties (Figure 3.1) on 28th, 29th and 30th November 2016. The surveyed sites were randomly selected through purposive sampling farmer fields and research station fields growing amaranth, nightshade and spider plant along a predetermined travel route set for each day. Collection and preservation of insect specimens was done according to (Craemer *et al.*, 2000; Frampton *et al.,* 2008).

3.1.1 Agro-ecological zones descriptions for the surveyed areas in each County

Busia County

KALRO Alupe and Bugengi - Lower Midland Sugar Cane Zone (LM1-SCZ) (Kenya Ministry of Agriculture, 2016).

Kakamega County

Eshitsiru - Upper Midland (UM).

Mwamba - Upper Midland (UM) (The Ministry of Agriculture, 2017).

Siaya County

Usula -Lower Midland (LM4) and Lower Midland (LM5).

Usula-Ludha – Lower midland (LM1).

Luanda - Lower Midland 3 (LM3) (The Kenya Ministry of Agriculture, 2016).

Homa Bay County

Adongo- Lower midland 2 (LM2).

Maguti- Lower Midland 4 (LM4).

Miyal west -Lower Midlands (LM5) (The Ministry of Agriculture, 2016).

Kisumu County

Marera (Maseno) - Upper Midland 1 (UM1) (The Ministry of Agriculture, 2016).

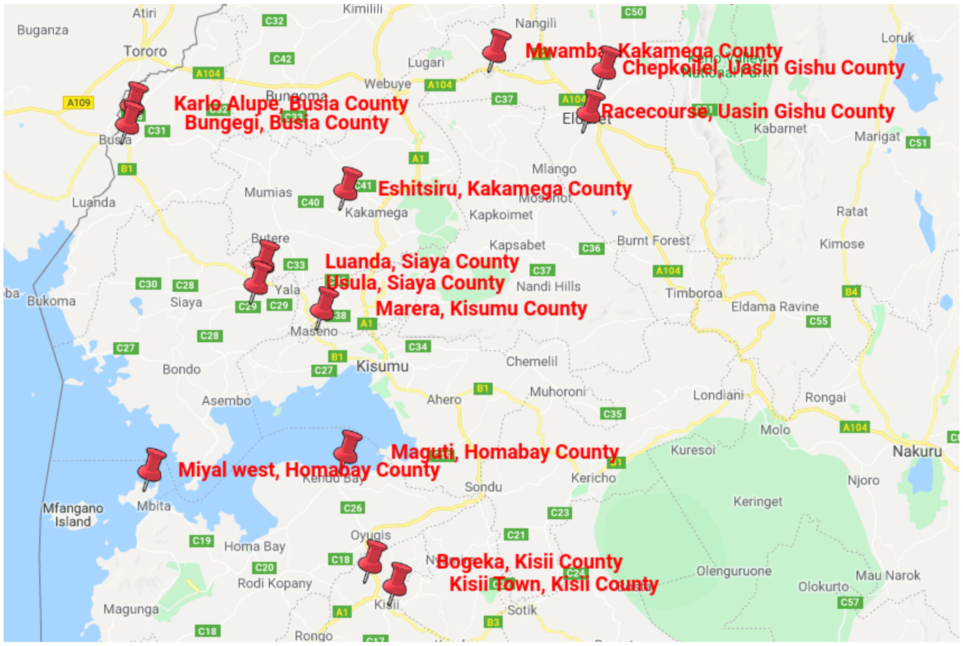
Kisii County

Bogeka and Kisii town outskirts Lower Highland (LH) (County, 2018-2022).

Uasin Gishu County

Chepkoilel -Lower Highland 3 (LH3).

Race course – Lower Highland (LH3) (County, 2018-2022).



Source: https://www.google.com/maps/@0.6323077,35.0187878,2588m/data=!3m1!1e3

Figure 3.1: Survey sites map.

3.2 Sample collection and preservation

Insects found on sampled AIVs (amaranth, spider plant and nightshade) were collected and recorded separately for every field and location. Collection was done using two methods: 1) hand picking using a No.2 soft brush for non-flying soft bodied insects, 2) sweep net for flying and active insects. Collected insects were labeled and preserved as either dry or wet (70% ethanol) specimens for subsequent species determination, while aphid specimens were preserved in 95% ethanol for DNA identification due to their tiny size. Dry preserved specimens were sorted into recognizable taxa, according to orders, pinned/ pointed and labeled. Pinned specimens were stored in carton boxes from BioQuip. Wet preserved specimens preserved in 70% ethanol were also sorted according to their taxonomic orders. Some insects preserved in alcohol vials were later removed and pinned or pointed. Adult Lepidoptera samples were put in vellum envelopes to protect the wings and stored in a container for subsequent identification.

3.3 Identification of insect pest species of AIVs

3.3.1 Morphological taxonomic determinations

Pinned and alcohol-preserved insect specimens were identified using family dichotomous keys at the National Museums of Kenya-Nairobi under the supervision of research scientists and technologists. All insects were then identified according to either taxonomic family, genus or species. Aphid specimens were identified using a combination of morphological characteristics (colour, appearance, cornicles sizes, cauda prominence and number of segments on antennae among others) and known host ranges of common aphids species in western Kenya.

3.3.2 Molecular taxonomic determinations

Species identification of aphids was done at Purdue University. Voucher samples of adult aphids collected from nightshade, amaranth and spider plant in western Kenya, preserved in 95% ethanol, were shipped to Purdue University for DNA extraction and bar cording. DNA was extracted from specimens individually using a Quiagen DNeasy® Blood and Tissue Kit. Once extracted, the DNA was stored in a freezer at -20°C while awaiting amplification. Fragments of the aphid COI gene were targeted for PCR amplification using selected aphid primers. The DNA was amplified using PCR, verified using agarose gels to visualize the PCR products, quantified using a nanodrop protocol and prepared for sager sequencing using a ‘cleanup kit’ (ExoSAP-IT PCR Product Cleanup Reagent ThermoFisher Scientific). Purified DNA samples were bidirectionally sequenced using an ABI 3730xl DNA sequencer (Applied Biosystems, Foster City, California) at the Purdue Genomics Core Facility, Purdue University Sequences were assembled, aligned and edited then the COI sequences were queried for species determination via the basic local alignment search tool (BLAST) at the GenBank database hosted by NCBI (http://www.ncbi.nlm.nih.gov) (Kinyanjui *et al.*, 2016).

3.4 Field experimentation

3.4.1 Site description

The field experiment was carried out in Mwamba-Lugari sub County, Kakamega County. The farm is located at 0º37’48.10” N, 35º01’03.13” E at an elevation of 1535m above sea level (Figure 3.2). Kakamega County has an average annual temperature of 21º C and receives 1100mm to 1400mm of precipitation each year. The soils are mostly acrisol, ferrasols and nitisols with a pH of around 5.4 (CIDP-UG, 2013-2018; Jaetzold &

Schmidt, 1983; Jaetzold *et al.*, 2006). Farmers in this area grow maize, beans, cassava, finger millet, sweet potatoes, bananas and vegetables (including AIVs). Yield losses due to insect pest in this area are great.

Source: https://www.google.com/maps/@0.6323077,35.0187878,2588m/data=!3m1!1e3
Figure 3.2: Mwamba map.

3.4.2 Field preparation

In the nursery, seeds were planted in germination trays and transplanted four weeks later. Before transplanting, fields were prepared by establishing plot boundaries. The field was then cleared of weeds by hand. Double digging was done to gain a fine tilth before establishing inner blocks and plots. Levelling plots, marking planting lines and aligning irrigation drip lines (for the dry season trial) followed.

Four weeks after germination, planting holes were dug and fertilizer added in each planting hole then seedlings were transplanted. Arthi river mining (ARM) Mavuno fertilizer (NPK 20:10:18 + micro-elements-sulphur, magnesium, zinc, copper, boron, manganese and molybdenum) at a rate of 5 gms per planting hole was mixed thoroughly with the soil before placing the seedlings. Watering followed transplanting and continued every day during the dry season using drip irrigation and sometimes during the rainy season when it did not rain for an entire week. Weeding was done manually every 3 weeks or earlier depending on weed emergence. General field hygiene practices like weeding, removing senescent leaves, clearing all solid plant residues, clearing nearby bushes and using clean knives for harvesting were observed throughout the season. Harvesting was done every 2 weeks after transplanting using cut back method whereby everything above 15 cm was cut off using a sharp knife. This was to encourage lateral shoot growth (Production, 2010). The yield per plot was weighed using a weighing scale, recorded and results used to relate crop yield losses with aphid populat2ion. This applied to both long and short rains seasons.

3.4.3 AIVs studied

AIV varieties selected for field trial were amaranth (var. Madiira 2) (Plate 1) and nightshade (Olevolosi) (Plate 2). These were planted during the long rainy season (May to August 2017) and during the short rains season (September to December 2017). The variety seeds were sourced from the World Vegetable Centre in Arusha through the Kenya Agricultural and Livestock Research Organization (KALRO).

Plate 1: Amaranth

(*Amaranthus spp*)

Plate 2: Nightshade

(*Solanum spp*)

3.4.4 Pest management treatments and application

The two AIV varieties were planted to evaluate the ability of selected pest management practices (treatments) to suppress aphids' abundance. The four insect pest management treatments included 1) wood ash, 2) synthetic insecticide- Karate, 3) commercial botanical pesticide neem- Nimbedicine and 4) plain water as a control (Table 1). Sieved wood ash sourced from a local farmer's kitchen was applied at a rate of 8 gms per plant using a manual shaker (modified 1kg container locally used for Vim brand scouring powder). A total of 2.3 kg of wood ash was applied to 288 plants on a weekly basis. The Syngenta East Africa Limited Karate 2.5 synthetic insecticide (lambda-cyhalothrin ai) was formulated using 20 g wettable granules dissolved in 16 L of water. The commercial botanical pesticide- neem oil (azadirachtin 0.03% ai) was applied at a rate of 40 ml in 16

L of water. The control was 16 L of plain water. The wood ash and plain water were acquired from a local farmer in Mwamba-Lugari sub-county. Wood ash was sieved to remove unburnt remains before usage. The synthetic insecticide and commercial neem oil were acquired from a commercial vendor of agricultural chemicals in Eldoret town (Moiben Agrovet). Drip irrigation (120 L per block) was done from September to December 2017 during the short rains period (September to January 2018).

Table 3.1: Treatments and varieties

AIV TREATMENTS	AIV Crops-VARIETIES
Control – T1	Nightshade (Olevolosi) – V1
Wood ash – T2	Amaranth (Madiira) – V2
Botanical pesticide (Neem oil- azadirachtin 0.03% AI) – T3	
Synthetic pesticide (Karate-lambda-cyhalothrin AI)– T4	

3.4.5 Experimental design

The field experiment was a split plot in randomized complete block design (RCBD) where main plots were the different AIV vegetables/ varieties, while the sub plots were different treatments (wood ash, synthetic pesticide, botanical pesticide and control). Each block had 12 plots measuring 3.6m by 2.5m to accommodate four treatments with three replicates each to minimize statistical and experimental errors. The plots were separated by 0.5m paths and the main blocks were separated by 1m paths. There was a total of 2 blocks made of 24 plots. Each plot contained 4 rows with 12 plants totaling 48 plants per plot and 1,152 plants per season. Inter-row spacing was 60 cm, while intra-row spacing was 30 cm (Figure 3.3).

Figure 3.3: Field layout

BLOCK 1 (NIGHTSHADE)			
1. V1*T2	2. V1*T3	3. V1*T3	4. V1*T4
8.V1*T4	7. V1*T1	6. V1*T4	5. V1*T2
9. V1*T3	10. V1*T1	11. V1*T2	12. V1*T1
BLOCK 2 (AMARANTH)			
1. V2*T3	2. V2*T2	3. V2*T3	4. V2*T1
8. V2*T1	7. V2*T4	6. V2*T4	5. V2*T4
9. V2*T2	10. V2*T2	11. V2*T3	12. V2*T1

3.4.6 Data collection

Data collection was done once a week starting from the first week after transplanting for 12 weeks. Five plants were sampled from the middle row plants by selecting every fourth plant following Omasaja, (2016) procedure. The plants were then tagged and used repeatedly for data collection until the end of the season. During data collection, the sampled plants were then divided into three foliage parts (top, middle and bottom). This was established by using the top 5 leaves, middle 5 leaves and the rest as bottom leaves of every plant (Machangi *et al.*, 2003). This ensured that pest densities were estimated on new and old plant growth after foliage harvesting. The total number of aphids found on sampled plants were counted visually using a magnifying glass headgear. Counts from both foliage including branches were recorded separately for each sampled plant and plant part (top, middle bottom). This was to allow for comparisons between different levels of the foliage where leaf texture, age and nutrient availability vary. Counts on the stem were also made separately for top, middle and bottom parts of the stems. Leaf counts were added to stem counts to get the total number of aphids for each plant section.

3.4.7 Data analysis

Results from the survey were subjected to quantitative data analysis (mean and mode) while results from the field experiment were subjected to qualitative data analysis (analysis of variance) using the statistical analysis program SAS 9.4 and means separated using Turkey-Kramer's test at 95 % confidence level. A PROC MIXED model procedure was used to determine the response of aphid to treatments applied over time. Due to the large number of zero in the values observed, the data was transformed using a square root of the mean (x + 0.05) transformation to avoid a zero-inflated poisson model. Replicates were random effects in the model and time was a repeated measure using the autoregressive (AR) covariance structure type.

CHAPTER FOUR

RESULTS

4.1 Inventory of insects on AIVs in western Kenya

An array of insects and birds (mouse bird) was observed on the AIVs sampled in western Kenya. All insects identified on the 3 AIVs fell in the following taxa: 6 orders, 28 families, 63 genera and 78 species. However not all insects were pests, some were non-pests and beneficial insects (predators and parasitoids). The largest insect species identified were pests at 84.6%. Beneficial insect species accounted for only 13.63% (predators 12.8% and parasitoids 2.6%) combined from all agroecological zones (Table 4.1).

Table 4.1: Overall insect observations

Overall	Pests	Predators	Parasitoids	Total
Orders	5	4	1	6
Families	25	4	1	28
Genera	54	9	2	63
Species	66 (84.6 %)	12 (12.8 %)	2 (2.6%)	78

Herbivorous insect pest species were identified under five orders Coleoptera-33 species, Hemiptera- 22 herbivorous species, Lepidoptera-8 species, Hymenoptera- 2 species and Orthoptera- 1 species. Predators were from three different orders and families (Appendix IV).

Some insect species were only hosted by specific AIV varieties. Amaranth hosted 3 unique (only found on amaranth and not any other AIV sampled) families, 13 unique genera and 13 unique species. 3 families, 11 genus and 13 unique insect species were hosted on nightshade .Spider plant had the highest number of unique insect taxa with 8 families, 16 genus and 19 unique insect species (Table 4.2).

Table 4.2: Insect species found on each AIV host plant

Insects found only on amaranth		
Family	**Genus**	**Species**
Pentatomidae	*Agonoscelis*	*Agonoscelis versicolor*
Bruchidae	*Callosobruchus*	*Callosobruchus maculatus*
Coreidae	*Cletus*	*Cletus ochraceus*
		Cletus ochraceus fuscescens
Pyrrhocoridae	*Dysdercus*	*Dysdercus nigrofasciatus*
Chrysomelidae	*Haltica*	*Haltica pyricosa*
	Lema	*Lema viridivittata*
Curculionidae	*Lixus*	*Lixus rhomboidalis*
Cicadellidae	*Micraspis*	*Micraspis sp.*
		Micraspis striata
Chrysomelidae	*Monoleta*	*Monolepta leuce*
Coccinellidae	*Platynaspis*	*Platynaspis capicola*
		Platynaspis sexguttata
Insects found only on nightshade		
Family	**Genus**	**Species**
Chrysomelidae	*Apthona*	*Apthona marshalli*
Aphididae	*Brevicoryne*	*Brevicoryne brassicae*
Chrysomelidae	*Cassida*	*Cassida dorsovittata*
Coccinellidae	*Cheilomenes*	*Cheilomenes aurora*
Aphididae	*Hysteroneura*	*Hysteroneura setariae*
Nymphalidae	*Junonia*	*Junonia sophia*
Lycaenidae	*Leptotes*	*Leptotes sp.*
Lagriidae	*Lagria*	*Lagria cyanicollis*
Chrysomelidae	*Luperodes*	*Luperodes exclamationis*
Lycaenidae	*Lycaena*	*Lycaena sp.*
Braconidae	*Lysiphlebus*	*Lysiphlebus fabarum*
Chrysomelidae	*Luperodes*	*Luperodes exclamationis*

Table 4.2: Insect species found on each AIV host plant (Continued)

Fulgoridae	Unknown *Fulgoridae genus*	Unknown *Fulgoridae sp.*
Lycaenidae	Unkown *Lycaenidae*	Unknown *Lycaenidae sp.*
Insects found only on spider plant		
Family	**Genus**	**Species**
Aphididae	*Aphis*	*Aphis gossypii*
Apionidae	*Apion*	*Apion sp.*
Pentatomidae	*Bagrada*	*Bagrada hilaris*
Meloidae	*Coryna*	*Coryna apicicornis*
Scarabaeidae	*Drepanocerus*	*Drepanocerus kirbyi*
Cicadellidae	*Exitianus*	*Exitianus sp.*
Noctuidae	*Helicoverpa*	*Helicoverpa armigera*
Lycidae	*Lycus*	*Lycus turneri*
Pentatomidae	*Nezara*	*Nezara viridula*
Chrysomelidae	*Phyllotreta*	*Phyllobrotica elegans* *Phyllotreta cheiranthi*
Noctuidae	*Plusia*	*Plusia sp.*
Chrysomelidae	*Podagrica*	*Podagrica weisi*
Aphididae	*Rhopalosiphum*	*Rhopalosiphum padi*
Cramidae	*Sameodes*	*Sameodes cancellalis*
Cantharidae	*Silidius*	*Silidius apicalis* *Silidius breviapicalis*
Acrididae	Unkown *Acrididae genus*	Unknown *Acrididae sp.* Unknown *Lycaenidae sp.*

Using the agro-ecological zones angle, LH hosted the highest total insect taxa at 23 with 11 unique insect taxa, while LM1-SCZ and LM4 had the least total insect taxas with no unique insect taxas in them (Table 4.3)

Table 4.3: AIV insect taxa by agroecological zones

Agro-ecological zone	Total Taxa	Unique Taxa
LH	23	11
LM1	22	10
UM	17	9
LH3	14	6
LM5	14	5
LM2	12	0
UM1	7	2
LM3	3	2
LM1-SCZ	2	0
LM4	2	0

When broken down further, separating the AIVs, showed that spider plant in agro-ecological zone LH had the highest number of insect taxa (16) followed by the same in agroecological zone LM1(15). Spider plant in LM4, LM1-SCZ, and nightshade in LM1-SCZ had the least insect taxas (1). Overall therefore, spider plant had the highest insect taxa in all combined agro ecological zones while nightshade had the least (Table 4.4).

Table 4.4: Insect taxa found on amaranth, nightshade and spider plant in each agro-ecological zone

Agro-ecological zone	Amaranth	Nightshade	Spider plant
LH	11	8	16
LH3	7	5	7
LM1	13	12	15
LM2	11	9	10
LM3	2	3	2
LM4	2	2	1
LM5	9	7	9
LM1-SCZ	2	1	1
UM	8	13	9
UM1	7	4	3

AM - double digit spp in LH, LM1 and LM2

NS - double digit spp in LM1 and UM

SP - double digit spp in LH, LM1 and LM2

Aphid barcode results confirmed 7 aphid species on nightshade, amaranth and spider plant (Table 4.5).

Table 4.5: Aphid species identified on African indigenous vegetables from western Kenya

Host crop	***Aphid species***	***Agro-ecological zones***
Spider plant	*Myzus persicae*	LH, LM1, LM2, LM3, LM5, UM, UM1
	Rhopalosiphum padi	LM2
	Aphis gossypii	LH
	Aphis fabae	LH, LH3, LM1, LM2, LM4, UM
Amaranth	*Myzus persicae*	LH, LM1, LM2, LM3, LM5, UM, UM1
	Aphis crassivora	LH, LH3, UM
Nightshade	*Aphis fabae*	LH, LH3, LM1, LM2, LM4, UM
	Myzus persicae	LH, LM1, LM2, LM3, LM5, UM, UM1
	Aphis crassivora	LH, LH3, UM
	Brevicoryne brassica	LH3, UM
	Hysteroneura setariae	UM

Some aphid species (*Aphis fabae*) were common in as many as 8 agroecological zones (Table 4.6).

Table 4.6: Insect taxa found in more than one agro-ecological zone.

Species	Agroecological zone
Aphis fabae	8
Jamesonia sp.	8
Scymnus trepidulus	6
Aphidius colemani	6
Myzus persicae	6
Poephila sp.	5
Scymnus sp.	5
Unknown *Cercopidae sp*.	5
Aphis craccivora	5
Deraeocoris ostentans	4

4.2 Aphid management strategies on AIVs under field conditions

Aphids were found on both crops (amaranth and nightshade) in both seasons (rainy season and dry season). More aphids were found on nightshade compared to amaranth with an early peak during the rainy season compared to dry season on both crops. Aphid numbers on nightshade were twenty nine times more abundant during the dry season compared to rainy season. However, there were half as many aphids on amaranth during the dry season compared to rainy season.

4.2.1 Efficacy of the management strategies for aphids on amaranth during both rainy and dry season

Cumulatively, during both rainy and dry season, aphid densities increased steadily in all treated crops following transplanting, but dipped relative to the control the fourth week of observations (five weeks after transplanting) following treatment applications on the third week after transplanting (Figure 1 and 2).

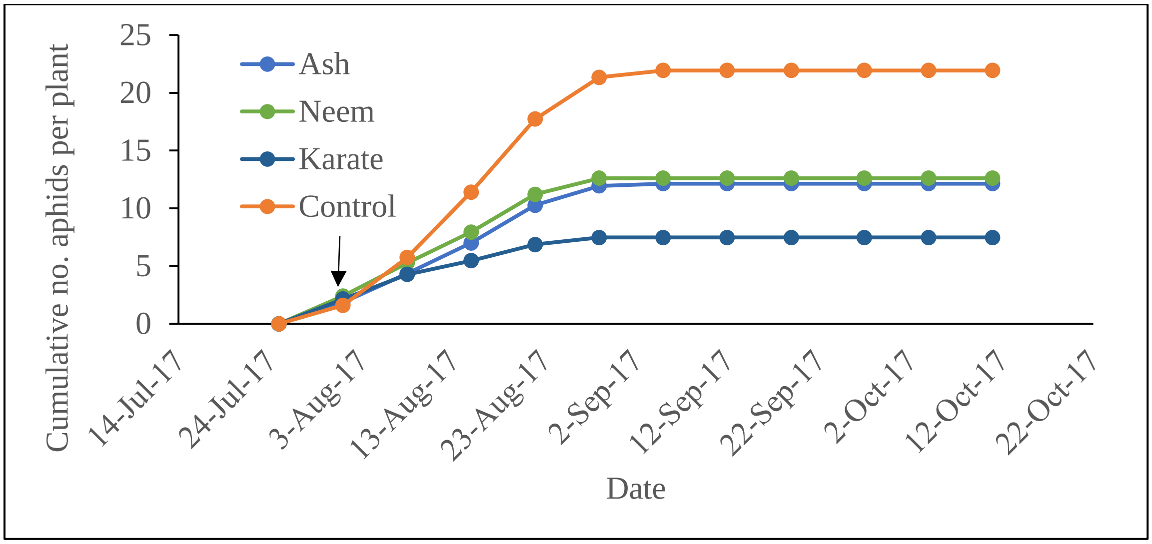


Figure 4.1: Cumulative aphids' density (per amaranth plant) during the rainy season. (Arrow points to start of treatment application).

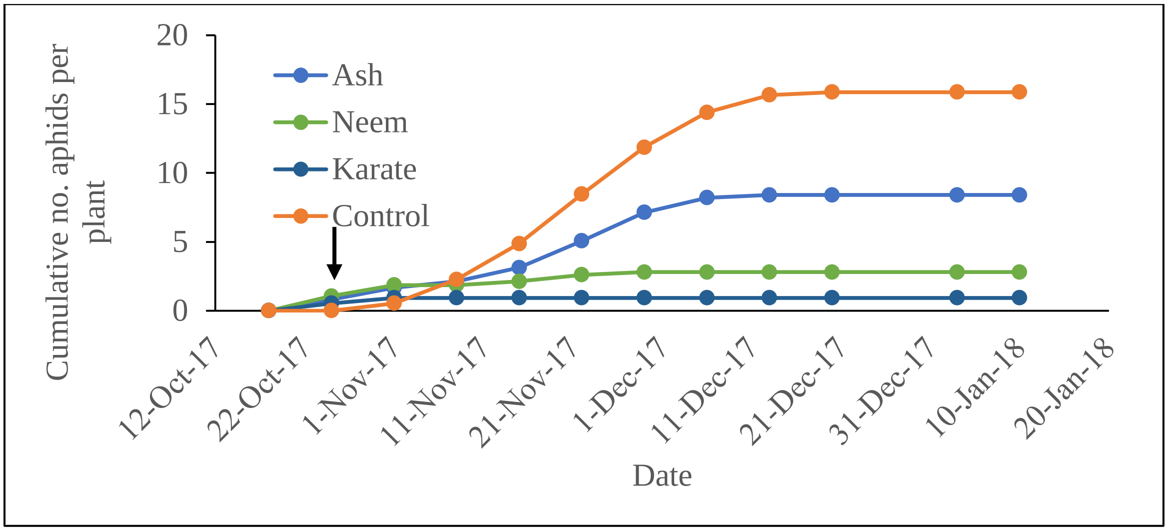


Figure 4.2: Cumulative aphids' density (per amaranth plant) during the dry season. (Arrow points to start of treatment application).

Although aphid pressure (densities) in the rainy season was relatively low in both seasons, significant differences were found on aphid densities between treatments (Table 4.7).

Table 4.7: Aphids density between treatments mean summary for amaranth during both rainy and dry season

Rainy season					**Dry season**			
Treatment	**N**	**Mean***	**Sd**	**StdErr**	**N**	**Mean***	**Sd**	**StdErr**
Control	3	22a	4.0	2.3	3	16a	4.0	2.3
Ash	3	12b	3.9	2.3	3	8b	2.4	1.4
Neem	3	13b	2.1	1.2	3	3c	0.8	0.5
Karate	3	8c	1.8	1.0	3	1d	1.4	0.8

* Means followed by the same letter are not significantly different.

Aphid densities varied with treatments whereby amaranth plants treated with plain water (control) had the highest aphid density, followed by plants treated with ash, neem and least densities were observed on amaranth plants treated with Karate. (Figures 4.3 and 4.4).

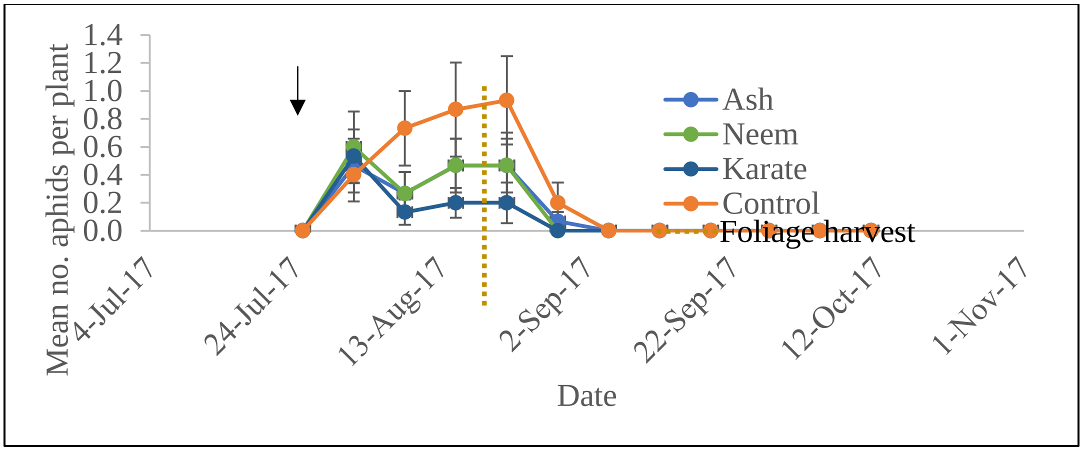


Figure 4.3: Mean number of aphids (per amaranth plant) during the rainy season. (Arrow points to first treatment application). (Error bars represent the treatments standard error n=3).

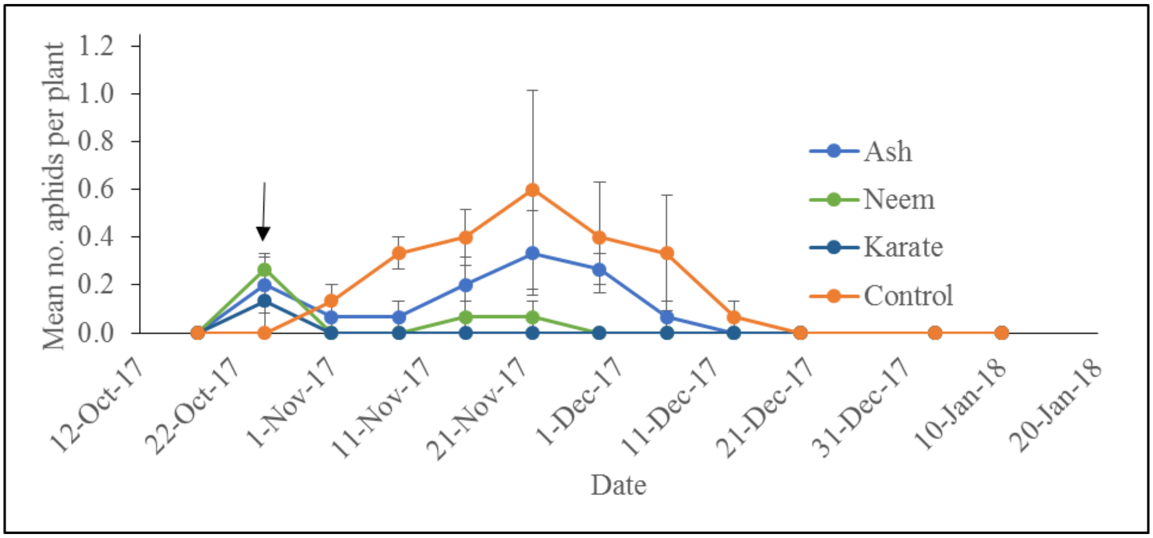


Figure 4.4: Mean number of aphids (per amaranth plant) during the dry season. (Arrow points to first treatment application). (Error bars represent the treatments standard error n=3).

4.2.2 Distribution of aphids on amaranth foliage by foliage levels during both rainy and dry seasons

Amaranth plants treated with plain water (control) had aphids on top and middle foliage levels, but none were found on the bottom foliage level during the rainy season. This pattern persisted throughout the growing season when aphids were present. Aphids population on top foliage level climaxed on the fourth week after transplanting while on the middle foliage level, climax was on the third week (Figure 4.5).

However, during the dry season, aphids on plants treated with plain water (control) were found on all three foliage levels, but at very low densities (Figure 4.6). Aphid were found on the top, middle and bottom foliage levels at different times of the season. However, during both seasons, differences between aphid means on the foliage levels were not statistically significant (GLIMMIX, N=108, F2,4 = 0.20, P > 0.8268, GLIMMIX, N=108, F2,4 = 2.0, P > 0.2496).

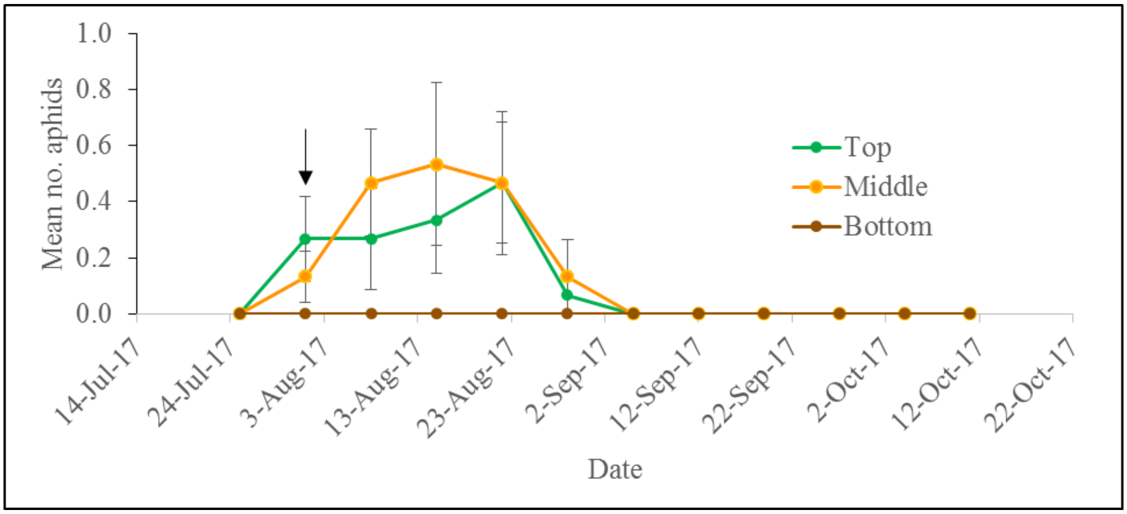


Figure 4.5: Mean number of aphids on the top, middle and bottom foliage levels of amaranth plants during the rainy season. (Arrow points to first treatment application). (Error bars represent the standard error n=3).

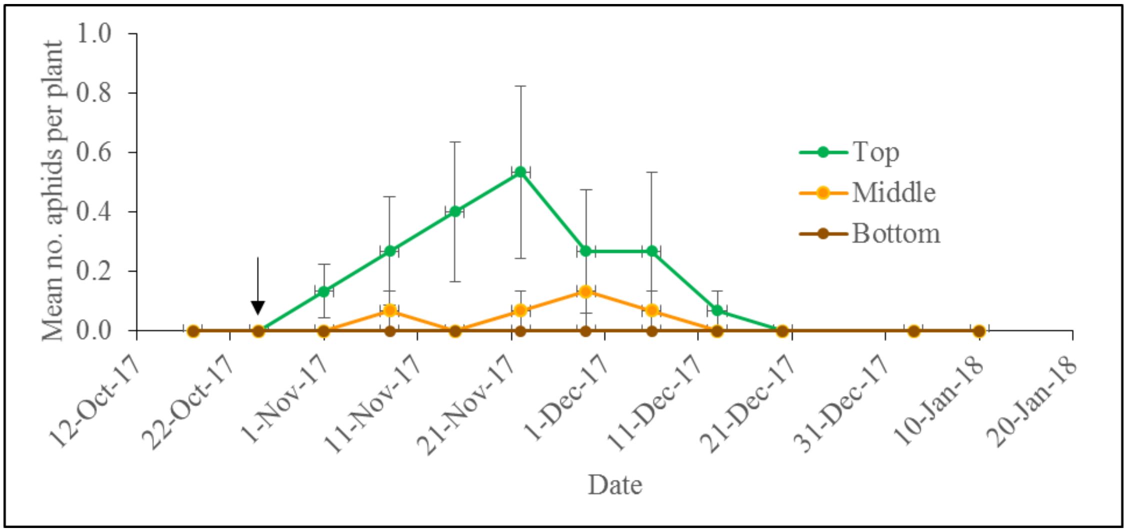


Figure 4.6: Mean number of aphids on the top, middle and bottom foliage levels of amaranth plants during the dry season. (Arrow points to first treatment application). (Error bars represent the standard error n=3).

4.2.3 Crop yields and pest losses on amaranth during both rainy and dry season

During the rainy season, at the beginning of the season both fresh, marketable weights and aphid pressure of amaranth from all treatments were not significantly different. However, as the season progressed, fresh weight from amaranth treated with Karate became significantly different from the rest of the treatments. The marketable weight of amaranth between treatments remained was not significantly different throughout the season (Table 4.8).

Table 4.8: Fresh and marketable yields of amaranth according to treatments during the rainy season- August 8 and August 22 respectively

August 8

	Fresh Wt (kg)			**Marketable Wt (kg)**		
Treatment	**Means***	**Stdev**	**Sterr**	**Means***	**Stdev**	**Sterr**
Control	0.112 a	0.097	0.056	0.112 a	0.097	0.056
Ash	0.338 a	0.377	0.218	0.338 a	0.377	0.218
Neem	0.624 a	0.979	0.565	0.624 a	0.979	0.565
Karate	0.531 a	0.840	0.485	0.531 a	0.840	0.485

* Means followed by the same letter are not significantly different

August 22

Fresh weight (kg)				**Marketable weight (kg)**		
Treatment	**Means***	**Stdev**	**Sterr**	**Means***	**Stdev**	**Sterr**
Control	0.202 a	0.102	0.059	0.152 a	0.095	0.055
Ash	0.977 a	0.136	0.078	0.639 a	0.074	0.042
Neem	1.454 a	0.588	0.339	1.181 a	0.552	0.319
Karate	2.199 b	1.178	0.680	1.675 a	1.109	0.640

* Means followed by the same letter are not significantly different

Aphid pressure increased 3 fold as the rainy season progressed in the amaranth control plot as significant differences were recorded between treatments (Table 4.9). By the end of the season amaranth yields trends from all treatments were highest in crop treated with

Karate, followed by neem, ash and least in plants treated with plain water (control). Aphid pressure was directly related to yields in that aphid pressure was highest on amaranth treated with plain water (control) which had lowest yields. Aphid pressure on amaranth treated with ash and neem had no significant differences. Lowest aphid pressure was recorded on amaranth treated with Karate.

Table 4.9: Aphid pressure on amaranth according to treatments applied during rainy season- August 8 and August 22 respectively

August 8				**August 22**		
Treatment	**Means***	**Stdev**	**Sterr**	**Means***	**Stdev**	**Sterr**
Control	5.7 a	1.32	0.76	18 a	3.7	2.1
Ash	4.3 a	1.50	0.87	10 b	3.4	2.0
Neem	5.3 a	1.12	0.64	11 b	2.2	1.3
Karate	4.3 a	1.06	0.61	7 c	1.3	0.8

* Means followed by the same letter are not significantly different

4.2.4 Efficacy of the management strategies for aphids on nightshade during both rainy and dry season

During the rainy season, aphid densities were significantly lower in nightshade plants treated with Karate. Aphid densities on plants treated with neem and ash had no significant differences while aphid densities on plants treated with plain water (control) were significantly higher (Figure 4.7 and Table 4.10).

During the dry season, aphid densities had significant differences with nightshade plants treated with plain water (control) having highest aphid densities, followed by plants treated with ash, neem and most effective in maintaining low aphid densities on plants was Karate (Figure 4.8 and Table 4.10).

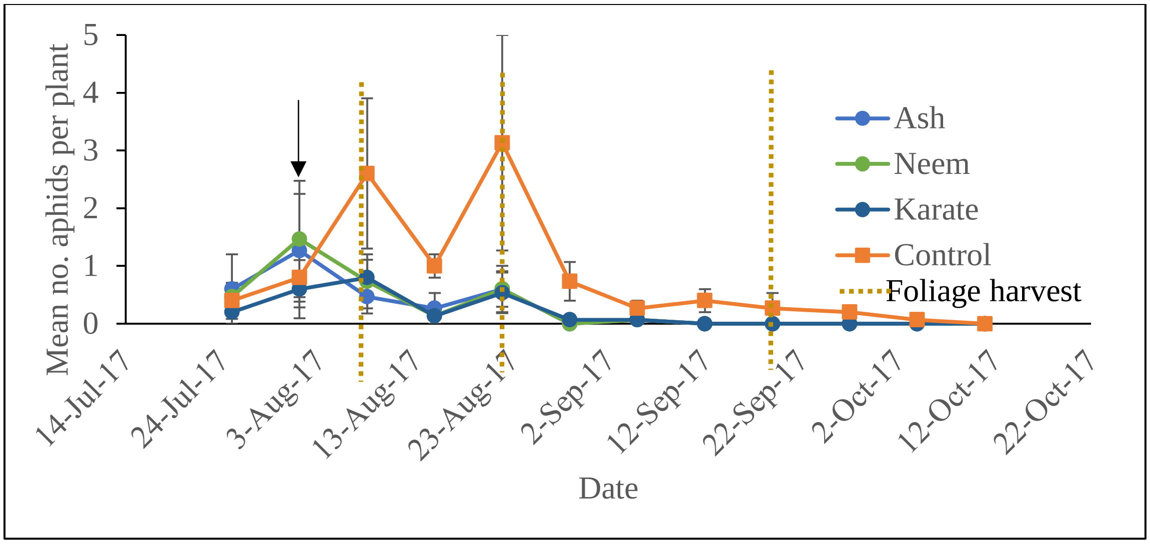


Fig 4.7: Mean number of aphids (per nightshade plant) during the rainy season. (Arrow points to first treatment application). (Error bars represent the standard error n=3).

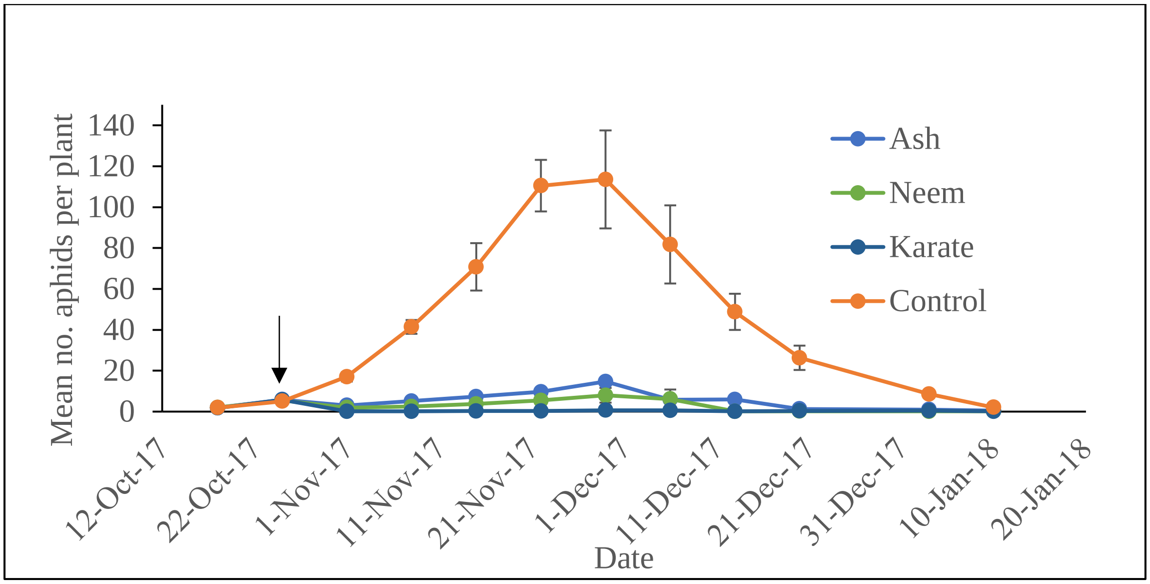


Fig 4.8: Mean number of aphids (per nightshade plant) during the dry season. (Arrow points to first treatment application). (Error bars represent the standard error n=3).

Table 4.10: Aphids density between treatments mean summary for nightshade during both rainy and dry season

Rainy season					**Dry season**			
Treatment	**N**	**Mean***	**Sd**	**StdErr**	**N**	**Mean***	**Sd**	**StdErr**
Control	3	68a	19.9	11.5	3	3808a	664.9	383.9
Ash	3	21bc	21.8	12.6	3	434b	20.5	11.8
Neem	3	23b	11.1	6.4	3	244c	27.2	15.7
Karate	3	16c	3.9	2.3	3	71d	8.1	4.7

* Means followed by the same letter are not significantly different

4.2.5 Distribution of aphids on nightshade foliage levels during both rainy and dry seasons

During both seasons, aphid were found on all nightshade foliage levels. However, aphid densities were lower during the rainy season compared to the dry season (Figure 4.9 and 4.10). In both seasons, aphid densities between foliage levels were not significantly different.

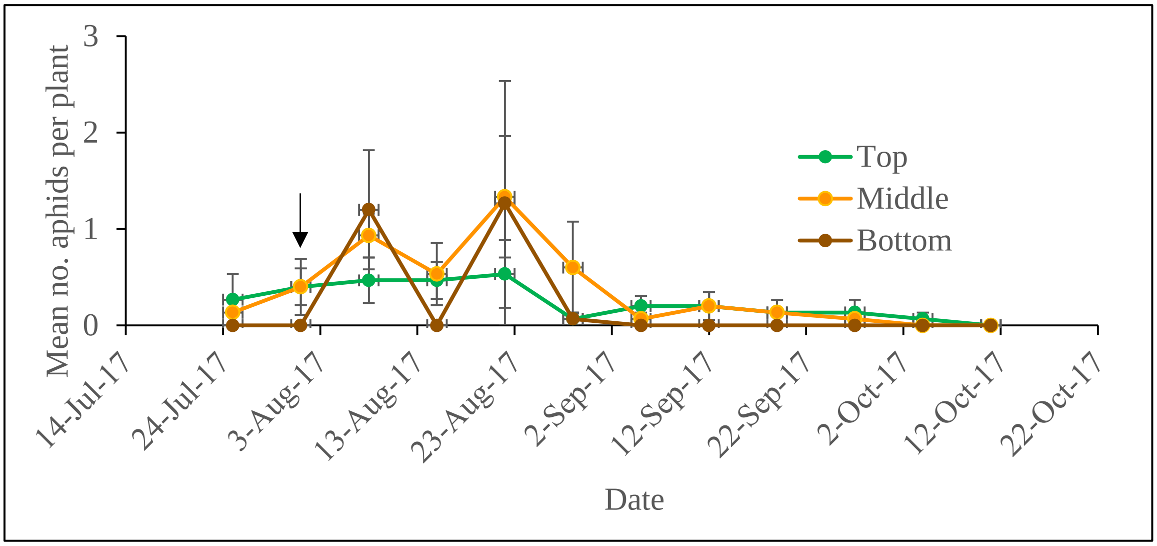


Fig 4.9: Mean number of aphids on the top, middle and bottom foliage levels of nightshade plants during the rainy season. (Arrow points to first treatment application). (Error bars represent the standard error n=3).

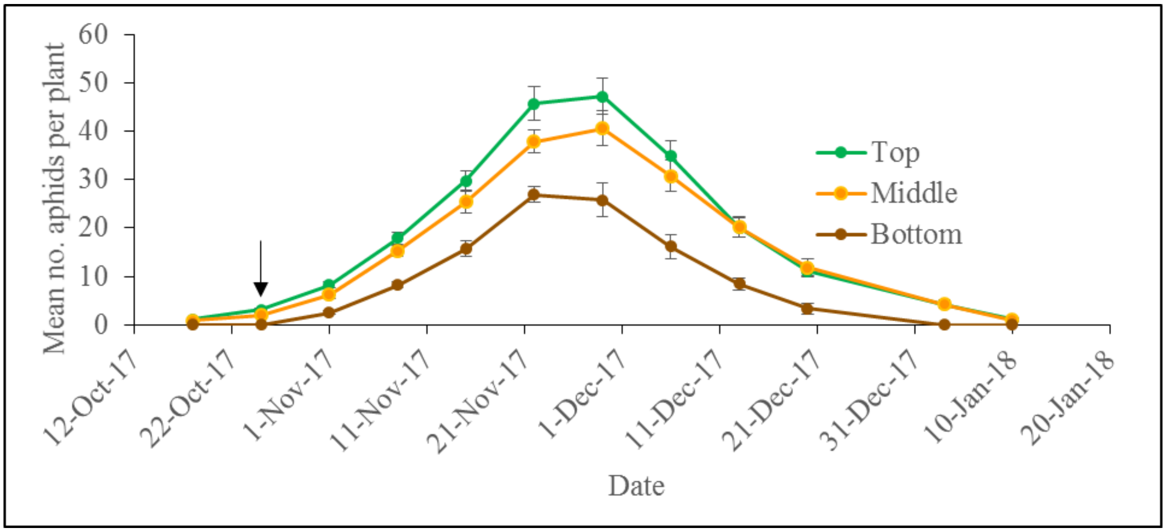


Fig 4.10: Mean number of aphids on the top, middle and bottom foliage levels of nightshade plants during the dry season. (Arrow points to first treatment application). (Error bars represent the standard error n=3).

4.2.6 Crop yields and pest losses on nightshade during both rainy and dry seasons

During the rainy season fresh and marketable weights were not significantly different throughout the season. However, during the dry season, only one harvest was done and both fresh and marketable weights of nightshade from all treatments were significantly different from each other. During both seasons, yield trends of amaranth from all treatments were higher in plants treated with Karate, followed by neem, ash and least in plants treated with plain water (control) (Tables 4.11 and 4.12).

Table 4.11: Fresh and marketable yields of nightshade according to treatment during the rainy season- August 8 and August 22 respectively

	Fresh Wt (kg)			**Marketable Wt (kg)**		
Treatment	**Means***	**Stdev**	**Sterr**	**Means***	**Stdev**	**Sterr**
Control	0.393 a	0.263	0.152	0.237 a	0.237	0.137
Ash	0.145 a	0.076	0.044	0.143 a	0.077	0.044
Neem	0.032 a	0.012	0.007	0.031 a	0.012	0.007
Karate	0.424 a	0.420	0.243	0.424 a	0.424	0.245

*Means followed by the same letter are not significantly different

	Fresh Wt (kg)			**Marketable Wt (kg)**		
Treatment	**Means***	**Stdev**	**Sterr**	**Means***	**Stdev**	**Sterr**
Control	0.538 a	0.322	0.186	0.066 a	0.047	0.027
Ash	1.423 a	0.931	0.537	0.905 a	0.294	0.170
Neem	1.416 a	1.675	0.967	1.349 a	1.567	0.905
Karate	2.179 a	1.548	0.894	1.663 a	1.125	0.650

*Means followed by the same letter are not significantly different

Table 4.12: Aphid pressure on nightshade according to treatments applied during the rainy season- August 8, August 22 and September 19 respectively

Treatment	August 8 Means *	Stdev	Sterr	August 22 Means *	Stdev	Sterr	September 19 Means *	Stdev	Sterr
Control	17.6 a	4.5	2.6	44.9 a	10.8	6.2	65 a	19.2	11.1
Ash	13.1 ab	15.7	9.0	18.8 a	20.6	11.9	21 b	21.8	12.6
Neem	15.1 ab	8.1	4.7	20.6 a	10.2	5.9	23 b	11.1	6.4
Karate	8.2 bc	2.6	1.5	13.7 b	3.0	1.8	16 b	3.9	2.3

* Means followed by the same letter are not significantly different

During both seasons, the aphid pressure on nightshade was significantly different between treatments (Tables 4.13 and 4.14). However, it was noted that, during the dry season this particular crop (nightshade) recorded the highest aphid pressure than amaranth in either season. Aphid pressure trends were least on plants treated with Karate, followed by those treated with neem, ash, and highest in plants treated with plain water (control).

Table 4.13: Fresh and marketable weight yields of nightshade according to treatments during the dry season- November 29

	Fresh Wt (kg)			Marketable Wt (kg)		
Treatment	Means*	Stdev	Sterr	Means*	Stdev	Sterr
Control	0.084 a	0.022	0.013	0.033 a	0.016	0.009
Ash	0.904 b	0.196	0.113	0.324 a	0.211	0.122
Neem	1.123 b	0.081	0.047	0.810 b	0.160	0.092
Karate	1.527 c	0.184	0.107	1.035 c	0.174	0.101

* Means followed by the same letter are not significantly different

Table 4.14: Aphid pressure on nightshade according to treatments during the dry season- November 29

Treatment	Means*	Stdev	Sterr
Control	2175 a	308.3	178.0
Ash	283 b	5.6	3.3
Neem	173 c	23.0	13.3
Karate	55 d	8.5	4.9

* Means followed by the same letter are not significantly different

4.2.7 Relationship between AIV harvest yields and aphid-days (aphid pressure)

The higher the aphid- days, the higher the yield losses and the lower the fresh weights as clearly seen on nightshade yields during the dry season (Table 4.15).

Table 4.15: Fresh weight (gms), aphid-days and yield losses for nightshade harvest

Treatments	Fresh wt (gms)	Aphid-days	Yield losses*
Karate	1527	55	0%
Neem oil	1123	173	26%
Ash	904	283	41%
Control	84	2175	95%

*Losses based on fresh weight differences between nightshade treated with Karate and nightshade treated with the other treatments

On nightshade, yields were significantly different between all pest management treatments and control. This relationship is clearly descried by the exponential function y = 1455.4e-0.001x (R2 = 0.9951) (Figure 4.11). Yield increased inversely when aphid days dropped. Also aphid-days and yield losses relationship is described by the exponential function y = 2926.2x2 - 527.16x + 55 (R2 = 0.9984) which demonstrates the relationship between aphid-pressure and yield losses (Figure 4.12).

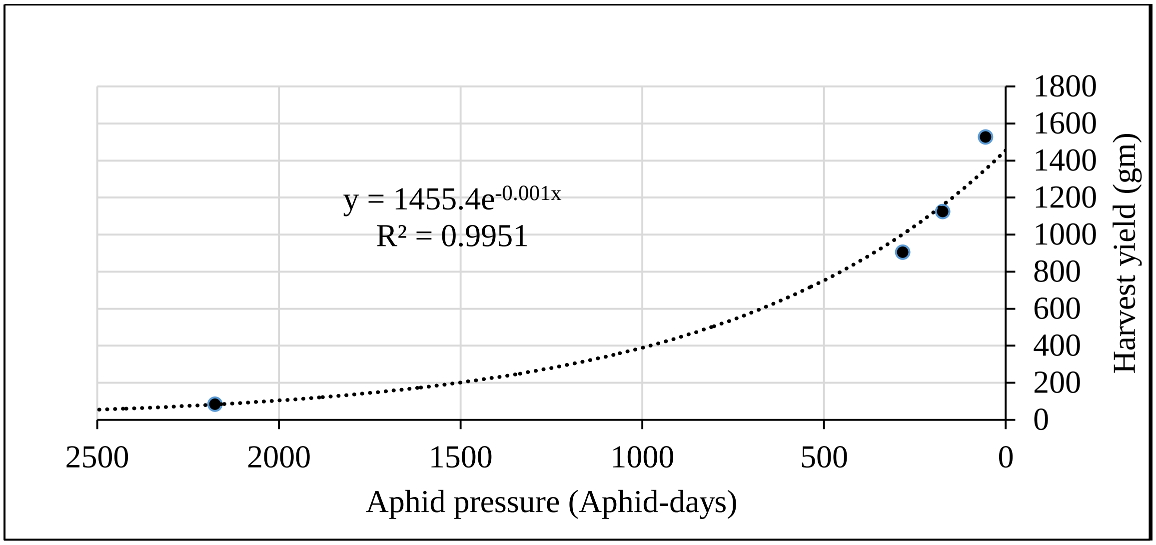


Figure 4.11: Harvest fresh weight yield and aphid days (aphid pressure) relationship

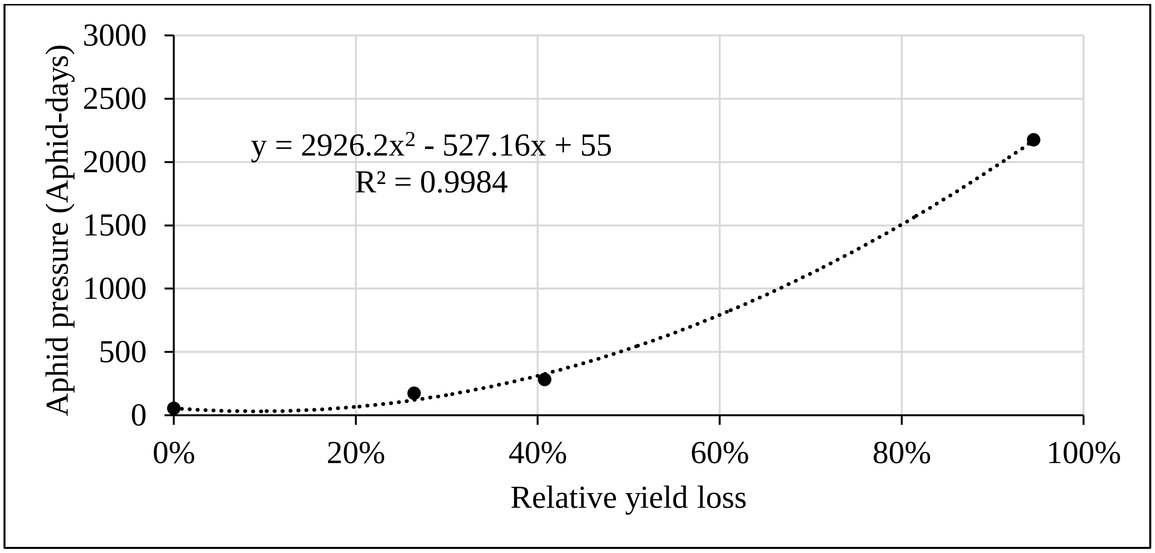


Figure 4.12: Aphid-days (aphid pressure) and yield loss relationship

On amaranth, only yield differences between the Karate and control treatments were significant with the yield from the Karate treatment more than 10 times higher than control.

CHAPTER FIVE

DISCUSSION

5.1 Inventory of insects on AIVs in western Kenya.

A study by Omasaja, (2016) found insect pests of AIVs to include hemipterans, coleopterans, dipterans and lepidopterans. Another study done on amaranth in Ibadan, Nigeria reported an array of hemipterans, coleopterans, lepidopterans and thysanopterans (Aderolu *et al.,* 2013). In yet another study by Mureithi *et al.,* 2015, Hemipterans, specifically aphids, were found to be the most common insect pests of AIVs in western Kenya. The difference in this survey results can be attributed to differences in study regions, study focus, difference in time of study, climatic changes, seasons and study focus.

Also the high number of insect pest diversity on spider plant could be attributed to the complex insect-plant preferences including similar feeding habits and dietary requirements (Prager *et al.,* 2014). Highest number of natural enemies on nightshade could be explained by the host-parasitoid relationship (Vinson, 2003). Parasitoids depend on previous experiences, odor associations, visual cues, host fitness and kairomones among other factors to help readily locate likely sites and concentrate on choosing a suitable insect host from these most profitable plant hosts (Tumlinson *et al.,* 1993).

Despite generally having high insect species diversity, spider plant had fewer aphid species than nightshade and amaranth. This might be due to better plant defenses provided by the high amount trichome structures on spider plant (Edeoga *et al.,* 2009). Leaf trichomes probably hinder aphid movement and feeding and act as mechanical barriers, particularly for immature aphids, that would make spider plant less attractive as seen with aphid plant interactions on wild hairy tomato (*Lycopersicon hirsutum* f. glabratum) (Musetti & Neal, 2003) .

Two aphid species (*Aphis fabae, Myzus persicae*) were common in all three AIVs. This could be because they are polyphagous in nature. There was however different aphid species noted on nightshade, e.g., *Hysteroneura setariae* and *Brevicornye brassicae*. *Hysteroneura setariae* host plant preference is majorly Poaceae family and Brevicornye brassicae host preference is the family Brassicaceae. This species has not been reported on AIVs before in western Kenya. *Aphis gossypii* which prefer Curcurbitaceae, Rutaceae and Malvaceae and *Rhopalosiphum padi* which prefer host in the family Poaceae were also identified as new aphid species on spider plants. *Rhopalosiphum padi* has been reported before from amaranth in Kenya, but not from spider plant as observed in this study. Since AIVs were not the only crops in the farm, this difference in insect-plant interaction could be attributed to several factors including agronomic practices which puts pressure on selection of quality host plants by having to learn new associations. Also this being a phytochemical driven process, it could also be attributed to insects receiving blends of plant volatiles from different crops nearby thereby making the new plant hosts more attractive compared to the individual volatiles from these new hosts which would turn out as repellant as seen in a study done on *Aphis fabae* (Bruce, 2015).

In this study, agro-ecological zones practicing annual polyculture had the highest insect diversity of both general and unique insect taxa. Low insect diversity was recorded in areas practicing perennial monoculture (sugar cane). This could be because perennial monoculture discourages insect diversity (Agustinur *et al.,* 2020).

5.2 Aphid management strategies on AIVs under field conditions

During the rainy season, aphid densities peaked earlier in the season than during the dry season and crashed a week later for the rest of season on both crops. This gradual increase and peak in populations probably reflects vigorous crop growth that provide adequate nutrients essential for aphid growth and reproduction. However, as the season progresses, increase in precipitation suppresses aphid population due to the physical impact of rainfall water droplets that washes away aphids. Possibility of fungal pathogens causing epizootics that devastate aphid populations cannot be over ruled. Increased precipitation may also improve plant vigor making them more tolerant to aphid attack (Abang *et al.*, 2018).

There were low aphid densities on both amaranth and nightshade during the rainy season although nightshade had higher aphid population per plant compared to amaranth. These results agree with different studies that showed high rainfall negatively affecting aphid population (Amin *et al.*, 2017; Kumar *et al.*, 2017; Patel *et al.*, 2016; Shivanna *et al.*, 2011). This could be due to different factors in play during this season like increased plant vigor (Mitchell *et al.*, 2016), physical force of rainfall that washed away aphids (Umar, 2016), high rainfall and humidity that favored growth of entomopathogenic fungi such as *Beauvaria bassiana* and *Metarhizium anisopliae* which attacks aphids (Mishra *et al.*, 2015). This study therefore differs with a study by Omasaja, (2016) which shows aphids being substantially more abundant during the rainy season especially on amaranth attributing it to plants having larger leaves compared to nightshade which had soft and more nutritious tissues therefore making it easy for aphids to feed (Omasaja, 2016).

The dry season had only a third of rainfall and half of the rainy days experienced during the rainy season. This had a negative impact on plant growth as was evident in crop yields, but presumably had a positive impact on aphid abundance on nightshade where aphids were 29 times more abundant than rainy season populations, warmer temperatures and less physical interference from the direct negative impact of rainfall provided perfect conditions for breeding and rapid buildup of insect pest populations just as aphids (Munyuli *et al.,* 2017). However, aphid populations were much higher on nightshade than amaranth during this season. This could be due to the substantial precipitation (which could have been enough for nightshade and not amaranth) early in the season which gave the plants a good start without the benefit of sufficient natural enemies to keep aphids on check. Amaranth on the other hand may have started off equally strong, but eventually suffered from lack of sufficient precipitation to keep the plants healthy and vigorous, which suppressed aphid population growth.

5.2.1 Aphid distribution by foliage levels on amaranth and nightshade during both rainy and dry season

Aphids are more frequent on upper and middle foliage plant levels because of the softer leaf tissues that are easier to penetrate and feed (Jakobs *et al.,* 2018). Previous studies done to establish effects of aphid infestation on phloem sap chemistry of different plant parts of *Tanacetum vulgare* L (Tancy) in regards to population growth of aphids on the different plant parts, concluded that aphid populations and distribution was significantly positively influenced by plant parts, in that populations were higher on stems than older leaves. The study attributed their results to phloem sap chemistry and availability whereby concentrations of metabolites were higher on stems than on older leaves (Jakobs *et al.*, 2018).

However in this study difference in aphid population by foliage was not significant across crops and seasons, suggesting that the different foliage levels were similar in nutritional quality. This could be explained by the systematic cut-back harvesting method used in this study which in as much as it encourages lateral growth of shoots, it took long for the lateral shoots to grow and have distinct plant parts before next harvest.

5.2.2 Efficacy of the management strategies for aphids on amaranth and nightshade during both rainy and dry season

Aphid density trend on AIVs under the different pest management strategies was similar across crops and seasons. These differences were clearly seen during the dry season on nightshade where aphid densities under the different pest management treatments were statistically different from one another. Karate is a pyrethroid with a mode of action that disrupts the central nervous system of targeted pests, causing continuous nerve stimulation and tremors within minutes of being applied. A treated pest is quickly unable to control their movements, stop feeding, become paralyzed and eventually die (He *et al.*, 2008). Neem contains Azadirachtin which is an anti-feeding deterrent that reduces hormone ecdysone which is responsible for the molting process in nymphs. Nymphs treated with neem become deformed or fail to mature and therefore die. In adults, it disrupts sexual communication and subsequent fecundity, the oil-based treatment also blocks spiracles leading to insect suffocation (Campos *et al.,* 2016). Wood ash, on the other hand is an alkaline contact material that corrodes the insects cuticle resulting in water loss and eventual death (Akami *et al.,* 2016).

5.2.3 Crop yields and pest losses on amaranth during both rainy and dry season

High yields were recorded on both AIV varieties when aphid pressure was low. Aphid pressure grows steadily when not held in checks as was evident in aphid densities on amaranth increasing three-fold in the control plots between the August 8 and 22 harvests. Similarly, aphid pressure on nightshade increased 47% between harvests during the same period. Although aphid pressure on amaranth as measured by aphid-days from the Karate treatment was significantly lower than the other treatments in the August 22 harvest, other harvests in the rainy season regardless of AIV crop were not significantly different. High precipitation suppresses pest densities and enhances plant vigor leaving little need or opportunity for pest management interventions. There were however, significant aphid pressure differences measured between the control and all the pest management treatments from the three rainy season harvests. This shows the potential for rapid aphid population growth if left unchecked. Between pest management treatments, Karate was more effective at reducing aphid densities than ash and neem thanks to its mode of action and almost immediate impact in the field and hence maintained high crop yields.

Amaranth marketable yields from both August 8 and August 22 were not significantly different between treatments. This can be attributed very low aphid numbers on vigorously growing plants. It might also be due to healthy amaranth plants being better able to resist aphid pressures (Mitchell *et al.,* 2016). Fresh weights and marketable weights from August 8 and August 22 nightshade harvests were not significantly different across all treatments. September 19 nightshade marketable weights were half as much as the fresh weights which could be due to the development of strong heavy branches that was removed from the fresh weight for the marketable harvest.

During the dry season, when precipitation was insufficient to support vigorous growth of amaranth, the crop never attained a harvestable height of 15cm above ground throughout the season. This extremely low plant vigor probably explains why the aphid counts were so low. There was a clear difference in efficacy between pest management treatments on nightshade during this season as seen from the respective aphid pressures. Nightshade harvest yields (both fresh and marketable weights) were low in the dry season compared to harvest yields during the rainy season. This followed increasingly hot and dry conditions which did not support reliable nightshade production even with periodic irrigation. On the contrary, aphid populations were very high during this season. Perhaps the high temperatures and low natural enemy pressure encouraged rapid aphid reproduction, especially in the control plots where no pest management treatments were applied to counteract their population growths. Additionally, crop's vigor was compromised by insufficient rainfall, as measured by the low harvested weights, thus making it more susceptible to aphid attack under these conditions.

5.2.4 Relationship between AIVs harvested yields and aphid-days (aphid pressure)

High aphid pressure resulted to higher yield losses due to damage caused by the insect pests. This was accurately described by an exponential function, while the corresponding pest losses was well described by a 2nd order polynomial function. These functions can therefore be used to estimate expected yields and yield losses given the measured aphid pressure.

CHAPTER SIX

CONCLUSIONS AND RECOMENDATIONS

6.1 Conclusions

- Agro-ecological zones influence AIV insect pest diversity.
- Choice of a suitable AIV insect pest management should be based on pest pressure and ability of treatment to suppress it (Karate has higher ability compared to neem oil and wood ash).
- Seasons influence pest densities on AIVs (rainy seasons- less pest density, dry season- high pest densities).
- Pest monitoring should be done before treatment to avoid pesticide misuse.
- Pest densities affect yield weights across crops and seasons (higher pest densities-lower yields, lower pest densities-higher yields).

6.2 Recommendations

- Suitable pest management strategies should be focused on the lower highland and upper midland areas where annual polyculture is practiced.
- More AIVs production should be encouraged in areas with lower insect pest diversity (Lower highland 1-sugar cane zone).
- Farmers should maximize on AIV production during the rainy season due to less pest densities.
- Before treatment application, pest pressure and product ability to suppress this pressure should be considered.

6.3 Further research work

- More research should also be done to determine reasons why spider plants host higher insect diversity.
- Effect of farming practices in the different agro-ecological zones across western Kenya on AIV insect pest density.
- Research work and recording should be done to substantiate AIV economic losses due to insect pests in Kenya and western Kenya.

REFERENCES

Abang, A. F., Srinivasan, R., Kekeunou, S., Hanna, R., Kamga, R. T., & Bilong, C.-F. B. (2018). Influence of Okra (*Abelmoschus spp*.) Accessions on Colonization by *Aphis gossypii* (Hemiptera: Aphididae) and their effects on aphid biological parameters. *Florida Entomologist,* 101(4), 549-558.

Abang, M., Kihurani, A. W., & Ramasamy, S. (2012). Managing Diseases and Pests of Indigenous Vegetables for GAP Compliance in Sub-Saharan Africa. *Scripta Horticulturae,* 15, 191-232.

Abate, T., Huis, A., & Ampofo, K. (2000). Pest Management Strategies in Traditional Agriculture: An African Perspective. *Annual review of entomology,* 45, 631-659. doi: 10.1146/annurev.ento.45.1.631

Abukutsa-Onyango, M. (2007). The diversity of cultivated African leafy vegetables in three communities in western Kenya. *African Journal of food, agriculture, nutrition and development,* 7(3).

Abukutsa-Onyango, M. (2010). African indigenous vegetables in Kenya: Strategic Repositioning in the Horticultural Sector Vol. 1. (pp. 63).

Aderolu, I. A., Omooloye, A. A., & Okelana, F. A. (2013). Occurrence, abundance and control of the major insect pests associated with Amaranths in Ibadan, Nigeria. *Entomology, Ornithology & Herpetology,* 2(3). doi: 10.4172/2161-0983.1000112

Agustinur, Sumeinika, L., & Sarong, M. (2020). Diversity of Insect Pest in Monoculture and Polyculture Nutmeg (Myristica fragrans Houtt.) Plantation in South Aceh District. IOP Conference Series: Earth and Environmental Science, 515, 012006. doi: 10.1088/1755-1315/515/1/012006.

Akami, M., Nukenine, E. N., Niu, C., & Vencl, F. V. (2016). Synergistic effects of wood ash and essential oil on fecundity, pupal eclosion and adult mortality of *Callosobruchus maculatus* (Coleoptera: Bruchidae) cowpea seed weevil. *American Journal of Experimental Agriculture* 11(6), 1-12.

Akombi, B. J., Agho, K. E., Merom, D., Renzaho, A. M., & Hall, A. J. J. (2017). Child mulnutrition in sub-Saharan Africa: A meta- analysis of demographic and health surveys (2006-2016). *PLOS ONE*.

Albouchi, F., Attia, M., Hanana, M., & Hamrouni, L. (2018). Ethnobotanical notes and phytopharmacologiques on *Solanum nigrum* Linn. (Family: Solanaceae). *American Journal of Phytomedicine and Clinical Therapeutics*, 6(1), 5. doi: 10.21767/2321-2748.100341

Amin, M. R., Afrin, R., Alam, M. Z., Hossain, M. M., & Kwon, Y. J. (2017). Effect of leaf trichomes and meteorological parameters on population dynamics of aphid and jassid in cotton *Bangladesh Journal of Agricultural Research*, 42(1), 13. doi: 10.3329/bjar.v42i1.31969

Andreas, W. E., Tien-hor, W., & San-tai, W. (2011). Vegetable amaranth (Amaranthus L.). In A. T. W. V. Center (Ed.): AVDRC.

Ashilenje, D. S., Omunyin, M. E., & Okalebo, J. R. (2011). Influence of potassium on aphid incidence and yield of vegetable African nightshades (Solanum L. section Solanum) *Annals of Biological Research*, 2(3), 317-326.

Atanu, S. (2018). Role of Intercropping Practices in Farming System for Insect Pest Management. *Acta Scientific Agriculture*, 2(2), 8-11.

Barbercheck, M. E. (2014). Biology and management of aphids in organic cucurbit production systems. In P. S. University (Ed.), *Extension: Oganic Agriculture*.

Bayissa, W., Ekesi, S., Mohamed, S. A., Kaaya, G. P., Wagacha, J. M., Hanna, R., & Maniania, R. K. (2016). Selection of fungal isolates for virulence against three aphid pest species of crucifers and okra. *Journal of pest science,* 90, 335-368.

Bhat, A., Satpathy, G., & Rajinder, K. G. (2015). Evaluation of Nutraceutical properties of Amaranthus hypochondriacus L. grains and formulation of value added cookies. *Journal of Pharmacognosy and Phytochemistry,* 3(5), 51-54.

Braima, J., Atacha-Ahowe, C., Godonou, I., Baimey, A., Geogen, G., Sikivou, R., & Toko, M. (2010). Integrated pest management in vegetable production. A guide for Extension workers in West Africa Ibadan, Oyo State, Nigeria: *International Insititute of Tropical Agriculture*.

Bruce, T. J. A. (2015). Interplay between insects and plants: dynamic and complex interactions that have coevolved over millions of years but act in milliseconds. *Jounal of Experimental Botany,* 66(2), 455-465.

Bua, B., & Onang, C. (2017). Validating the role of African indigenous vegetables for food and nutrition security in Uganda. *Journal of Food Science and Engineering,* 7, 316-322.

Campos, E. V. R., Oliveira, J. L., Pascoli, M., Lima, R., & Fraceto, L. F. (2016). Neem oil and crop protection: From now to the future. *Frontiers in Plant Science, 7*(1494). doi: 10.3389/fpls.2016.01494

Capinera, J. L. (2005). Relationships between insect pests and weeds: an evolutionary perspective *Weed Science,* 53, 892-901.

Chege, P. M. (2012). Efficacy of dried amaranth leaves(Amaranthus cruentus) consumption on vitamin A, iron and zinc of children in Kajiado county, Kenya (PhD), Kenyatta University.

Chepkoech, W., Mungai, N. C., Stöber, S., Bett, H. K., & Lotze-Campen, H. (2018). Farmers' perspectives: Impact of climate change on African indigenous vegetable production in Kenya. *International Journal of Climate Change Strategies and Management*, 10(4), 551-579. doi: 10.1108/IJCCSM-07-2017-0160

Chweya, J. A., & Mnzava, N. A. (1997). Cat's whiskers. *Cleome gynandra* L.: Promoting the conservation and use of underutilized and neglected crops. 11. Rome, Italy: Institute of Plant Genetics and Crop Plant Research, Gatersleben/International Plant Genetics Resources Institute.

Chweya, J. A., Mnzava, N. A., Heller, J., & Engels, J. M. M. (1997). *Cat's whiskers. Cleome gynandra* L.

CIDP-UG. (2013-2018). Uasin Gishu County Development Plan

County, K. (2018-2022). County Integrated Development Plan.

Craemer, C., Dippenaar-Schoeman, A. S., Eardley, C. D., Grobbelaar, E., Mansell, M. W., Millar, I. M., . . . Ueckermann, E. A. (2000). Collecting and preserving insects and Arachnids: Isteg Scientific Publications.

De Conti, B. F., Bueno, V. H. P., Sampaio, M. V., & Sidney, L. A. (2010). Reproduction and fertility life table of three aphid species (Macrosiphini) at different temperatures. *Revista Brasileira de Entomologia*, 54(4), 654-660.

Diao, X., Hazel, P., & Thurlow, J. (2010). The role of agriculture in African development. *World development*. doi: 10.1016/j.worlddev.2009.06.011

Edeoga, H. O., Omosun, G., Osuagwu, G. G. E., Mbaebie, B. O., & Madu, B. A. (2009). Micromorphological characters of the vgetative and floral organs of some cleome species from Nigeria. *American-Eurasian Journal of Scientific Research,* 4(3), 124-127.

Edmonds, J. M., & Chweya, J. A. (1997). Black nightshades. Solanum nigrum L. and related species.

El-Wakeil, N. E. (2013). Botanical pesticides and their mode of action. *Gesunde Pflanzen,* 65(4), 125-149. doi: 10.1007/s10343-013-0308-3

Fajinmi, A., Odebode, C. A., & Fajinmi, O. B. (2011). The effect of agro-ecological zones on the inidence and distribution of aphid vectors of pepper vienal mottle virus, on cultivated pepper (Capsicum annuum L.) in Nigeria. *Journal of Central European Agriculture,* 12(3), 528-542. doi: 10.5513/JCEA01/12.3.951

Frampton, M., Droege, S., Conrad, T., Prager, S., & Richards, M. H. (2008). Evaluation of Specimen Preservatives for DNA Analyses of Bees. *Journal of Hymenoptera Research,* 17(2), 195-200.

Fuzesi, I., Heil, B., & Kovacs, G. (2015). Effects of Wood Ash on the Chemical Properties of Soil Vitalityin Small Plot Experiments. 11(1), 55-64.

Gido, E., Bokelmann, W., Mutai, B., & Bett, H. K. (2015). Demand Analysis for African Indigenous Vegetables among Rural and Urban Consumers in Kenya. Paper presented at the Management of land use systems for enhanced food security: conflicts, controversies and resolutions, Berlin, Germany.

Gido, E. O., Ayuya, O. I., Owuor, G., & Bokelmann, W. (2017). Consumption intensity of leafy African indigenous vegetables: towards enhancing nutritional security in rural and urban dwellers in Kenya. *Agricultural and Food Economics,* 5(14).

Gido, E. O., Bett, H. K., & Bokelmann, W. (2016). Importance of African indigenous vegetables in food systems. *African Journal of Horticultural Science,* 10, 34-41.

Guerrieri, E., & Digilio, M. C. (2008). Aphid-plant interactions: A review. *Journal of Plant Interactions, 3*(4), 223-232. doi: 10.1080/17429140802567173

He, L. M., Troiano, J., Wang, A., & Goh, K. S. (2008). Environmental Chemistry, Ecotoxicity, and Fate of Lambda-Cyhalothrin. *Reviews of environmental contmination and toxicology,* 195, 71-91.

Hillocks, R. (1998). The potential benefits of weeds with reference to small holder agriculture in Africa. *Integrated Pest Management Reviews,* 3, 155-167. doi: 10.1023/A:1009698717015

Jaetzold, R., & Schmidt, H. (1983). Farm Management Handbook of Kenya *1*.

Jaetzold, R., Schmidt, H., Hornetz, B., & Shisanya, C. (2006). Farm management handbook of Kenya. Natural conditions and farm management information-western Kenya.

Jagatheeswari, D., Bharathi, T., & Sheik Jahabar Ali, H. (2013). Black Night Shade (Solanum nigrum L.) - An Updated Overview. *International Journal of Pharmaceutical & Biological Archives,* 4(2), 288-295.

Jakobs, R., Schweiger, R., & Muller, C. (2018). Aphid infestation leads to plant part-specific changes in phloem sap chemistry, which may indicate niche construction. *New Phytologist,* 221(1).

Kamga, R. T., Kouame, C., Atangana, A. R., Chagomoka, T., & Ndago, R. (2013). Nutritional Evaluation of Five African Indigenous Vegetables. *Journal of Horticultural Research,* 21(1), 99-106.

Kariuki, C. W. (1999). The infestation of some potato cultivar by aphid and other insects in Lari, Kiambu district. Paper presented at the Towards increased use of demand driven technology.

Kaufui, V. W. (2017). Amaranth Grain and Greens for Health Benefits. *Nutrition and Food Science International Journal,* 2(2). doi: 10.19080/NFSIJ.2016.02.555584

Keatinge, J. D. H., Wang, J. F., Dinssa, F. F., Ebert, A. W., Hughes, d. A. J., Stoilova, T., . . . Ravishankar, M. (2015). Indigenous vegetables worldwide: Their importance and future development. *Acta horticulturae,* 1102(1102), 1-20. doi: DOI: 10.17660/ActaHortic.2015.1102.1

Kebede, S. W., & Bokelmann, W. (2017). African indigenous vegetables and their production practices: Evidence from the HORTINLEA survey in Kenya. *Agrotechnology, 6*(3). doi:10.4172/2168-9881.1000170

Kenya Ministry of Agriculture, L. a. F. M. (2016). Climate risk profile for Busia. Nairobi, Kenya.

Kinyanjui, G., Khamis, F. M., Mohamed, S., Ombura, L. O., Warigia, M., & Ekesi, S. (2016). Identification of aphid (Hemiptera: Aphididae) species of economic importance in Kenya using DNA barcodes and PCR-RFLP based approach. *Bulletin of Entomology Research,* 106, 63-72.

Kirigia, D., Kasili, R., & Mibus, H. (2017). African Leafy Vegetables Pre-harvest and Post-harvest constrains and Technologies for losses reduction along the field to consumer chain. *African Journal of Horticultural Science,* 12, 51-60.

Kouamé, C. M., Abang, M., Hanna, R., & Fotso, A. K. (2014). Assessing Vegetable Farmer Knowledge of Diseases and Insect Pests of Vegetable and Management Practices Under Tropical Conditions AU - Abang, A. F. *International Journal of Vegetable Science,* 20(3), 240-253. doi: 10.1080/19315260.2013.800625

Kujeke, G. T., Gonye, E., Edziwa, X., Ncube, A., Masekesa, R. T., Icishahayo, D., . . . Chabata, I. (2017). Field performance of spider plant (*Cleome Gynandra* L) under different agronomic practices. *African Journal of food, agriculture, nutrition and development,* 17(3), 12179-12197. doi: 10.18697/ajfand.79.15985

Kumar, G. S., Raju, S. V. S., & Kattula, S. Y. (2017). Impact of abiotic factors on the population fluctuations of sucking insect pests on okra (*Abelmoschus esculentus* L.). *Journal of Entomology and Zoology Studies,* 5(3), 1258-1262.

Liburd, O. E., Nyoike, T. W., & Razze, J. M. (2015). Biology and management of aphids in sustainable field production of cucurbits. *University Of Florida EDIS IFAS Extension, ENY847*.

Lingunya, K. S., Moraa, O. C., Wangai, K. J., & Chao, K. D. (2015). Potential of intercropping for management of some arthropod and nematode pests of leafy vegetables in Kenya. *Journal of Agricultural Sciences,* 60(3), 301-314.

Machangi, J. M., Olubayo, F. M., Nderitu, J. H., Njeru, R. W., El-Bedewy, R., & Obudho, E. O. (2003). Effect of aphids and virus diseases on yield of seed potatoes in Kenya. African Crop Science Society, 6, 220-223.

Mavengahama, S. (2013). The contribution of indigenous vegetales to food security and nutrition within selected sites in South Africa. (PhD Thesis), Stellenbosch University.

Mishra, S., Kumar, P., & Malik, A. (2015). Effect of temperature and humidity on pathogenicity of native *Beauveria bassiana* isolate against *Musca domestica* L. *Journal of Parasitic Diseases*, 39(4), 697-704. doi: 10.1007/s12639-013-0408-0

Mishra, S. S., Moharana, S. K., & Dash, M. R. (2011). Review on Cleome gynandra. *International Journal of Research in Pharmacy and Chemistry, 1*(3), 681-689.

Mitchell, C., Brennan, R. M., Graham, J., & Karley, A. J. (2016). Plant defense against herbivorous pests: Exploiting resistance and tolerance traits for sustainable crop protection. *Frontiers in Plant Science*, 7(1132). doi: 10.3389/fpls.2016.01132

Mureithi, D. M., Fiaboe, K. K. M., Ekesi, S., & Meyhöfer, R. (2017). Important arthropod pests on leafy Amaranth (*Amaranthus viridis, A. tricolor and A. blitum*) and broad-leafed African nightshade (*Solanum scabrum*) with a special focus on host-plant ranges. *African Journal of Horticultural Science*, 11, 1-17.

Muhanji, G., Roothaert, R. I., Webo, C., & Mwangi, S. (2011). African indigenous vegetable enterprise and market access for small-scale farmers in East Africa. *International Journal of Agriculture Sustainability*, 9(1), 194-202. doi: 10.3763/ijas.2010.0561

Munyuli, T., Kalimba, Y., Mulangane, E. K., Mukadi, T. T., Ilunga, M. T., & Mukendi, R. T. (2017). Interaction of the fluctuation of the population density of sweet potato pests with changes in farming practices, climate and physical environments: A 11-year preliminary observation from South-Kivu Province, Eastern DRCongo. *Open Agriculture, 2*, 495-530.

Mureithi, D. M., Mworia, J. K., Meyhoefer, R., Murungi, L. K., Losenge, T., Senyo Akutse, K. S., Ekesi, S., Komi, K., Fiaboe, M. (2015). Survey for pest and natural enemies of amaranth and African nightshades in Kenya and Tanzania. Paper presented at the Management of land use systems for enhanced food security: conflicts, controversies and resolutions, Berlin, Germany.

Muriuki, E. N. (2015). Nutritional Diversity of Leafy Amaranth (Amaranthus) Species Grown in Kenya. (Msc. Food Science and Nutrition), Jomo Kenyatta University of Agriculture and Technology.

Musetti, L., & Neal, J. J. (2003). Resistance to the pink potato aphid,*Macrosiphum euphorbiae*,in two accessions of *Lycopersicon hirsutum f. glabratum*. *Entomologia Experimentalis et Applicata*, 84, 137-146.

Mwaura, S. N., Muluvi, A. S., & Mathenge, M. K. (2013). African Leafy Vegetables and Household Wellbeing in Kenya: A Disaggregation by Gender. Paper presented at the 4th International Conference of the African Association of Agricultural Economists, Hammamet, Tunisia.

Ntawuruhunga, D. (2016). Farmers knowledge, attitude and practice towards indigenous vegetables in Kenya. (Msc Thesis), Jomo Kenyatta University of Agriculture and Biotechnology.

Nyirenda, S. P., Gudeta, W., Sileshi, G. W., Steven, R., Belmain, S. R., Kamanula, J. F., Mvumi, B. M., Sola, P., Nyirenda, G. K. C., Stevenson, P. C. (2011). Farmers' ethno-ecological knowledge of vegetable pests and pesticidal plant use in Northern Malawi and Eastern Zambia African *Journal of Agriculture Research*, 6(2).

Odongo, G. A., Schlotz, N., Baldermann, S., Neugart, S., Huyskens-Keil, S., Ngwene, B., Trierweiler, B., Schreiner, M., Lamy, E. (2018). African Nightshade (*Solanum scabrum* Mill.): Impact of cultivation and plant processing on its health promoting potential as determined in a human liver cell model. *Nutrients*, 10(1532). doi: 10.3390/nu10101532

Okello, J. J., Hutchinson, A. J., Mwang'ombe, A., Ambuko, J., Olubayo, F., & Mwakangalu, M. (2015). Consumer demand for value-added products of African indigenous vegetables in coastal Kenya: The case of sundried and frozen cowpea leaves *Journal of Agriculture, Food Systems, and Community Development*, 6(1), 189-207. doi: 10.5304/jafscd.2015.061.004

Okolle, N. J., Afari-Sefa, V., Bidogeza, J.-C., Tata, P. I., & Ngome, F. A. (2016). An evaluation of smallholder farmers' knowledge, perceptions, choices and gender perspectives in vegetable pests and diseases control practices in the humid tropics of Cameroon. *International Journal of Pest Management*, 62(3), 165-174. doi: 10.1080/09670874.2016.1184772

Okutu, P. C., Uyobisere, E., & Dowtiro, Y. D. (2014). The Use of Wood Ash for Insect Pests Management by Paw-paw Famers in Samaru and Shika, Nigeria. *World of Engineering and Pure Applied Science,* 3(2), 1.

Oladele, O. I. (2011). Contribution of indigenous vegetables and fruits to poverty alleviation in Oyo State, Nigeria. *Journal of Human Ecology,* 34(1), 1-6.

Olubayo, F., Kibaru, A., Nderitu, J., Njeru, R., Shibaro, S., & Kasinya, M. (2008). Management of aphids and aphid- Transmitted viruses in stored seed potatoes in Kenya. *International Journal Sustain Crop Production,* 3(5), 40-45.

Oluoch, M. O., Pichop, G. N., Silue, D., Abukutsa-Onyango, M., Diouf, M., & Shackleton, C. M. (2009). Production and harvesting systems for African indigenous vegetables. In C. M. Shackleton, M. Pasquini, & A. W. Dreschler (Eds.), *African Indigenous Vegetables in Urban Agriculture* (1 ed., pp. 145-176): Earthscan publication.

Omasaja, S. A. (2016). Occurence and abundance of insect pests on African indigenous vegetables under different fertilizer treatments and seasons in Kitale, Kenya. (Masters in Crop Protection), University of Eldoret.

Ondieki, M. J., Aguyoh, J. N., & Opiyo, A. (2011). Variations in growth and yield characteristics of three black nightshade species grown under high altitude conditions *Agriculture and biology journal of north America,* 2(3), 401-406. doi: 10.5251/abjna.2011.2.3.401.406

Oniang'o, R. K., Mutuku, J. M., & Malaba, S. J. (2003). Contemporary African food habits and their nutritional and health implications. *Journal of Clinical Nutrition,* 12(3), 231-236.

Ontita, E. G., Onyango, C. M., Onwonga, R. N., & Nyamongo, D. (2016). Indigenous knowledge on the uses of African nightshades (*Solanum nigram* L.) species among three Kenyan communities *Asian Journal of Agricultural Extension, Economics & Sociology*, 14(3), 1-8.

Onwuka, M. I., Ozurumba, U. V., & Nkwocha, O. S. (2016). Changes in Soil pH and Exchangeable Acidity of Selected Parent Materials as Influenced by Amendments in South East of Nigeria. *Journal of Geoscience and Environment protection*, 4, 80-88.

Onyango, C. M., Kunyanga, C. N., Ontita, E. D., Narla, R. D., & Kimenju, J. W. (2013). Production, utilization and indigenous knowledge of spider plant in Kenya. *African Crop Science Society*, 11, 925-930.

Onyango, C. M., Ontita, E., Onwonga, R., Nyamongo, D., & Gapusi, J. (2016). Status and production practices of vegetable African nightshade (*Solanum nigrum* L.) in selected communities of Kenya. *American Journal of Experimental Agriculture*, 13(3), 1-12. doi: 10.9734/AJEA/2016/27363

Owusu, F. A., Kyerematen, R., Akotsen-Mensah, C., & Afreh-Nuamah, K. (2014). Effect of some climatic factors on insects associated with citrus agro-ecosystems in Ghana. *Journal of Biodiversity and Environmental Sciences*, 5(4), 428-436.

Pasquini, M. W., Komlan, F. A., Voster, I., Shackleton, C. M., & Onyango, M. O. A. (2009). The Production of Arican Indigenous Vegetables in Urban and Peri-Urban Agriculture: A Comparative Analysis of Case Studies from Benin, Kenya and South Africa. In C. M. Shackleton, M. Pasquini, & A. Drescher (Eds.), *African Indigenous Vegetables in urban agriculture* (pp. 177-224): Earthscan.

Patel, M. L., Patel, R. K., Sheth, D. B., & Patel, P. R. (2016). Influence of abiotic factors on population dynamics of sucking insect pests in transgenic cotton. *Advances in Life Sciences, 5*(5).

Pichop, G. N., & Weinberger, K. (2009). Marketing of African indigenous vegetables along urban and peri-urban supply chains in sub-Saharan Africa: Earthscan.

Prager, S. M., Esquivel, I., & Trumble, J. T. (2014). Factors Influencing Host Plant Choice and Larval Performance in *Bactericera cockerelli*. *PLOS ONE, 9*(4). doi: 10.1371/journal.pone.0094047

Pretty, J., & Bharucha, Z. P. (2015). Integrated pest management for sustainable intensification of agriculture in Asia and Africa. *Insects,* 6, 152-182. doi: 10.3390

Production., D. P. (2010). *Amaranthus production guidelines*. Pretoria, South Africa: Department of Agriculture, Forestry and Fisheries.

Risch, S. J. (1983). Environmental Management. *Environmental Management,* 7(1), 9-14.

Shackleton, C. M., Pasquini, M. W., & Young, E. M. (2009). *African indigenous vegetables in urban agriculture*: Earthscan.

Shiundu, K. M., & Oniang'o, R. K. (2007). Marketing African leafy vegetables: Challenges and opportunities in the Kenyan context. *African Journal of food, agriculture, nutrition and development,* 7(4).

Shivanna, B. K., Gangradhara, N. B., Basavaraja, M. K., Nagaraja, R., Kalleswara, S., & Karegowda, C. M. (2011). Impact of abiotic factors on population dynamics of sucking pests in transgenic cotton ecosystem. *International Journal of Science and Nature,* 2(1), 72-74.

Sithanantham, S. (2004). Development and Dissemination of IPM for vegetables in eastern Africa (K. Kebaara Ed.): ICIPE Science Press.

Sithanantham, S., Matoka, C. M., Maundu, M., Jakani, M., & Agong, G. S. (2005). Integrated crop protection research for sustainable production of indigenous vegetable crops in eastern Africa,. Paper presented at the Proceedings of the Third Horticulture Workshop on Sustainable Horticultural Production in the Tropics, Maseno University, Maseno, Kenya.

Skaljac, M., & Vilcinskas, A. (2016). *Biology and Ecology of Aphids*. London: CRC Press

The Kenya Ministry of Agriculture, l. a. F. M. (2016). *C*limate risk profile for Siaya County. Nairobi, Kenya.

The Ministry of Agriculture, l. a. F. M. (2016). Climate risk profile for Homa Bay County. Nairobi, Kenya.

The Ministry of Agriculture, l. a. F. M. (2017). Climate risk profile for Kakamega County. Nairobi, Kenya.

Tubene, L. S., & Myers, D. R. (2008). Ethnic and specialty vegetables handbook. University of Maryland.

Tumlinson, J. H., Lewis, W. J., & Vet, L. E. M. (1993). How Parasitic Wasps Find Their Host. *Scientific American*.

Tumwet, T. N. (2013). The role of African indigenous leafy vegetables in immune boosting (PhD Thesis), University of Nairobi.

Umar, A. (2016). Evaluation of anti – aphids properties of the aqueous crude fruit sap extract of *Solanum incanum.* (Msc Thesis), Kenyatta University.

Unger, J. (2014). Evaluation of local knowledge applied by farmers towards management of crop pests and diseases in the Masaka region, Uganda. (Msc Thesis), Swedish University of Agricultural Sciences, Alnarp.

Van den Heever, E., & Venture, S. L. (2007). Nutritional and medicinal properties of *Cleome gynandra*. *Acta horticulturae,* 752(752), 127-130. doi: 10.17660/ActaHortic.2007.752.17

Vinson, S. B. (2003). Host Selection by Insect Parasitoids. *Annual review of entomology,* 21(1), 109-133. doi: 10.1146/annurev.en.21.010176.000545

Wemali, E. N. C. (2014). Contribution of cultivated African indigenous vegetables to Agro-biodiversity conservation and community livelihood in Mumias sugarbelt, Kenya. (PhD Thesis), Kenyatta University.

Wesonga, N. L., Ngugi, K. E., Onyango, M. C., & Nyamongo, D. (2016). Diversity among selected African nightshade genotypes found in Kenya. Paper presented at the Fifth RUFORUM Biennual Regional Conference, Cape Town, South Africa. http://repository.ruforum.org

Wiklund, J. (2017). Effects of wood ash on soil fertility and plant performance in southwestern Kenya (Master's in Soil Science), Swedish University of Agricultural Sciences, Uppsala

Yang, R. Y., & Keding, G. B. (2009). Nutritional Contributions of Important African Indigenous Vegetables. London, UK: Earthscan.

APPENDICES

Appendix I: Common pests of nightshade

Plate 4a: Cut worm damage

Plate 4b: Aphid damage

Plate 4c: Aphids

Plate 4d: Spider mite damage

Plate 4e: Bird damage

Plate 4f: Mouse bird

Appendix II: Common pests of amaranth

Plate 5a: Caterpillar

Plate 5b: Leaf-miner mines

Plate 5c: Stink bug

Appendix III: Common pests of spider plant

Plate 6a: Coreid bug (Source; Author, 2017)

Plate 6b: Ants (Source; Author, 2017)

Appendix IV: Inventory of AIV insect species found on AIVs in western Kenya

Species	Order	Family	Diet	Agro-ecological zone	AIV host*
Agonoscelis versicolor	Hemiptera	Pentatomidae	Herbivore	LH3	AM
Aphidius colemani	Hymenoptera	Braconidae	Parasitoids	LH3, LM1, LM2, LM5	NS, SP
Aphis craccivora	Hemiptera	Aphididae	Herbivore	LH, LH3, UM	AM, NS, Kale
Aphis fabae	Hemiptera	Aphididae	Herbivore	LH, LH3, LM1, LM2, LM4, UM	AM, NS,SP
Aphis gossypii	Hemiptera	Aphididae	Herbivore	LH	SP
Apion sp.	Coleoptera	Apionidae	Herbivore	LM1	SP
Apthona marshalli	Coleoptera	Chrysomelidae	Herbivore	LM3	NS
Apthona sp.	Coleoptera	Chrysomelidae	Herbivore	LM1, LM2	AM, SP
Asbecesta cyanipennis	Coleoptera	Chrysomelidae	Herbivore	LM5	AM, SP
Aspavia armigera	Hemiptera	Pentatomidae	Herbivore	Not recorded	AIVs
Aspidomorpha sp.	Coleoptera	Chrysomelidae	Herbivore	Not recorded	AIVs
Athalia sp.	Hymenoptera	Tenthredinidae	Herbivore	Not recorded	AIVs
Bagrada hilaris	Hemiptera	Pentatomidae	Herbivore	LH3	SP
Brevicoryne brassicae	Hemiptera	Aphididae	Herbivore	LH3, UM	NS
Callosobruchus maculatus	Coleoptera	Bruchidae	Herbivore	LM2, UM1	AM
Cassida dorsovittata	Coleoptera	Chrysomelidae	Herbivore	LM1	NS
Cheilomenes aurora	Coleoptera	Coccinellidae	Predator	LH3	NS
Cheilomenes sulpherea	Coleoptera	Coccinellidae	Predator	LM1, LM2	AM, NS, SP
Chilocous sp.	Coleoptera	Coccinellidae	Predator	LM1	NS

Cletus ochraceus	Hemiptera	Coreidae	Herbivore	LH, LH3	AM
Cletus ochraceus fuscescens	Hemiptera	Coreidae	Herbivore	UM	AM
Cletus orientalis	Hemiptera	Coreidae	Herbivore	Not recorded	AIVs
Coryna apicicornis	Coleoptera	Meloidae	Herbivore	LM1	SP
Deraeocoris ostentans	Hemiptera	Miridae	Herbivore	LH, LH3, UM	AM, SP
Drepanocerus kirbyi	Coleoptera	Scarabaeidae	Herbivore	LM1	SP
Dysdercus nigrofasciatus	Hemiptera	Pyrrhocoridae	Herbivore	LH, LH3	AM
Epilachna sp.	Coleoptera	Coccinellidae	Herbivore	LH	AM
Epitrix sp.	Coleoptera	Chrysomelidae	Herbivore	LM1	NS
Epitrix torvi	Coleoptera	Chrysomelidae	Herbivore	LM1	SP
Exitianus sp.	Hemiptera	Cicadellidae	Herbivore	LM1	SP
Forficula senegalensis	Dermaptera	Forficulidae	Predator	Not recorded	AIVs
Haltica pyricosa	Coleoptera	Chrysomelidae	Herbivore	LM1	AM
Helicoverpa armigera	Lepidoptera	Noctuidae	Herbivore	LH	SP
Hippodamia variegate	Coleoptera	Coccinellidae	Predator	LH, LM1, LM5	AM, NS, SP
Hypolixus nr nubilosus	Coleoptera	Curculionidae	Herbivore	Not recorded	AIVs
Hysteroneura setariae	Hemiptera	Aphididae	Herbivore	UM	NS
Jamesonia sp.	Coleoptera	Chrysomelidae	Herbivore	LH, LM1, LM2, LM3, LM5, UM1	AM, NS, SP
Junonia Sophia	Lepidoptera	Nymphalidae	Herbivore	UM	NS
Lagria cyanicollis	Coleoptera	Lagriidae	Herbivore	LH, UM	NS
Lagria purpurascens	Coleoptera	Lagriidae	Herbivore	Not recorded	AIVs
Lema viridivittata	Coleoptera	Chrysomelidae	Herbivore	LM1	AM
Leptotes sp.	Lepidoptera	Lycaenidae	Herbivore	UM	NS
Lixus pulcher	Coleoptera	Curculionidae	Herbivore	Not recorded	AIVs

Lixus rhomboidalis	Coleoptera	Curculionidae	Herbivore	LM1, LM5	AM
Luperodes exclamationis	Coleoptera	Chrysomelidae	Herbivore	LH	NS
Lycaena sp.	Lepidoptera	Lycaenidae	Herbivore	LM5	NS
Lycus turneri	Coleoptera	Lycidae	Herbivore	LH	SP
Lysiphlebus fabarum	Hymenoptera	Braconidae	Parasitoid	UM	NS
Macrosteles sp.	Hemiptera	Cicadellidae	Herbivore	LH	SP
Macrosteles strifrons	Hemiptera	Cicadellidae	Herbivore	UM1	AM
Micraspis sp.	Coleoptera	Coccinellidae	Predator	LM5	AM
Micraspis striata	Coleoptera	Coccinellidae	Predator	LM5	AM
Monolepta leuce	Coleoptera	Chrysomelidae	Herbivore	LH3	AM
Myzus persicae	Hemiptera	Aphididae	Herbivore	LH, LM1, LM2, LM3, LM5, UM, UM1	AM, NS, SP
Nematocerus castaneipennis	Coleoptera	Curculionidae	Herbivore	Not recorded	AIVs
Nezara viridula	Hemiptera	Pentatomidae	Herbivore	UM	SP
Phyllobrotica elegans	Coleoptera	Chrysomelidae	Herbivore	LH3	SP
Phyllotreta cheiranthi	Coleoptera	Chrysomelidae	Herbivore	LH, LH3, UM	SP
Platynaspis capicola	Coleoptera	Coccinellidae	Herbivore	LH	AM
Platynaspis sexguttata	Coleoptera	Coccinellidae	Herbivore	UM1	AM
Plusia sp.	Lepidoptera	Noctuidae	Herbivore	LH	SP
Podagrica weisi	Coleoptera	Chrysomelidae	Herbivore	LM5	SP
Poephila sp.	Coleoptera	Chrysomelidae	Herbivore	LM1, LM2, LM5, UM	AM, NS, SP
Rhopalosiphum padi	Hemiptera	Aphididae	Herbivore	LM2	SP
Rhynocoris vulneratus	Hemiptera	Reduviidae	Predator	UM	AM, NS, SP
Sameodes cancellalis	Lepidoptera	Cramidae	Herbivore	LH	SP
Scymnus sp.	Coleoptera	Coccinellidae	Predator	LM2,LM4,UM1,LM1-SCZ	AM, NS

Scymnus trepidulus	Coleoptera	Coccinellidae	Predator	LH, LM1, LM2, LM5, UM, UM1	AM, NS, SP
Silidius apicalis	Coleoptera	Cantharidae	Herbivore	LH	SP
Silidius breviapicalis	Coleoptera	Cantharidae	Herbivore	LH	SP
Sitophilus sp.	Coleoptera	Curculionidae	Herbivore	LH3	SP
Unknown Acrididae sp.	Orthoptera	Acrididae	Herbivore	UM	SP
Unknown Cercopidae sp.	Hemiptera	Cercopidae	Herbivore	LM2,LM1-SCZ,LH,LM1	AM, SP
Unknown Fulgoridae sp.	Hemiptera	Fulgoridae	Herbivore	LM3	NS
Unknown Lycaenidae sp.	Lepidoptera	Lycaenidae	Herbivore	UM	NS
Unknown Lycaenidae sp.	Lepidoptera	Lycaenidae	Herbivore	LM5	SP
Unkown Tenthredinidae sp.	Hymenoptera	Tenthredinidae	Herbivore	Not recorded	AIVs
Unknown Tingidae sp.	Hemiptera	Tingidae	Herbivore	LM1, LM2	AM, NS

Appendix V: Monthly rainy and dry season precipitation data for Eldoret

Year	Month	Amount (mm)	Rainy days
2017	Jan	6.81	4
	Feb	21.01	10
	Mar	33.88	12
	Apr	80.03	22
	May	115.53	26
	Jun	21.89	18
	Jul	86.24	27
	Aug	97.78	28
	Sep	93.79	26
	Oct	96.01	18
	Nov	43.2	18
	Dec	9.47	10
2018	Jan	3.7	6

Source: World weather Online.com

Appendix VI: Mean summary and statistics for amaranth during the rainy season

Type III Tests of Fixed Effects

Effect	Num DF	Den DF	F Value	Pr > F
Treatment	3	8	38.39	<.0001

Differences of Treatment Least Squares Means*

Treatment	Treatment	Estimate	Standard Error	DF	t Value	Pr > |t|	Adj P
Ash	Control	-0.5921	0.09238	8	-6.41	0.0002	0.0009
Ash	Karate	0.4855	0.1201	8	4.04	0.0037	0.0157
Ash	Neem	-0.03774	0.1039	8	-0.36	0.7257	0.9824
Control	Karate	1.0776	0.1094	8	9.85	<.0001	<.0001
Control	Neem	0.5543	0.09127	8	6.07	0.0003	0.0013
Karate	Neem	-0.5232	0.1192	8	-4.39	0.0023	0.01

*Adjustment for Multiple Comparisons: Tukey-Kramer

Appendix VII: Mean summary and statistics for nightshade during the rainy season

Type III Tests of Fixed Effects

Effect	Num DF	Den DF	F Value	Pr > F
Treatment	3	8	382.17	<.0001

Differences of Treatment Least Squares Means*

Treatment	Treatment	Estimate	Standard Error	DF	t Value	Pr > |t|	Adj P
Ash	Control	-1.4159	0.06271	8	-22.58	<.0001	<.0001
Ash	Karate	0.2627	0.08532	8	3.08	0.0151	0.0595
Ash	Neem	-0.08199	0.07797	8	-1.05	0.3238	0.7261
Control	Karate	1.6786	0.06988	8	24.02	<.0001	<.0001
Control	Neem	1.3339	0.06069	8	21.98	<.0001	<.0001
Karate	Neem	-0.3447	0.08385	8	-4.11	0.0034	0.0144

*Adjustment for Multiple Comparisons: Tukey-Kramer

Appendix VIII: Mean summary and statistics for amaranth during the dry season

Type III Tests of Fixed Effects

Effect	Num DF	Den DF	F Value	Pr > F
Treatment	3	8	67.12	<.0001

Differences of Treatment Least Squares Means*

Treatment	Treatment	Estimate	Standard Error	DF	t Value	Pr > |t|	Adj P
Ash	Control	-0.636	0.1102	8	-5.77	0.0004	0.0019
Ash	Karate	2.1972	0.2817	8	7.8	<.0001	0.0002
Ash	Neem	1.0986	0.1782	8	6.17	0.0003	0.0012
Control	Karate	2.8332	0.275	8	10.3	<.0001	<.0001
Control	Neem	1.7346	0.1674	8	10.36	<.0001	<.0001
Karate	Neem	-1.0986	0.3086	8	-3.56	0.0074	0.0303

*Adjustment for Multiple Comparisons: Tukey-Kramer

Appendix IX: Mean summary and statistics for nightshade during the dry season

Type III Tests of Fixed Effects

Effect	Num DF	Den DF	F Value	Pr > F
Treatment	3	8	21097	<.0001

Differences of Treatment Least Squares Means*

Treatment	Treatment	Estimate	Standard Error	DF	t Value	Pr > |t|	Adj P
Ash	Control	-2.1692	0.01307	8	-165.9	<.0001	<.0001
Ash	Karate	1.8154	0.0331	8	54.84	<.0001	<.0001
Ash	Neem	0.5768	0.02065	8	27.93	<.0001	<.0001
Control	Karate	3.9845	0.03098	8	128.6	<.0001	<.0001
Control	Neem	2.746	0.01705	8	161.06	<.0001	<.0001
Karate	Neem	-1.2385	0.03487	8	-35.52	<.0001	<.0001

*Adjustment for Multiple Comparisons: Tukey-Kramer

Appendix X: Type III Tests of Fixed Effects (Amaranth during the rainy season)

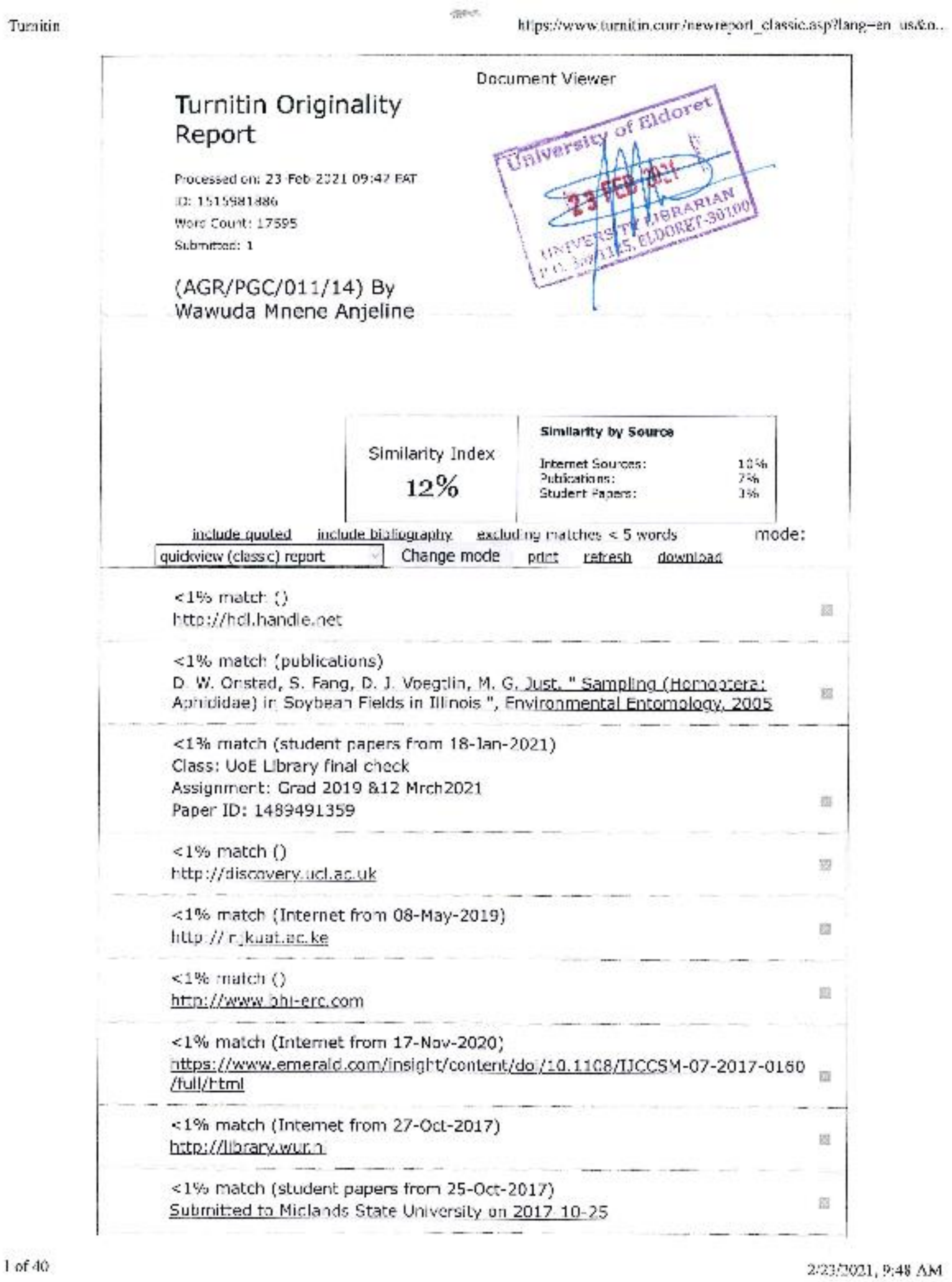
Effect	Num DF	Den DF	F Value	Pr > F
Treatment	3	6	12.24	0.0057
Date	11	22	3.47	0.0062

Differences of Treatment Least Squares Means* (Amaranth during the rainy season)

Treatment	Treatment	Estimate	Standard Error	DF	t Value	Pr > |t|	Adj P
Ash	Control	-0.5921	0.1636	6	-3.62	0.0111	0.0418
Ash	Karate	0.4855	0.2127	6	2.28	0.0626	0.2041
Ash	Neem	-0.0377	0.1839	6	-0.21	0.8442	0.9966
Control	Karate	1.0776	0.1937	6	5.56	0.0014	0.0058
Control	Neem	0.5543	0.1616	6	3.43	0.0140	0.0519
Karate	Neem	-0.5232	0.2112	6	-2.48	0.0479	0.1614

*Adjustment for Multiple Comparisons: Tukey-Kramer

Appendix XI: Similarity Index/Anti-Plagiarism Report



Turnitin https://www.turnitin.com/newreport_classic.asp?lang=en_us&o..

Document Viewer

Turnitin Originality Report

Processed on: 23-Feb-2021 09:42 EAT
ID: 1515981886
Word Count: 17595
Submitted: 1

(AGR/PGC/011/14) By
Wawuda Mnene Anjeline

Similarity Index
12%

Similarity by Source
Internet Sources: 10%
Publications: 7%
Student Papers: 3%

include quoted include bibliography excluding matches < 5 words mode: quickview (classic) report Change mode print refresh download

<1% match ()
http://hdl.handle.net

<1% match (publications)
D. W. Onstad, S. Fang, D. J. Voegtlin, M. G. Just. " Sampling (Homoptera: Aphididae) in Soybean Fields in Illinois ", Environmental Entomology, 2005

<1% match (student papers from 18-Jan-2021)
Class: UoE Library final check
Assignment: Grad 2019 &12 Mrch2021
Paper ID: 1489491359

<1% match ()
http://discovery.ucl.ac.uk

<1% match (Internet from 08-May-2019)
http://r.jkuat.ac.ke

<1% match ()
http://www.bhi-erc.com

<1% match (Internet from 17-Nov-2020)
https://www.emerald.com/insight/content/doi/10.1108/IJCCSM-07-2017-0160/full/html

<1% match (Internet from 27-Oct-2017)
http://library.wur.nl

<1% match (student papers from 25-Oct-2017)
Submitted to Midlands State University on 2017-10-25

1 of 40 2/23/2021, 9:48 AM