OCCURRENCE AND ABUNDANCE OF INSECT PESTS ON AFRICAN INDIGENOUS VEGETABLE VARIETIES UNDER DIFFERENT FERTILIZER TREATMENTS AND SEASONS IN KITALE, KENYA

BY

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DECLARATION

Declaration by the Candidate

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DEDICATION

I dedicate this work to my special and lovely parents Mr. and Mrs. Francis Omasaja who have been an encouragement and a pillar in my life. To my husband Solomon Omukatia, my daughter Precious Agape and Mrs. okalebo who were there to provide moral support and make me believe that I can make it in life even during trying moments.

ABSTRACT

African indigenous vegetables (AIVs) once wild are now among the plants domesticated and are increasingly popular in peoples' diet. Due to this, they have commercial potential and farmers use fertilizers and improved varieties to enhance their productivity all year round (both wet and dry seasons). Insect pests could be a major constraint to AIVs productivity yet little has been documented about them. It is therefore important to study how improved varieties, fertilizer application and seasonal changes affect the behavior of insect pests so that the best intervention strategies to deal with potential AIV insect pests can be identified. This research aimed at improving the productivity of AIVs by looking at how cultivar and fertilizer affects the occurrence and abundance of insect pests during the rainy and dry seasons. At KALRO- Kitale, three varieties of each of the three AIVs (amaranth, nightshade and spider plant) were planted under three different fertilizer treatments (manure, mavuno and no fertilizer) in a split plot field experiment. The insects that occurred were noted on 5 plants in each plot and their numbers recorded. The data was analyzed using SAS 9.4 and the means with significant differences separated using Tukey's test at 95% ($P<.05$). The diversity of insect pests associated with the AIVs included an array of hemipterans, coleopterans, dipterans and lepidopterans commonly found on leafy vegetables. Beetles and Bagrada bugs were common on spiderplants, while stink bugs and soldier beetles were only associated with Amaranth. Leafminers were associated with Nightshade and Amaranth. It was also evident that all pests with the exception of cotton strainers and soldier beetles, which were only observed during the rainy season, were common during both the rainy and the dry seasons. Aphids numbers were the highest recorded on all the AIVs during both seasons although with lower densities during the dry season, particularly on spiderplant. Fertilizer application did not significantly ($P<0.05$) affect the abundance of pests on Nightshade varieties. However, there was a significant ($P<0.05$) effect of fertilizer application on the abundance of insect pests on Amaranth and Spiderplant varieties. The abundance of aphids differed significantly among amaranth and nightshade varieties. In order to develop the best pest management strategy, it is vital to take into consideration the crop's ecosystem and the seasonal changes.

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LIST OF ABBREVIATIONS

AVRDC	Asian Vegetable Research and Development Centre
AIVs	African Indigenous Vegetables

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CHAPTER ONE

INTRODUCTION

1.1 Background of the study

A majority of the people in Sub-Saharan Africa fully depend on agriculture. However, most of the people in these countries are still food and nutritionally insecure and improving agriculture is the only remedy (Shiundu and Oniang'o, 2007). This supports the argument for more research in agriculture. Lenne (2000) stated that "Agricultural research is the best hope - the only hope - of winning the race between population and food". While food security ensures sufficient food required for a healthy life at all times, nutritional security ensures adequate nutrition in terms of proteins, energy, vitamins and minerals for all household members at all times. For a healthy life therefore, the food supplied should be adequately nutritious.

While staple foods eaten by Africans provide calories needed by the body for energy, they are very low in other nutrients and a diet that includes African indigenous vegetables (AIVs) will help to improve the nutrition. This is because AIVs contain nutrients such as proteins, vitamins, oils and minerals that are necessary for the health of a population (Adebooye and Opadobe, 2004). AIVs therefore, can play a big role in alleviating malnutrition (Afari-sefa *et al.,* 2012). As noted by Abukutsa-Onyango *et al*., (2005), the consumption and utilization of AIVs is one of the most direct and cheapest ways for children, lactating mothers, urban and rural poor to improve their nutritional health and income status, which can mainly be provided by AIVs that are eaten as side dishes with these staple foods (Kaya, 2012).

African Indigenous vegetables are derived from plants adapted to the local geography, hydrology and climate of a region (Smith and Eyzaguirre, 2007), and they have Africa as their primary or secondary center of origin (Abukutsa-Onyango, 2009). They have their natural habitat in sub-Saharan Africa (Smith and Eyzaguirre, 2007) where they have become part of food systems for generations. They are either grown or collected from the wild, and those that grow them, do so for home consumption and/or for use commercially (Owuor and Olaimer-Anyara, 2007).

AIVs have proven to be vital to food & nutritional security. However, research shows that their consumption in Sub-Saharan African is still low (Onim and Mwaniki, 2008); (Afari-Sefa *et al*., 2012). Kiminywe *et al.,* (2007) reported a decline in the consumption of AIVs as a result of lack of knowledge of the correct choice of foods and hence reduced dietary diversity. Smith and Eyzaguirre, (2007) indicated a decline in the production and consumption of AIVs as a result of the introduction of exotic vegetables. Ekesa *et al*., (2009) noted that some indigenous vegetables are at risk of extinction since they are being replaced by high yielding commercial vegetables. It is therefore evident that the productivity and consumption of AIVs is still low (Afari-Sefa *et al*., 2012), and there is need to improve their productivity.

Vegetables production can be constrained by insect pests (Patra *et al*., 2013) which attack the crops during all stages of development (Abate *et al*., 2000) and their loss can reach up to 100% as reported by James *et al*., (2010). However, due to the commercial potential of the AIVs, farmers are using production inputs such as fertilizer and improved varieties to ensure improved productivity of the AIVs. They are also producing them all year round to ensure their continued supply to the market. However the impact that this production practices may have on the insect pests of AIVs is not known. Efforts are therefore needed to mitigate insect pest problems if AIV production is to be improved. This research is aimed at improving the productivity of AIVs by looking at how fertilizer and varieties affect the diversity, occurrence and abundance of insect pests on a selection of locally popular AIV crops during the rainy and the dry seasons. The inferences obtained from this study may be useful in assessing the losses caused by the most common insect pests to AIV production, so that the most appropriate pest control strategies can be developed and deployed as part of a sustainable Integrated Pest Management (IPM) approach.

1.2 Statement of the problem

As indicated by Onim and Mwaniki (2008), AIVs are believed to be more stress tolerant since they are better adapted to the local growing conditions. They were once wild but are now domesticated and have commercial potential. Due to this, farmers use fertilizers and improved varieties to enhance their productivity all year round (both wet and dry seasons). In Kitale, AIVs are wildly grown and Insect pests could be a major constraint to their productivity yet little has been documented about them. There is also little information on the impact of seasonal changes and the production practices such as fertilizer application and use of improved varieties on the insect pests attacking these AIVs.

1.3 Justification

Pests and diseases are important agronomic constraints to the production of leafy vegetables including AIVs. They reduce crop yield and blemish the physical appearance of the vegetables thus reducing their market value (Oerke, 2005). In addition to constraining the current productivity of these crops, they also contribute to the loss of crop diversity (Adebooye and Opabode, 2004) since farmers will stop planting a crop that is attacked by pests. It is therefore, vital to focus research efforts on minimizing the damage by insect pests to the AIVs. This can be achieved by first studying the effect of season and agronomic practices such as improved crop varieties and fertilizer on the diversity, occurrence and abundance of the most common insect pests found on these crops.

1.4 Objectives

1.4.1 General objective

- To improve the productivity of African indigenous vegetables (AIVs) by managing insect pests.

1.4.2 Specific objectives

- To determine the effect of seasonal changes on the diversity, occurrence and abundance of insect pests of AIVs.
- To determine the effect of improved crop varieties and fertilizer application on the diversity, occurrence, abundance and population dynamics of insect pests of AIVs.

1.5 Research hypotheses

- The diversity, occurrence and abundance of the most common insect pests on AIVs will differ with changes in planting seasons
- The occurrence, abundance and population dynamics of insect pests on AIVs will be influenced by the use of Improved AIVs varieties and fertilizer application

CHAPTER TWO

LITERATURE REVIEW

2.1 Importance of African indigenous vegetables

African indigenous vegetables are not only vital for food and nutritional security, but are also easy to grow as they require minimum external inputs and so are particularly suitable for the resource poor (Abukutsa-Onyango *et al*., 2005). Though they respond well to external inputs, they can still be produced without or with less input such as fertilizers and pesticides. The consumption and utilization of AIVs is the most affordable way for the resource-poor to improve their nutritional and health status (Abukutsa-Onyango, 2007). Nutritional deficiencies lead to ill health especially to the infants, pregnant women, elderly and the sick. The nutrients needed to alleviate this problem can be obtained from locally available indigenous vegetables (Rubaihayo *et al*, 2003). This includes proteins, vitamins, oils and minerals (Adebooye and Opadobe, 2004).

The presence of secondary metabolites like alkaloids, oxalates and other phenolic compounds give AIVs health properties that are used as traditional medicine to cure various diseases (Abukutsa–Onyango, 2007; Pandey, 2011). AIVs have been widely used as traditional medicine. Additionally, the presence of non-nutrient bioactive physiochemicals in these vegetables protect against cardiovascular and other degenerative diseases (Kwenin *at al.,* (2011). Pandey (2011) noted that AIVs can help in the prevention of diseases such as cancer, diseases of the heart, liver, lung, stomach, intestine, spleen and skin, diabetes, diarrhea, rheumatism, nervous disorders, stroke, inflammation, fever, cough, cold and ulcer.

In addition to their nutritional and medicinal properties, AIVs are very important in the generation of income especially for the rural poor who produce them for sell to the urban population (Abukutsa–Onyango, 2007; Onim and Mwaniki, 2008). When sold to the urban population, AIVs usually fetch higher prices compared to exotic vegetables. AIVs are also a source of employment to those involved both in the production process and selling (Kwenin *et al*, 2011). As opposed to other crops such as grain crops, AIVs can be produced all year round as a result of their diversity (Alphone *et al*., 2002). They also grow very fast to meet the emergent food needs; some can be harvested 3-4 weeks after planting (Abukutsa-Onyango, 2007). Due to the popularity and the commercial potential of AIVs, more research should focus on improving their productivity.

2.2 African indigenous vegetables commonly grown in Kenya

Indigenous vegetables which include hundreds of species are an important component in the people's diet throughout sub Saharan Africa. The most commonly consumed AIVs in Kenya are spider plant, amaranth and nightshade (Kimiywe, 2007). Other AIVs grown in Africa include: Jews mallo (*Chorchorus spp*), cowpea (*Vigna unguiculata*), and pumpkin (*Cucurbita pepeo*).

2.2.1 Spider plant (*Cleome gynandra*)

Spider plant also called cat's whiskers belongs to the family Capparaceae, subfamily Cleomoideae. The leaves are eaten as a vegetable and are said to be more nutritious than most exotic vegetables such as cabbage and spinach. It contains nutrients such as vitamin A, C and minerals, and these nutrients are not significantly lost through boiling or cooking (Chweya and Mnzava, 1997). In addition to its use as a vegetable, spider plant also has other advantages. For example the presence of volatile oils in the leaves gives the crop the repellent/medicinal properties that can repel mites and livestock ticks (Nyalala and Grout, 2007). The vegetable is also known to have antimalarial properties, and also alleviate diseases like diphtheria, vertigo, headache, pneumonia, septic ears and stomach ailments, scurvy, marasmus, and can also be eaten by expectant mothers to ease childbirth by reducing the length of their labor (Chweya and Mnzava, 1997).

Spider plant grows well during warm seasons under irrigation and it performs best on sandy soils and at temperatures above 15^{o}C (www.infonet-biovision). Increasing soil fertility causes its crude protein content to increase; while B-carotene, ascorbic acid, iron content of the leaves and the harvest index are reduced (Chweya and Mnzava, 1997). Mishra *et al*. (2011) indicated that the crop, as a C4 plant, has the ability to survive in drier and hot environments. Its nutritional value varies depending on soil fertility, environment, plant type, plant age and the production techniques used. Presumably, pest population dynamics and species complexity also vary according to these factors since the pests feed on the crop. Ng'etich *et al*., (2012) noted that spider plant has insecticidal, antifeedant and pest repellant characteristics. However, there are some pests that are known to attack spider plant. Such include: pentatomids, locusts, nematodes, flea beetles, green vegetable bugs, cotton jassids and hurricane bugs (*Bagrada* spp.) (Chweya and Mnzava, 1997).

2.2.2 Amaranth (Amaranthus spp.)

Amaranth is a leafy vegetable belonging to the family Amaranthaceae. Its leaves and seeds are edible and are rich in nutrients such as proteins, vitamin and minerals such as iron and calcium (Blodgett and Swart, 2002). Its protein content as reported by Aderolu *et al*., (2013), is well balanced in amino acid such as lysine. Amaranth has a very high mineral requirement and prefers fertile and well-drained soils (Keller *et al*., 2004). Research has shown that amaranth has the ability to synthesize amino acids from a wide range of virtually unlimited and readily available primary materials such as water, carbon dioxide and atmospheric nitrogen (Fasuyi, 2007). Insect pests are one of the major constraints in amaranth productivity (Aderolu et al., 2013; Ogedegbe and Ezeh, 2015). Among the most important insect pests of amaranth are the leaf caterpillar (*Hymenia recurvalis*) and *Psara basalis* (Aderolu *et al*., 2013).

2.2.3 African nightshade (*Solanum spp.*)

Nightshade is a leafy vegetable in the family Solanaceae. Various species exist but the most consumed nightshades in Kenya include *Solanum villosum* mill, subsp miniatum (Bernth. ex Willd.) Edmonds and *Solanum sarrachoides* Sendtner (Masinde *et al*., 2006). The leaves of nightshade are rich in proteins, amino acids, fat, fibre, minerals such as calcium, iron and phosphorus, and vitamins such as vitamin A and C (Edmonds and Chweya, 1997) It grows well in soils rich in organic matter since it requires large quantities of nitrogen and other nutrients (Keller, 2004).

The nutritive value of nightshade varies with soil fertility, plant age, and plant type (Edmonds and Chweya, 1997), and this may have a significant effect on the pest population dynamics and species complexity. The roots of nightshade are sensitive to low soil moisture, and so they do well under irrigation during the dry periods (Keller, 2004). *Solanum* species are not well adapted to water stress (Masinde *et al*., 2006), and can be a host to aphids, potato leaf roll virus and *Phytophthora infestans* (Alverez and Surmnavasan 2005; Olanya *et al*., 2008). Nightshade is also eaten by ants, caterpillars and grasshoppers (Schippers, 1998).

Given the nutritional value and the commercial potential of amaranth, spider plant and nightshade, there is need for more research so as to ensure their continued and improved productivity.

2.3 Constraints to AIVs production

Constraints to AIVs production as listed by Abukutsa–Onyango (2007) include: poor seed quality, pests and diseases, drought, poor marketing channels, transport to the markets, lack of agronomic packages, perishability and neglect. Seed quality affects the germination of the crops. When the quality of the seed is poor, the germination will also be poor (Abukutsa–Onyango, 2007). The quality of the seed is affected by the agronomic practices used, the time of harvest and the seed processing procedures (Abukutsa–Onyango, 2007). Insect pests are a major constraint to vegetables production. Among the major insect pests of vegetables are diamond back moth and aphids (Patra *et al*., 2013). Other insect pests that may be of economic importance to vegetables production include: beetles, leaf miners, leafhoppers and whiteflies (James *et al*, 2010).

Insect pests reduce crop yield as a result of feeding that in turn reduce productivity. For example, flea beetles are chewing insects that leave numerous holes in the plant foliage.

Plants damaged in this manner are not attractive to consumers and fetch much less from the market. If flea beetles attacked a crop at the seedling stage, they would cause the death of that crop (Ulmer and Dosdall, 2005). Pests, apart from damaging the crops, increase the costs of production when measures are taken to control them. There is little information on the insect pest complexity of AIVs and this supports the need for more research to establish the insect pest complex of AIVs especially under the introduced production practices and different seasons. There is also little known about the amount of damage caused by insect pests on AIVs. It is therefore important to research on the most common insect pests of AIVs so that the amount of damage they cause on AIVs can later be identified and then minimized.

2.4 Seasonal occurrence and abundance of insect pests

The occurrence and abundance of insect pests varies from season to season with the changes in weather (Osman and Mahmoud, 2008). Weather changes affect the status of insect pests including their population dynamics, distribution, abundance and feeding behaviors (Khaliq *et al*., 2014). Different seasons reflect different weather conditions, for instance rainy seasons support vigorous plant growth that promote insect pest populations, while dry seasons typically have high temperature and low relative humidity that suppress insect populations.

Differences in abiotic factors especially high or low temperatures, affect the insect multiplication, diapauses, emergence, flight and dispersal rate (Khaliq *et al*., 2014). Where temperatures are high, insect development is also generally accelerated (Lastuvka, 2009). As noted by Asif *et al*., (2010), the population of leafhoppers increased with an increase in temperature and a decrease in relative humidity, while the population of aphids increased with decrease in temperature and relative humidity. On the other hand, high temperatures may change the nutritional quality of the vegetation causing pests to respond positively or negatively to food quality (Lastuvka, 2009). It can be difficult to predict the response of insect pests to increased temperatures since accelerated development may decrease the effectiveness of predators or decrease the reproductive capacity of smaller individuals.

In a study by Aderolu *et al*. (2013) to determine the occurrence and abundance of major insect pests associated with amaranth, it was evident that species diversity and abundance of insect pests varied from season to season. As indicated by Lastuvka (2009), changes in season may affect the quality of a crop, which in turn may result in more or less nutrients in a crop exposed to insect pests. The previous studies show that different pest species behave differently in different seasons and there is therefore need to establish the different behaviors of different pests in different seasons so that this information may be useful for pests' management. This supports the need for more research on the effect of seasonal changes on insect pests of AIVs.

2.5 Variety improvement and AIVs productivity

The genetic make-up of a plant influences its growth characters. Different varieties therefore may differ in their growth characters (Saijan *et al*., 2002). Crop varieties may differ in their leaf arrangement, chlorophyll content and activities of photosynthetic enzymes (Enujeke, 2013). Some crop varieties are known to resist pests and diseases (Ogedegbe and Ezeh, 2015). Most of the work on genetic improvement has been done to improve yield and resistance to diseases (AVRDC, 2008; AVRDC, 2003). However, there is little about AIVs resistance to insect pests. Given the commercial importance of amaranth, spiderplant and nightshade, it is therefore important to focus more research efforts on the effect of these improved varieties on insect pests of these vegetables.

2.8 Fertilizer application in crop production

Continuous cropping is gradually depleting soil fertility, and farmers are being forced to add fertilizers to improve and maintain soil fertility needed for sustained food production (Wesonga *et al*., 2002). Farmers also use fertilizers to supply essential mineral elements needed by the plants for their growth and development (Islam *et al*., 2011). For instance, application of fertilizers containing nitrogen, promote vegetative growth and the formation of the dark green color found in vegetables. Nitrogen is a constituent of chlorophyll and is essential for protein synthesis as noted by Wesonga *et al*., (2002). Fertilizers not only improve crop yield directly by supplying essential elements, but they can also improve crop yield indirectly through the improvement of soil physical and chemical properties. Improved chemical and physical properties of soil have a positive effect on the growth and development of the crops, which lead to, improved yield as stated by Mgbeze and Abu (2010).

Fertilizers that affect the vigor of a plant also favor pests and diseases attacking these parts. For instance, when nitrogen promotes lush vegetative growth, it can create a micro-climate favorable for the pests (Ogedegde and Ezeh, 2013). Nitrogen supplied to the crop promotes vegetative growth of the crop and pests find the leaves of these crops succulent and fresh (Asawalam *et al*., 2004). The use of fertilizers in AIVs production may as well create the microclimate that would favor insect pests yet little is documented about it. This supports the need for more research on the effect of fertilizer application on the insect pests of AIVs and their effects on AIVs production.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Site description

An on-farm experiment was done at Kenya Agricultural and Livestock Research Organization (KALRO), Kitale centre. Kitale is located in Trans-Nzoia County, which is part of the lower highland agro-ecological zone, lying between 1800-2400m above sea level. It has an annual mean temperature of between 15°C and 18°C. It lies in the latitude 1°N and longitude 35°E. Kitale receives an average rainfall of 1143 mm per annum, which is fairly distributed. The soils are ferralsols, which are well drained and responsive to nitrogen fertilizers (DAO, 1999-2005).

Figure 3.1: Kitale map. Source:http://www.tiptopglobe.com/city-map/kenya/kitale-population-location-town

3.2 AIVs studied

Three AIVs (spider plant, nightshade and amaranth) were planted during the long rains of 2013 (May – July) and the dry season of 2014 (January - February).

Nightshade *(Solanum ssp)*, *(***source; author)**

Spiderplant *(Cleome spp)* **(source; author)**

Amaranth *(Amaranthus ssp)* **(source; author)**

3.3 Treatments

Three varieties of each AIV species were planted to determine the effect of crop variety on the occurrence and abundance of pests. Likewise, the effect of fertilizer on the occurrence and abundance of insect pests on the AIVs was determined by applying three different fertilizer treatments (no fertilizer (control), mavuno fertilizer and chicken manure). Mavuno fertilizer was obtained from the local market while chicken manure was obtained from a farmer in Elgon view estate in Eldoret. 400g of mavuno fertilizer and 4.2kg of chicken manure were applied per plot at planting time (500kg/ha of mavuno and 5,250 kg/ha of manure). Drip irrigation was only done during the dry season.

AIV VARIETIES

NIGHTSHADE	**SPIDER PLANT**	**AMARANTH**
N1= BG-16	**S1**= ML SF-29	**A1**= EX-ZIM
N2= SS49	**S2**= UG-SF-15	**A2**= UG-AM-40
N3= LV-NS (local)	**S3**= LV-SP (Local)	**A3**=LV-AM (Local)

FERTILIZER TREATMENTS

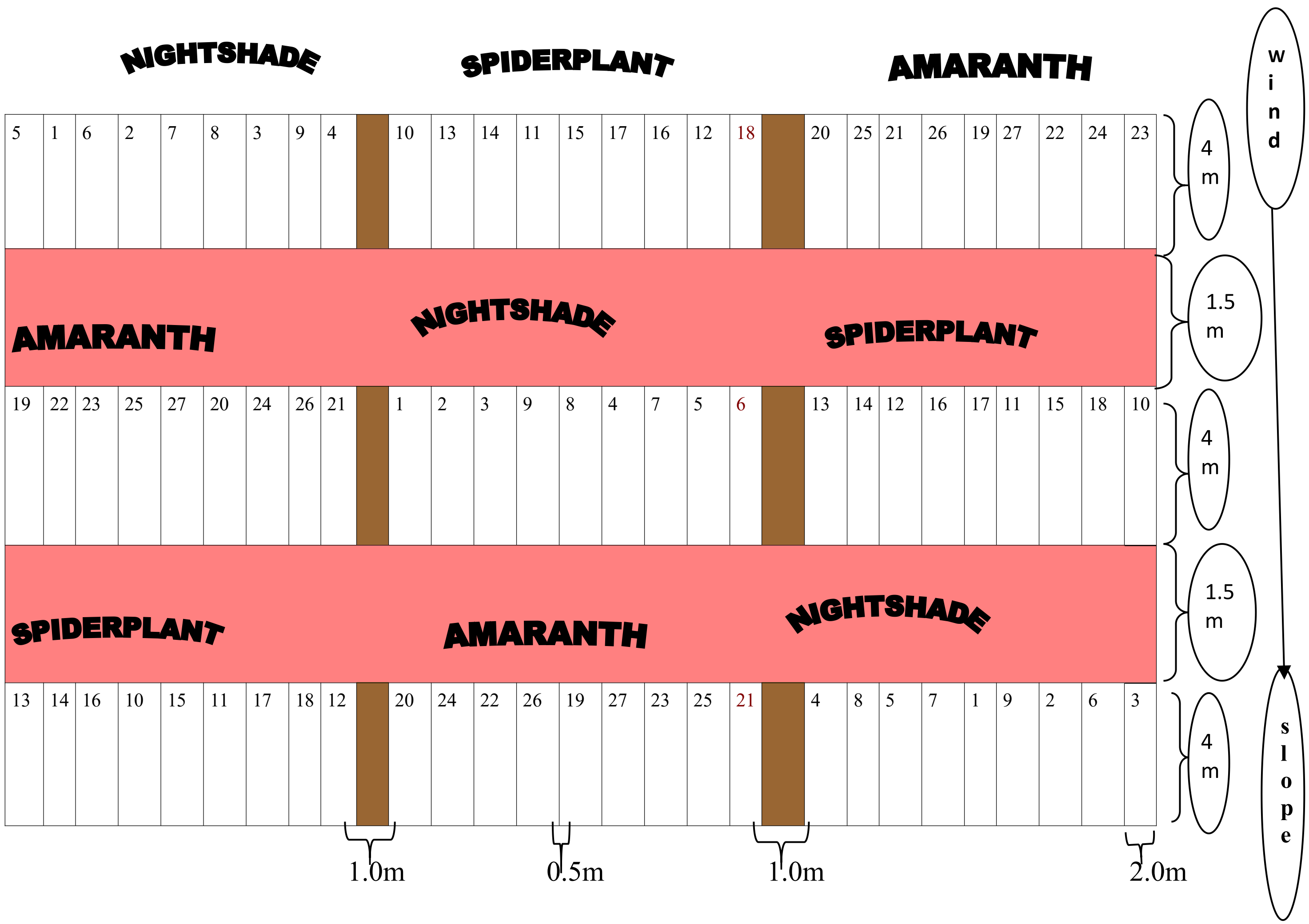
F0=NO FERTILIZER (CONTROL), **F1=** MAVUNO, **F2=** CHICKEN MANURE

KEY TO TREATMENTS

1= N1*F0	**10=** S1*F0	**19 =**A1*F0
2= N2*F0	**11**=S2*F0	**20** =A2*F0
3= N3*F0	**12**=S3*F0	**21** =A3*F0
4= NI*F1	**13**=S1*F1	**22 =**A1*F1
5= N2*F1	**14=** S2*F1	**23**=A2*F1
6= N3*F1	**15**=S3*F1	**24**=A3*F1
7= N1*F2	**16=** S1*F2	**25**=A1*F2
8= N2*F2	**17**=S2*F2	**26=** A2*F2
9 =N3*F2	**18=** S3*F2	**27** =A3*F2

3.4 Experimental design

The experiment was a split plot in a randomized complete block design (RCBD) whereby the AIV varieties formed the main plots, as the three fertilizer treatments formed the sub-plots. Each sub-plot measured 4m by 2m, and the spacing of plants between the rows was 60 cm for all species. The spacing between spider plants was 40 cm, and 25 cm between the black nightshade plants and amaranth plant.



Field layout (1-27=treatments)

3.5 Crop management

In addition to varieties, fertilizer and irrigation, other crop management practices included thinning during early plant growth and weeding. Plants were thinned when they had developed three true leaves (this was two weeks from emergence). Weeding was done manually as long as weeds were found to ensure field hygiene, which was usually every two weeks. Crops were harvested every two weeks to prevent them from early flowering and ensure enough time to collect data on vegetative growth. However, the first harvest was done two weeks after thinning.

3.6 Data collection

Five plants randomly selected from the 2 middle rows of each plot were observed for the presence or absence of insect pests. Each of the 5 plants was critically examined to determine the specific species of insect pests and their corresponding abundance. Unknown insects were collected, given provisional names and kept in vials containing 70% alcohol for later identification at the National Museum of Kenya. The 70% alcohol as recommended by Millar *et al.,* (eds) (2000), acted as a general killing and preserving agent.

Insect pest abundances were determined in the field through direct *(in situ)* visual counts. Five plants randomly selected from the two middle rows of each plot were examined for pest counts. All pests on the plant were counted every week beginning one week after crop emergence up to flowering. Pest counts were done early in the morning while temperatures were still comparatively mild. It was at this time that the insects were relatively inactive and the plant could be held by hand and also bent to note the pests from all the parts. Enumeration of some insects such as aphids was by sub sampling whereby their numbers on one leaf was counted and multiplied by the number of leaves containing them. When the number of aphids on a leaf was particularly large, the leaf was divided into portions of two or four parts, and the aphids on one portion was counted and multiplied by the number of portions then by the number of leaves to arrive at the abundance per plant.

3.7 Data analysis

Experimental results from the field were analyzed using the statistical analysis program SAS 9.4. A PROC MIXED model was selected to measure the response of insect pest densities (response variable) to variety, fertilizer and time (all fixed-effect parameters, e.g., categorical variables) for each AIV crop species once during the rainy season and once during the dry season. More zero values were observed in the data than normally expected in a poisson distribution, so to avoid a zero-inflated poisson model, the numbers observed summed across all 5 plants sampled in each replicate were used to reduce the number of zero values in the data. Responses were normalized by adding 0.5 to each observation then transformed by taking their square root. Replicates were treated as random effects in the model, while time was treated as a repeated measure using the AR (autoregressive) covariance structure type. Means comparisons were done using the Tukey-Kramer method.

CHAPTER FOUR

RESULTS

4.1 The common insect pests of amaranth, nightshade and spider plant

The insect pests associated with amaranth, nightshade and spider plant included an array of hemipterans, coleopterans, dipterans and lepidopterans commonly found on leafy vegetables. Insect pests such as aphids, caterpillars, leafhoppers and whiteflies were common to all the three AIVs, while others were associated with only one or two of the AIV species. For instance, flea beetles and Bagrada bugs were only found on spider plants, while stink bugs and soldier beetles were only associated with amaranth. Leafminers were associated with nightshade and amaranth. It was also evident that all insects with the exception of cotton stainers and soldier beetles, which were only observed during the rainy season, were common during both the rainy and the dry seasons (Table 4.1). Photographs of the common insect herbivores found on amaranth, nightshade and spider plant are included in the appendix (appendices 1-3)

Table 4.1: Common insect pests found on AIVs during the rainy and dry seasons

Pest	Specific names	Season of Occurrence	AIV crop attacked
Aphids (Hemiptera: Aphididae)	*Myzus persicae*	Rainy and dry	Amaranth, Spider plant and Nightshade
Flea beetles (Coleoptera: Chrysomelidae)	*Phyllotreta undulata Phyllotreta spp*., *Luperodes exclamationis,*	Rainy and dry	Spider plant
Caterpillars (Lepidoptera: Noctuidae, Cramidae)	*Sameodes cancellalis, Plusia spp., Helicoverpa armigera*	Rainy and dry	Amaranth, Spider plant and Nightshade
Bagrada bugs (Hemiptera: Pentatomidae)	*Bagrada hilaris*	Rainy and dry	Spider plant
Leafminers (Diptera: Agromyzidae)	*Liriomyza spp.*	Rainy and dry	Amaranth and Nightshade
Leafhoppers (Hemiptera: Cicadellidae)		Rainy and dry	Amaranth, Spider plant and Nightshade
Cotton stainers (Hemiptera: Pyrrhocoridae)	*Dysdercus nigrifasciatus*	Rainy	Amaranth, Spider plant and Nightshade
Stink bugs (Hemiptera: Pentatomidae)	*Cletus orientalis, C. ochraceous*	Rainy and dry	Amaranth
Whiteflies (Hemiptera: Aleyrodidae)	*Bemisia spp.*	Rainy and dry	Amaranth, Spider plant and Nightshade
Soldier beetles (Coleoptera: Cantharidae)	*Silidius breviapicalis, S. apicalis*	Rainy	Amaranth
Mirid (Hemiptera: Miridae)	*Deraeocoris ostentans*	Dry	Amaranth, Spider plant and Nightshade

4.2 Abundance of insect pests on AIVs during the rainy and dry season

The occurrence and abundance of insect pests on AIVs differed from season to season and from AIV species to another (Table 4.2). Aphids occurred throughout the year on all the three AIVs but were much more abundant during the rainy season compared to the dry season. Some pests were more abundant on one AIV species compared to the other. Flea beetles for instance were more abundant on spider plant compared to amaranth and nightshade as were leafminers on amaranth during the rainy season, and whiteflies and leafhoppers on amaranth and spider plants during the dry season (Table 4.2)

Table 4.2: Abundance of common insect herbivores found on AIVs during the rainy and dry seasons

	Rainy season (2013)			Dry season (2014)		
Insect pest	**Amaranth**	**Nightshade**	**Spider plant**	**Amaranth**	**Nightshade**	**Spider plant**
Aphids	+++++	++++	+++++	++++	+++	+++
Flea beetles	+	+	++++	++	+	+++
Leafminers	++	+		++		
Leafhoppers		++	++	+++	+++	+++
Grasshoppers	++	++	++			
Whiteflies	+	++	+	+++	++	+++
Caterpillars	+	++	++	+	+	++
Stink bugs	++		+	+	+	+
Mirids				++	++	++

(+++++ = >10/plant/season, ++++ = >1 <10, +++ = >0.1 < 1, ++ = >0.01 <0.1, + < 0.01,

blank = no score)

Aphids were the most abundant insect pest recorded on all the three AIVs during both seasons although with lower densities during the dry season (Tables 4.2). During the rainy season, there were more aphids on amaranth (>10 aphids/plant) and spider plant(>10 aphids/plant) compared to nightshade (>1<10 aphids/plant). There were more flea beetles on spider plant during both the rainy and the dry seasons (>1<10 flea beetles/plant). The number of leaf hoppers recorded on all the AIVs were more during the dry season (>0.1 < 1 leaf hoppers/plant) compared to the rainy season where >0.01 <0.1 leaf hoppers/plant were recorded on nightshade and spider plant. There were no leaf hoppers on amaranth during the rainy season (Table 4.2)

4.3 Abundance of pests on Nightshade varieties

During the rainy season, only aphids showed a significant difference in abundance between nightshade varieties. The local nightshade variety had the lowest mean population of aphids (4.35 aphids per plant) compared to 12.1 and 11.4 for the improved varieties, BG-16 and SS-49, respectively (Table 4.3). There was no significant effect of fertilizer on the abundance of insect pests on the nightshade varieties. During both seasons, the interaction between variety and fertilizer did not show any significant effect on the abundance of pests.

Table 4.3: aphids population means on nightshade varieties during the rainy season (2013)

Variety	Aphids
NS LOCAL	4.35a
NS BG-16	12.07b
NS SS-49	11.42b

NB: means followed by the same letters along the column are not significantly different (P<0.05)

4.4 Abundance of pests on Amaranth varieties

The abundance of aphids was significantly different between amaranth varieties during the rainy season. UG-AM-40 had significantly (P<0.01) fewer aphids (28.2 aphids per plant) compared to the local (41.2 aphids per plant) and EX-ZIM (46.9 aphids per plant). During the dry season, the abundance of leafhoppers was significantly different among amaranth varieties. The local variety had significantly more leafhoppers per plant (0.49) compared to the improved variety UG-AM-40 (0.19), but similar to the improved variety EX-ZIM (table 4.4.1).

There was a significant difference on the abundance of aphids and leafhoppers on the amaranth varieties under different fertilizer treatments only during the dry season. Amaranth plots treated with manure and mavuno had significantly more aphids (2.73 and 2.00 aphids per plant, respectively) compared to plots without fertilizer (Table 4.4.2). However, plots treated with mavuno were not significantly different from plots treated with manure. Similarly, leafhoppers were significantly higher on plots treated with fertilizer compared to plots without fertilizer treatment (Table 4.4.2).

Table 4.4.1: Pest population means of Amaranth varieties during the rainy season (2013)

Variety	Aphids
AM LOCAL	41.21a
AM EX-ZIM	46.85a
AM UG-AM-40	28.23b

NB: means followed by the same letters along the column are not significantly different (P<0.05)

Table 4.4.2: Pest population means of Amaranth varieties under different fertilizer treatments during the dry season (2014)

Fertilizer	Aphids	Leafhoppers
Control	0.27a	0.15a
Mavuno	2.00b	0.49b
Manure	2.73b	0.41b

NB: means followed by the same letters along the column are not significantly different (P<0.05)

4.5 Abundance of pests on Spiderplant varieties

There was no significant difference on the abundance of insect pests on the Spiderplant varieties during both the rainy and dry seasons. However, fertilizer significantly affected the abundance of aphids, flea beetles and leafhoppers during the rainy season and of leafhoppers and whiteflies during the dry season.

The populations of aphids were significantly lower on plots without fertilizer (2.67 aphids per plant) compared to plots treated with mavuno (14.56 aphids per plant) and manure (13.21 aphids per plant) (Table 4.5.1). Similarly, populations of flea beetles and leafhoppers were significantly lower on plots without fertilizer as compared to plots treated with fertilizer. Populations of leafhoppers and whiteflies during the dry season were significantly lower on plots without fertilizers. Leafhopper numbers in plots treated with mavuno (0.2 per plant) or manure (0.18 per plant) were similar, greater than numbers found in the control plots. Whiteflies showed a similar pattern with higher numbers found on plots treated with mavuno and manure compared to the control(Table 4.5.1). The interaction between variety and fertilizer did not significantly affect the abundance of pests during both the rainy and the dry season.

Table 4.5.1: Pest population means of Spiderplant varieties under different fertilizer treatments during the rainy season (2013)

Fertilizer	Aphids	Flea beetles	Leafhoppers
Control	2.67b	0.627b	0.02a
Mavuno	14.56a	3.98a	0.08b
Manure	13.21a	3.533a	0.06b

NB: means followed by the same letters along the column are not significantly different (P<0.05)

Table 4.5.2: Pest population means of spiderplant varieties under different fertilizer treatments during the dry season (2014)

Fertilizer	Leafhoppers	Whiteflies
Control	0.09a	0.19a
Mavuno	0.20b	0.62b
Manure	0.18b	0.54b

NB: means followed by the same letters along the column are not significantly different (P<0.05)

4.6 Insect pest population dynamics during the rainy and dry seasons

Aphids numbers were the highest recorded on all the AIVs during both seasons although with lower densities during the dry season, particularly on spiderplant. During the early stages of crop development, all AIVs recorded low number of pests. Most insect pest populations increased over the period of observation with the notable exception of aphids and to some degree, leafminers. The populations of aphids in figures 4.3.1a, 4.3.2a, 4.3.2c and 4.3.3a are starting at low numbers and increase gradually to their peaks at the 7^{th}, 5^{th}, 3^{rd} and 6^{th} counts respectively. However, as observed in figures 4.6.1-4.6.5, a common trend of fluctuation in the pest population is observed.

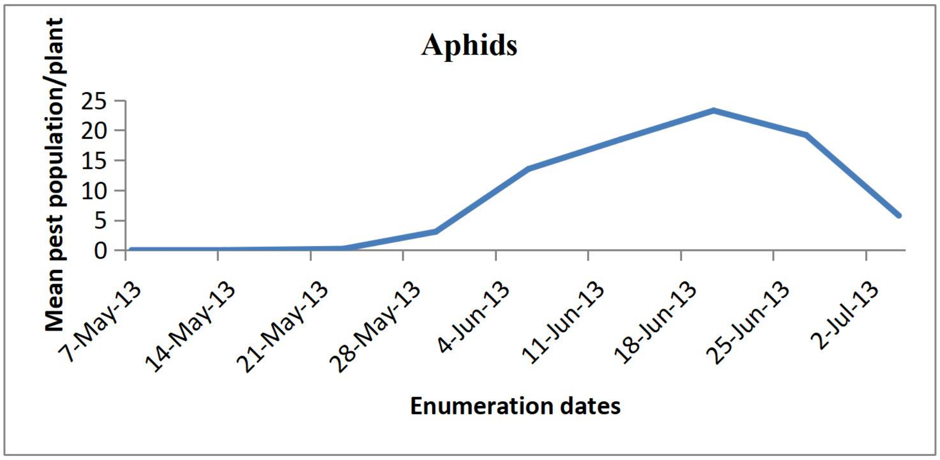


Figure 4.6.1: Aphids population dynamics on nightshade during the rainy season

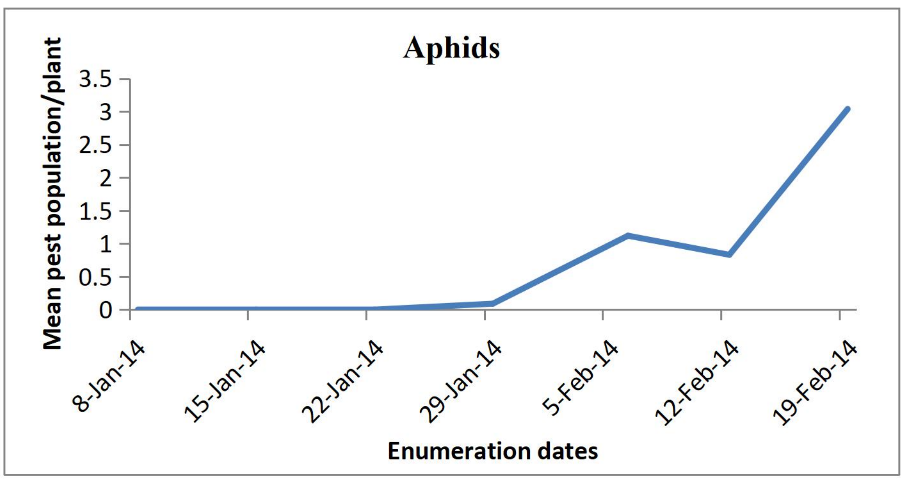


Figure 4.6.2: Aphids population dynamics on nightshade during the dry season

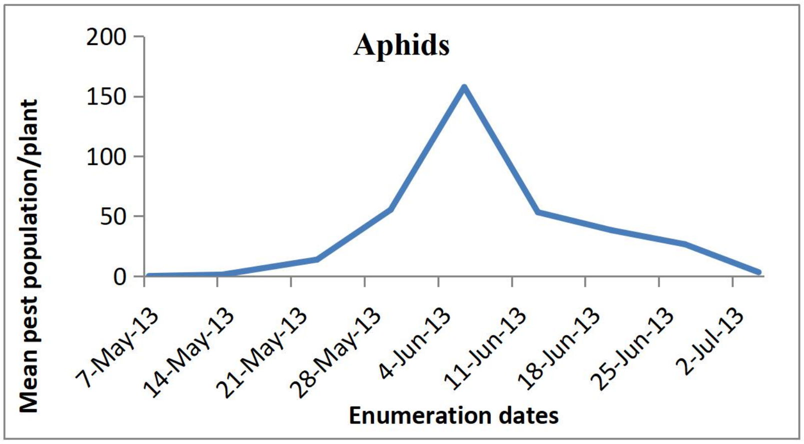


Figure 4.6.3: Aphids population dynamics on amaranth during the rainy season

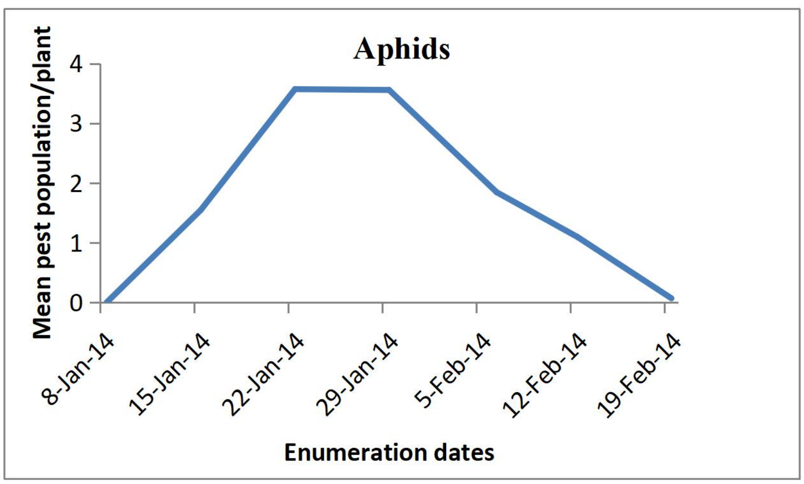


Figure 4.6.4: Aphids population dynamics on amaranth during the dry season

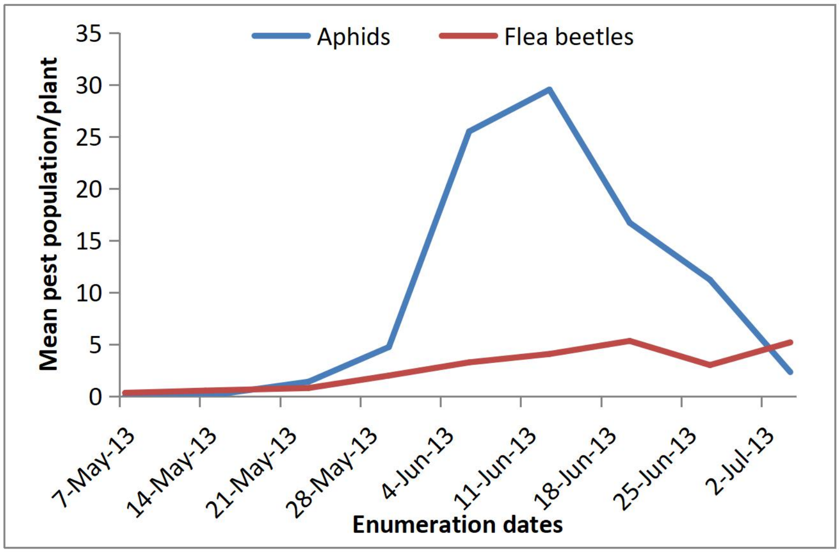


Figure 4.6.5: Aphids and flea beetles population dynamics on spider plant during the rainy season

CHAPTER FIVE

DISCUSSION

5.1 Common insects of amaranth, nightshade and spider plants

The diversity of insect pests found associated with local amaranth, nightshade and spider plant varieties included an array of hemipterans, coleopterans, dipterans and lepidopterans commonly found on other leafy vegetables. In a study by Aderolu *et al*., (2013), the insect pests found associated with amaranth included coleopterans, dipterans, hemipterans, hymenoperans, lepidopterans, orthopterans and thysanopterans. hemipterans, coleopterans, dipterans and lepidopterans, were common to both studies with exceptions of hymenopterans, orthopterans and thysanopterans. This could be attributed to the difference in the study areas and production practices which were employed in this study.

5.2 Occurrence and abundance of insects on AIV varieties

Common insects found on AIVs differed between varieties as well as between crops. Different varieties have different genotypes that could lead to differences in tastes that cause insects to prefer one variety over another. These results differ from the findings by Ganie *et al*., 2013 who showed that local crop varieties do not show satisfactory resistance to insect pests while hybrid varieties are resistant. In this study, some local varieties and some improved varieties showed no resistance at all. Some local varieties were liked by insects compared to others. As indicated by Patra *et al*., 2013, the incidence of insects depends on the suitability of the host and the climatic conditions. From the findings of this study, it is evident that different AIV varieties interact differently with the environment to affect insect populations. For instance there were more generally aphids during the rainy season than the dry season regardless of AIV crop.

5.3 Abundance of insects on AIVs under different fertilizer treatments

The effect of fertilization on the abundance of insects was evident for all the three AIV crops evaluated during the rainy season and for amaranth and spider plants during the dry season. The plots treated with either mavuno or manure had the highest numbers of insects. As noted by Altieri and Nicholls (2003), fertilization affects the quality of the plant, and in turn affects the abundance of insects on the crop. Different fertilizers affect the quality of crops differently and hence their effect on the abundance of insects differs. Altieri and Nicholls (2003) indicated that the use of chemical fertilizers creates nutrient imbalance in the crop which in turn reduces resistance to insects while the organic fertilizers which supply both secondary and trace elements to the crop stimulates resistance to insect attack. In this study, there was no measurable difference between mavuno and manure treatments when they showed a positive effect compared to the control. This could be because both mavuno and manure fertilizers supplied the same amount of nitrogen to the crops which is essential for the vegetative growth of the crops making them have more lush better and able to harbor more insects.

Seasonal differences affected the effect of fertilizer on the abundance of insects on the AIV varieties. As evident from the results obtained from amaranth varieties during the dry season where plots treated with fertilizers had significantly higher densities of leafhoppers and aphids. This difference is realized because of the harsh conditions of the dry season, which are stressful to the crop. However, the addition of fertilizer ensures that the crops are well nourished despite the harsh conditions such as high temperatures and low humidity that can affect the crop's development.

5.4 Occurrence and abundance of insects on AIVs during the rainy and dry seasons

Rainfall varies from season to season and therefore, the occurrence and abundance of insects often reflect this variation. The rainy season is wet, humid and cool while the dry season is dry, non-humid and hot. The results obtained from this study indicated that aphids and flea beetles were substantially more abundant during the rainy season, while other insects, e.g., whiteflies, leafhoppers and mirids were marginally more abundant during the dry season. Differences in weather conditions can alter the physiological susceptibility of crops and make them more favorable for insects to multiply (Karuppaiah and Sujayanad 2012).

Some, insects may find it conducive to thrive during the rainy season yet others thrive well during the dry season. In a study by Aderolu *et al* (2013), they found out that differences in seasons affected the abundance of insect pests of amaranths. This concurs with the findings of this study, which revealed that seasonal changes affected the abundance of insect pests on the AIVs. From the results of this study, the aphid densities on all AIV crops evaluated and flea beetles on spider plants were high during the rainy season as compared to the dry season. This was not in line with the results obtained by Shivana *et al*., (2011) which indicated that the population of aphids and whiteflies was positively correlated with maximum temperatures and negatively correlated with minimum temperatures and rainfall. The difference in these results could be attributed to the fact that during the rainy season the crop tissues are soft as compared to the dry season when they are tough due to harsh weather conditions. As indicated by Karuppaiah and Sujayanad (2012), changes in environment may also affect insect populations indirectly by altering the host's physiology. Aphids are sucking insects and it is easier for them to probe plant tissue that is soft. When feeding has been made easier, the insects reproduce and multiply easily. Soft plant tissues also make it easier for insects with biting and chewing mouthparts such as flea beetles to feed. It is therefore possible that during the rainy season, the population of most insects could increase compared to the dry season. It is also during the dry season that the life cycle of the crop is short thus shortening the breeding period of the insects leading to lower numbers recorded.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

6.1.1 All the three African indigenous vegetables in this study were attacked by insect pests whose diversity included an array of hemipterans, coleopterans, dipterans and lepidopterans.

6.1.2 The occurrence and abundance of insect pests of the AIVs in this study differed from one season to another.

6.1.3 The occurrence and abundance of insects pests of AIVs was affected by fertilizer application.

6.1.4 The abundance of insect pests of the three AIVs differed from one variety to another.

6.2 Recommendations

6.2.1 Farmers use fertilizers in AIVs production should carry out frequent monitoring for insect pests and manage them

6.2.2 Its recommended that farmers produce AIVs under irrigation during the dry season when pest infestation is low for better yields.

6.2.3 It’s recommended that farmers should consider planting amaranth variety- UG-AM-40 and nightshade variety - local since they show low levels of insect pest infestation

6.3 Further research

6.3.1 More research should be done in order to determine crop loss as a result of insect pest attack

6.3.2 Pest management strategies for major insect pests of AIVs should be established to help manage the insect pests of AIVs

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APPENDIX

Appendix I

Common insect pests of Nightshade

Plate 1a: Leafhopper (Source; Author, 2013)

Plate 1b: Caterpillar(Source; Author, 2013)

Plate 1c: Leafminers(Source; Author,2013)

Plate 1d: Soldier beetle(Source; Author, 2013)

Appendix II

Common insect pests of Amaranth

Plate 2a: Aphids(Source; Author, 2013)

Plate 2b: Leafminers (Source; Author,2013)

Plate 2c: Whiteflies(Source; Author,2013)

Plate 2d: Stink bugs(Source; Author,2013)

Appendix III

Common insect pests of Spider plant

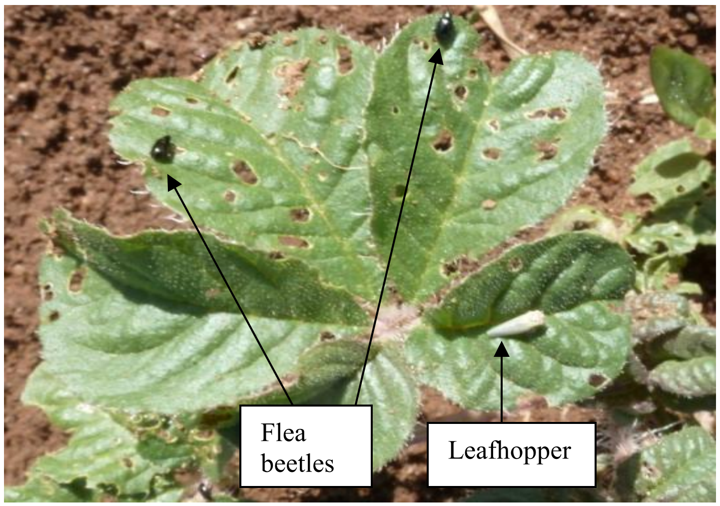

Plate 3a: Flea beetles and Leafhopper(Source; Author,2013)

Plate 3b: Caterpillar (Source; Author,2013)

Plate 3c: Bagrada Bug (Source; Author,2013)

Plate 3d: Aphids (Source; Author,2013)

Appendix IV

Type 3 tests of fixed effects for aphids on nightshade during the rainy season (2013)

Effect	**Num DF**	**Den DF**	**F Value**	**Pr > F**
Fert_type	2	151	6.28	0.0024
Variety	2	151	8.53	0.0003
Variety*Fert_type	4	151	0.52	0.7184
Time.	8	151	28.69	<.0001
Time*Fert_type	16	151	2.82	0.0005
Time*Variety	16	151	2.03	0.0146
Time*Variety*Fert_type	32	151	0.74	0.8437

Appendix V

Type 3 tests of fixed effects for aphids on nightshade during the dry season (2014)

Effect	**Num DF**	**Den DF**	**F Value**	**Pr > F**
Fert_type	2	124	2.05	0.1336
Variety	2	124	0.74	0.4811
Variety*Fert_type	4	124	0.59	0.6674
Time.	6	124	1.18	0.3196
Time*Fert_type	12	124	0.68	0.7684
Time*Variety	12	124	0.65	0.7913
Time*Variety*Fert_type	24	124	1.29	0.1837

Appendix VI

Type 3 tests of fixed effects for aphids on amaranth during the rainy season (2013)

Effect	**Num DF**	**Den DF**	**F Value**	**Pr > F**
Fert_type	2	160	4.25	0.0160
Variety	2	160	6.65	0.0017
Variety*Fert_type	4	160	0.73	0.5731
Time.	8	160	69.08	<.0001
Time*Fert_type	16	160	4.50	<.0001
Time*Variety	16	160	1.89	0.0251
Time*Variety*Fert_type	32	160	0.64	0.9298

Appendix VII

Type 3 tests of fixed effects for aphids on amaranth during the dry season (2014)

Effect	Num DF	Den DF	F Value	Pr > F
Fert_type	2	124	5.86	0.0037
Variety	2	124	15.40	<.0001
Variety*Fert_type	4	124	1.56	0.1882
Time.	6	124	4.64	0.0003
Time*Fert_type	12	124	1.41	0.1720
Time*Variety	12	124	1.83	0.0509
Time*Variety*Fert_type	24	124	0.48	0.9802

Appendix VIII

Type 3 tests of fixed effects for aphids on spider plant during the rainy season (2013)

Effect	Num DF	Den DF	F Value	Pr > F
Fert_type	2	136	11.67	<.0001
Variety	2	136	0.06	0.9459
Variety*Fert_type	4	136	0.84	0.5028
Time	8	136	16.22	<.0001
Time*Fert_type	16	136	1.65	0.0652
Time*Variety	16	136	0.75	0.7418
Time*Variety*Fert_type	28	136	0.75	0.8130

Appendix IX

Type 3 tests of fixed effects for aphids on spider plant during the dry season (2014)

Effect	Num DF	Den DF	F Value	Pr > F
Fert_type	2	124	0.92	0.3994
Variety	2	124	0.05	0.9520
Variety*Fert_type	4	124	0.14	0.9681
Time	6	124	1.03	0.4060
Time*Fert_type	12	124	1.14	0.3355
Time*Variety	12	124	0.52	0.8983
Time*Variety*Fert_type	24	124	0.72	0.8239

Appendix X

Type 3 tests of fixed effects for flea beetles on spider plant during the rainy season (2013)

Effect	**Num DF**	**Den DF**	**F Value**	**Pr > F**
Fert_type	2	136	39.18	<.0001
Variety	2	136	0.05	0.9518
Variety*Fert_type	4	136	0.59	0.6716
Time	8	136	22.51	<.0001
Time*Fert_type	16	136	3.97	<.0001
Time*Variety	16	136	0.85	0.6268
Time*Variety*Fert_type	28	136	0.92	0.5815

Appendix XI

Type 3 tests of fixed effects for flea beetles on spider plant during the dry season (2014)

Effect	**Num DF**	**Den DF**	**F Value**	**Pr > F**
Fert_type	2	124	0.39	0.6811
Variety	2	124	4.19	0.0173
Variety*Fert_type	4	124	0.70	0.5920
Time	6	124	1.40	0.2212
Time*Fert_type	12	124	0.49	0.9149
Time*Variety	12	124	0.54	0.8867
Time*Variety*Fert_type	24	124	1.07	0.3847