An integrated pest management approach of amaranth insect pests in Buuri District, Meru County, Kenya

Robert Nesta Kagali

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DECLARATION

This research thesis is my original work and has not been presented in any other institution for a degree award.

Signature: ______________________ Date: _______________________

KAGALI ROBERT NESTA

Declaration by Supervisors

This research thesis has been submitted for examination with our approval as supervisors.

Signature: ______________________ Date: _______________________

DR. ZIPPORAH OSIEMO LAGAT

JKUAT, Kenya

Signature: ______________________ Date: _______________________

DR. SHADRACK MUYA

JKUAT, Kenya

Signature: ______________________ Date: _______________________

DR. ESTHER KIOKO

National Museums of Kenya

DEDICATION

This work is dedicated to my late cousin Patson Davis whom we have gone through thick and thin of this world. Above all, to Almighty God, the source of everything that I am.

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Great praise goes to Almighty God for giving me good health, sound mind and guiding every step of the way in the pursuit of knowledge.

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ABBREVIATIONS AND ACRONYMS

ALVs	African Leafy Vegetables
ASAL	Arid and Semi-Arid Land
Bt	*Bacillus thuringiensis*
F.A.O.	Food Agricultural Organization
IPM	Integrated Pest Management
J.K.U.A.T	Jomo Kenyatta University of Agriculture and Technology
K.A.P.A.P	Kenya Agricultural Productivity and Agribusiness Project
MUCST	Meru University College of Science and Technology
NMK	National Museums of Kenya
PCQ	Point-Centered Quarter

ABSTRACT

Production of amaranth is hampered by insect pests which reduce the yields considerably. The control of these pests is mainly through the use of pesticides, but their intensive usage has resulted in major environmental pollution and direct toxicity to humans, non-target insects and other mammals. Therefore, there is need to develop a pest control strategy that poses little or no risk to environment, man and other non-target organisms. The focus of this research was to identify amaranth pests and their natural enemies since correct pest identification forms the basis of any efficient integrated pest management. This research consisted of both ex-situ and in-situ experiments. The ex-situ research was conducted in Buuri District, Meru County where sampling was done using stratified random method. Surveys of insect pests were done on randomly selected farms from farmers who were growing amaranth in Meru County between April 2012 and April 2013 using Point-Centered Quarter Method to determine their diversity and abundance. The insects were collected by hand, sweep nets, knock down and pit-hole techniques depending on the type of insect. The effects planting dates, amaranth varieties, use of botanical pesticides on insect pest population were investigated on in-situ plots at Meru University College of Science and Technology. A total of 1256 specimens were collected, stored in alcohol, pinned on boards, identified and archived at National Museums of Kenya, Nairobi. Insect pests were classified into 5 orders, 15 families and 33 species with the most damaging insects being *Cletus* sp. (Heteroptera) which attacks the grain causing up to 40% loss, *Hepertogramma bipunctalis* (Lepidoptera) which feeds on stems and leaves resulting to 27% yield loss and *Hypolixus nubilosus* (Coleoptera) which also causes stem and leaf damage. The important natural enemies were grouped into 2 orders, 5 families and 8 species. There are diverse insect pests attacking amaranth causing considerable damage to yield of leaves, stems and grain hence requiring control measures. The insect pests caused a significant loss to the yield (P=0.0000112, F=13.67, n=24 and df =7, 16 during the first season and P=0.0000975, F=52.41628, n=24 and df=7, 16 during the second planting season) with a further separation of means showing a higher loss in plots with *Amaranthus cruentus*. All the pests groups resulted to a consolidated loss of 50% of the total yield with 49% being attributed to grain pests and 42.5% caused by stem and foliage pests. Neem (*Azadirachta indica*) leaf extracts are effective in the reduction of pest population and have little impact on the beneficial insects. Chemical control reduces the pest population considerably but reduces also the population of beneficial insects. A considerable number of naturally occurring enemies, parasites and parasitoids were collected indicating there is potential to conserve these insects for biological control. An effective integrated pest management strategy can be achieved with correct planting lines, use of botanical pesticides (*Azadirachta indica* extract), and judicious use of less potent chemical pesticides. Planting dates and seasons do not have an effect on pest population and diversity.

CHAPTER ONE

1.0 INTRODUCTION AND LITERATURE REVIEW

1.1 Background Information

Indigenous vegetables are all categories of plants whose leaves, seeds or roots are locally acceptable for use as vegetables (FAO, 1988). These vegetables are widely consumed and are crucial to food security particularly during famine or natural disasters. The plants grow as weeds in wild or are semi-cultivated or even cultivated in some areas. If domesticated, these crops require little or no inputs at all. Most of these vegetables are gathered when in season, or are grown in home gardens or intercropped with staple foods (Schippers, 2000). Over 20 indigenous leafy vegetables species are commonly used across Africa; with some only known and used locally in Kenya (Maundu *et al*., 1999; Ngugi *et al*., 2007).

Amaranthus species belong to the plant family Amaranthaceae. The early use of Amaranth (*Amaranthus* spp.) is believed to be in Mexico during the Azetic civilization where it was grown as a principal grain crop (NAS, 1985; Grubben, 2004). It is a member of family Amaranthaceae and it is mainly consumed as a leafy vegetable or grain amaranth (Maundu, 2004).

The Ministry of Agriculture registered amaranth as a crop in Kenya in Legal notice No. 287 in the year 1991 but there has been a very slow spread since then (Amaranth News Magazine, 2007). There is a growing need among farmers in Kenya to diversify agricultural production especially vegetable production, in this case, shift from over-reliance on exotic vegetables and grow more African Leafy Vegetables (ALVs) that include both indigenous and traditional vegetables (Mbugua *et al*., 2006).

The main constrain is that there is limited research that has been put in to enhance production of ALVs (Abukutsa-Onyango, 2006). As many other crops amaranth production faces a major challenge due to pest infestation. From the research by

Palada & Chang (2003) the insect pests that attack amaranth include leafminers (*Liriomyza* spp.), Aphids (*Myzus persicae*), bugs and Pigweed weevil (*Hypolixus haerens*). Over-reliance on organochlorides and organophosphates or their derivatives as a control strategy for pest is facing resistance due to rising impact on the environment and health of human beings and their animals due to persistence in soils and biomagnifications. Use of biological control agents, pesticides derived from natural sources, cultural control of pest and judicious use or complete abstinence from persistent pesticides is the way forward in the management of insect pests (Losenge, 2005).

Integrated Pest Management (IPM) strategy employs a combination of various control strategies starting with the cheapest and less risky to the environment and health e.g. cultural practices and gradually moving to the more risky methods including judicious use of pesticides when all other control strategies break right from planting to harvesting (Anyango, 2006).

1.2 Amaranth

1.2.1 Taxonomy of amaranth

Amaranths belong to the order Caryophyllales and are grouped into the Amaranthaceae family and genus *Amaranthus* which is a cosmopolitan genus of herbs. This genus consist of approximately 60 species but only limited number are cultivated types, while most are considered weeds. There is no distinct separation between the vegetable and grain type since the leaves of young grain type plants can be consumed as vegetables (Schippers, 2000). The genus Amaranthus shows a wide variety of morphological diversity among and even within certain species (Juan, 2007). The genus has very few distinguishing features among the 60 species even though the family is distinctive. This results into hybridization (Judd, 2008). At least every ethnic community in Kenya has a name for amaranth, for instance Kikuyu's call it *Terere*, Swahili *Mchicha*, Luhya's *Omboga*, Luo's *Ododo*, Pokot's *Sikukuu* or *Chepkuratian*, Turkana *Lookwa* or *Epespes* and Teso *Ekwala*.

1.2.2 Agronomic characteristics and morphology

Amaranth is an annual herb with green or red leaves depending on species and has branched flower stalk that bear small seeds which also vary in colour including cream, gold, pink or black (Stallknecht & Schulz-Schaeffer, 1993). Amaranth grows to about 1.5 m to 2 m and it has broad leaves (dicot). The flower head is small with clove-like flowers which profuse with feathery plumes. It produces very tiny seeds that are lens shaped. Each plant can produce from 40000 to 60000 seeds (Mbugua *et al*., 2006).

1.2.3 Distribution and varieties of amaranth

Amaranthus sp. are among the most commonly used leafy vegetables in Kenya and most of Africa (Maundu *et al.*, 1999). Though there are over 60 species and 4000 to 6000 varieties of amaranth in the world, at least 13 occur wild in Kenya. Most of these (with exception of *A. thunbergii*, *A. sparganiocephalus* and *A. graecizans*) have been introduced from other parts of the world especially from Asia and Central America (Brenan, 1981). Because of their close resemblance and the fact that many are newcomers, they are often known by the same local names and used in the same manner. There is no clear distinction between grain type and vegetable type (Maundu *et al*., 1999). Some of the species grown widely as a source of grain and leafy vegetables include:

1.2.4 *Amaranthus dubius* Mart. ex Thell

Amaranthus dubius is believed to be of American origin. It has ridged leaves, simple leaves with long petiolates, ovate lamina and conspicuous veins underneath. It is fast growing and can take approximately three weeks for harvesting of vegetables to begin. It has a distinctive green pigmentation, broad and ridged leaves (Brenan, 1981). It grows in most tropical parts of the world and usually found in most sub-humid parts of Kenya below 2000M. It is short compared to other species and varieties. It is the only known tetraploid (2n = 64) in the genus. Leaves and tender shoots are used as a vegetable, sometimes cooked with bitter vegetables such as black nightshade (*Solanum nigrum*) especially among Luos (Mbugua *et al*., 2005).

Plate 1.1: ***Amaranthus dubius***

1.2.5 *Amaranthus cruentus* L.

This species has long stems and bears large inflorescence. It is mainly grown in Africa and other warmer regions of the world as source of grains. The grains are small in size with the colour ranging from cream to gold. It is fast growing and takes about 55 days to reach maturity. It is believed to have originated in America and introduced in Africa (Maundu *et al*., 1999). When left to grow to maturity under optimum conditions it grows to above 1m in height with a diameter of about 5 cm for the stem. The leaves can also be harvested as a source of green vegetable. This species is often treated as a subspecies of A. hybridus (Maundu *et al*., 1999).

Plate 1.2: ***Amaranthus cruentus***

1.2.6 *Amaranthus hybridus* L.

It originated from tropical America but now it has a wider distribution throughout the world especially in the tropics (Bosch *et al*., 2009). It is a fast growing species and it is resistant to moisture stress making it suitable for areas with uneven rainfall distribution. Stems are green or tinted red and ridged. It produces a good yield of grain with sorghum – like heads. The colour of the grains greatly varies depending on the variety. It is widespread in tropical and subtropical regions of the world and widely distributed in humid to sub-humid areas in Kenya; mainly as a weed of cultivation. It is common in the middle altitudes and highlands (1400 – 2400 M) (Maundu *et al*., 1999).

Plate 1.3: *Amaranthus hybridus*

1.2.7 *Amaranthus tricolor* L.

This species is native to India and pacific Islands. It is mainly grown as a source of vegetable. It is also referred to as spinach amaranth. The plants are very succulent, low growing and compact (Maundu *et al*., 1999).

1.2.8 Uses of Amaranth

1.2.8.1 As a Leafy Vegetable

Amaranth has been domesticated in various parts of the world and is grown mainly as a source of leafy vegetables and also as a source of high-protein grain. In Kenya the leaves from Amaranth are cooked either alone or combined with other local vegetables such as, spider plant and black nightshade (Mbugua *et al*., 2006). The leaves are a rich source of calcium, iron and Vitamins A, B and C (Stallknecht & Schulz-Schaeffer, 1993; Ouma, 2004).

1.2.8.2 As a source of Grains

The grains are also highly nutritious and are unusually high in protein for a non-legume. It is rich in dietary fiber, calcium and minerals such as iron, magnesium, phosphorus, copper and manganese. It is a good source of essential amino acids especially lysine which is very high in this grains (Ouma, 2004). The grains can be cooked as a whole grain, mixed with other cereals such as, rice or can be milled into flour which can be used to prepare various meals. Grain amaranth is highly recommended for infants because of its protein digestibility, absorption and retention by the baby's body system (Maundu *et al*., 1999).

1.2.8.3 Medicinal value

Amaranth has been found to be having medicinal values, which can reduce or combat common diseases such as diabetes, hypertension, liver disease, hemorrhage, TB, HIV/AIDS, wound healing, kwashiorkor, marasmus, skin disease among others (Martirosyan *et al*., 2007). This is supported by works of Ouma (2004) who also found out that amaranth seeds and biomass are rich in soluble and insoluble diet fibers important in prevention of coronary heart diseases. They also contain compounds that enhance human growth and development, improve general health, and strengthen immune responses to combat diseases.

1.2.8.4 Nutritional value

According to Pospisil *et al* (2006) Amaranth has a high nutritional value because of the high levels of essential micronutrients like carotene, vitamin A, B, C and D, iron and calcium. It has also been found to be especially rich in lysine, and essential amino acid that is lacking in diets based on cereals and tubers. It also contains high levels of minerals especially iron, phosphorous and magnesium more than what is found in animal products like milk and meat. The fat content in amaranth seed is high (7 – 8%) double that of other cereals (Maundu *et al*., 1999).

1.2.9 Pest of Amaranth

A wide range of insect pests have been recorded to be attacking Amaranth worldwide with some described as major pest while others as minor depending on the magnitude of the damage they cause and they include:

1.2.9.1 Aphids

Aphids are a major pest of vegetables including Amaranth (Picker *et al*., 2004). Amaranth is majorly attacked by Myzus persicae. Aphids feed by sucking sap from plant tissues especially leaves causing the leaves to curl, wrinkle and discolour. They also result to overall slow and stunted growth of plant and under heavy infestation it may cause the plant to dry out. Seed production is also hampered by aphid infestation where it may lead to deformed seeds, decreased flower and seed formation or reduced seed viability (Picker *et al*., 2004).

Plate 1.4: Aphids (*Myzus persicae*)

1.2.9.2 Plant Bugs

Makwali (2002) in his research on grain amaranth reported that the most prevalent bugs infesting grain Amaranth are *Cletus* sp. and *Cletomorpha* sp. whose population often reaches peak during the seed head: the critical milky seeds stage. This was supported by the research done by Oke and Ofuya (2011) which showed that this bugs feed on the seeds causing discolouration, shriveling and premature dying of seeds thereby reducing seed yield and viability.

Plate 1.5: Bugs feeding on amaranth flowering head

1.2.9.3 Weevils/Beetles

Hypolixus spp. is a major pest of cultivated amaranth (Tara *et al*., 2009). The eggs overwinter in the soil or inside the debris of harvested plants. Adults defoliate the plants while the larvae feed on the internal tissues of the stem and branches to form irregular zigzag tunnels resulting in galls. Females lay eggs 40 minutes after copulation singly in excavated holes in stems, branches, petiole or midrib of the leaves. The presence of adults in the field is noticed by the scratched stem, branches and eaten up tender margins of leaves (Agarwal, 1985). The weevil has a slow steady development with overlapping generations. Adults are dark brown, variegated with white hairs and several dark patches of dense pubescence. The body is medium sized measuring 11.7 mm with females being slightly larger than males. They have chewing mouth parts with prominent mandibles that are used to borrow through the stem (Tara *et al*., 2009).

Plate 1.6: White grab of amaranth weevil inside Amaranthus stem

1.2.9.4 Leaf miners

These are serious pests of the leaves of amaranth. Leaf miners (*Liriomyza* spp.) are small flies, 1.3 - 1.6 mm in length and the maggots are the most damaging stage (Picker *et al*., 2004). They tunnel inside the leaves resulting to long, slender mines in leaves. These mines may later turn yellow and the leaves may be shed off prematurely (Holloway *et al*., 1987).

Plate 1.7: Damage on leaf by leaf miners (*Liriomyza* spp.)

1.2.9.5 Nezara viridula

This is a serious pest of amaranth. They attack developing grains of amaranth crop. The proboscis punctures in developing seed causing necrosis and it ends up either rotten or fall – off under developed (Picker *et al*., 2004). It is also called the green stink bug due to the colour of the mature bug which is predominantly green. The adults are large shield bugs of about 15 x 8 mm there are five nyphal instars. The first instar does not feed. They remain clustered near the remains of the eggs. After molting they disperse and start feeding. They suck the sap from soft plant tissues but prefer feeding on developing seeds (Lopez-Olguín *et al*., 2011).

Plate 1.8: The first and third instar nymph of Green Stink Bug (*Nezera viridula*)

1.2.10 Control Methods

In view of the fact that amaranth is consumed directly from the farm as a leafy vegetable or grain and sometimes consumed as a raw salad it is important then to develop pest control options that are safe, as well as cheap and simple to adopt (Sithananthan *et al*., 2004). Some of the strategies used to control pests in other ALVs can also be employed in control of pests in Amaranth. These methods include:

1.2.10.1 Botanical pesticides

This are mainly extracts from plants or plant parts such as seeds, barks, leaves, roots. Seeds and leaves of neem (*Azadirachta indica*) and its relative Persian lilac (*Melia azedarach*) have been used widely in organic farming in Kenya to control insects

(Sithanantham *et al.*, 2004). Another plant that has been used extensively is pyrethrum.

1.2.10.2 Microbial Bio-pesticides

The use of microbes to control insect pest and diseases is an area that has attracted a lot of attention from researchers throughout the world including Kenya in recent times. Several microbes including fungi, bacteria, viruses and entomopathogenic nematodes (EPN) have been employed to control insect pests. These include: Bacteria such as *Bacilus thuringensis* (Bt), *Agrobacterium* sp.; Fungi: *Trichoderma* sp., *Meterhizium* sp., *Beuveria* sp.; Nematodes: *Steinernerma* sp. and *Heterorhabditalis* sp. (Neuenschwender *et al*., 2003).

1.2.10.3 Cultural practices

Cultural controls employ practices that make the environment less attractive to pests and less favorable for their survival, dispersal, growth and reproduction, and that promote the pest's natural controls. The objective for this control strategy is to reduce pest numbers, either below economic injury levels, or sufficiently to allow natural or biological controls to take effect (Sithanantham *et al*., 2004).

Cultural control employs environmentally supportive and knowledge/skill-intensive techniques, such as the optimal design and management of agro-ecosystems in time and space which include; management of adjacent environments, use of companion crops, rotations, timing of seeding, harvesting and field operations as well as more heavy-handed interventions like burning of crop residues, flooding and destruction of uncultivated areas containing alternative hosts of pests (Losenge, 2005).

1.2.11 Integrated Pest Management (IPM)

According to Agrios (2005) integrated pest management can be described as a pest management system that utilizes all suitable techniques in as compatible manner as possible and maintains the pest population levels below those causing economic injury. Integrated Pest Management relies on a combination of common-sense practices such as, the associated environment and the population dynamics of the pest species which are effective and environmentally sensitive (Mullen *et al*., 1997).

The concept of IPM was first introduced in the mid-1970s to reduce the over-dependence on pesticides that were used for reducing losses due to pests (Metcalf & Luckman, 1975).

Integrated pest management programs utilize current comprehensive information on the life cycles of pests and their interaction with the environment. This information, in combination with available pest control methods, is used to manage pest damage by the most economical means, and with least possible hazard to people and the environment (Antle & Pingali, 1994). This strategy is knowledge-intensive and farmer-based decision making process and it encourages natural control of pests. It also prevents pest outbreaks and the development of pest resistance. The pesticide-free agricultural commodities from the IPM-practiced fields have a great scope to increase the income of farmers (Mullen *et al.*, 1997).

1.3 Statement of the Problem

Several surveys have been conducted worldwide to identify the insect pest complex of amaranth. However, there is still limited information on amaranth insect pest complex in Kenya and with increasing production there is need to identify these insects so as to design the right control strategy. This research will seek to identify various pest of amaranth and consequently develop a farmer based IPM program for management of pests in amaranth as well as test the efficacy of these strategies.

1.4 Justification of the Study

Development of a sustainable IPM will go a long way in lowering the levels of pesticides used in production of amaranth. This will ease the effects that some of these chemicals have on the environment and health of the people in Kenya. IPM is a relatively cheap method of controlling insect pests hence the results from this study will contribute towards lowering of the production cost of amaranth for small-scale farmers. The results of this study will lead to increased awareness among farmers on the importance of amaranth, its contribution towards health and nutrition thus leading to enhanced production. This research will also contribute to the government commitment to eradicate poverty through diversification of draught tolerant crops.

1.5 Hypotheses

1. Insect species associated with Amaranth in Meru County are not diverse.
2. Insect pest infestation has no impact on the crop yield of Amaranth in Meru County.
3. Different pest control mechanisms of amaranth insect pest in Meru County have the same effect.

1.6 Objectives

1.6.1 General Objective

The general objective of this study was to develop a farmer based Integrated Pest Management Plan (IPMP) for Amaranth pests in Meru county Kenya.

1.6.2 Specific Objectives

The specific objectives of this study were:

1. To determine the diversity and abundance of insect pests and natural enemies associated with Amaranth crop.
2. To determine the yield loss as a result of insect pest damage and if it warrants control intervention.
3. To determine the effects of planting dates, Amaranth varieties and the use of botanical pesticides on the population of insect pest of Amaranth.

CHAPTER TWO

2.0 MATERIALS AND METHODS

2.1 Study site

The in-situ research was conducted in Meru county, Buuri district, Nchoroiboro and Ruiri locations. Sampling of the insect pests and their natural enemies was done from farmers growing Amaranth who were randomly selected from various zones in Buuri district. The ex-situ demonstration plots were located at Meru University College of Science and technology (MUCST). Identification and preservation of insect specimen was conducted at the National Museums of Kenya – Zoology Department, Invertebrate Zoology section, in Nairobi.

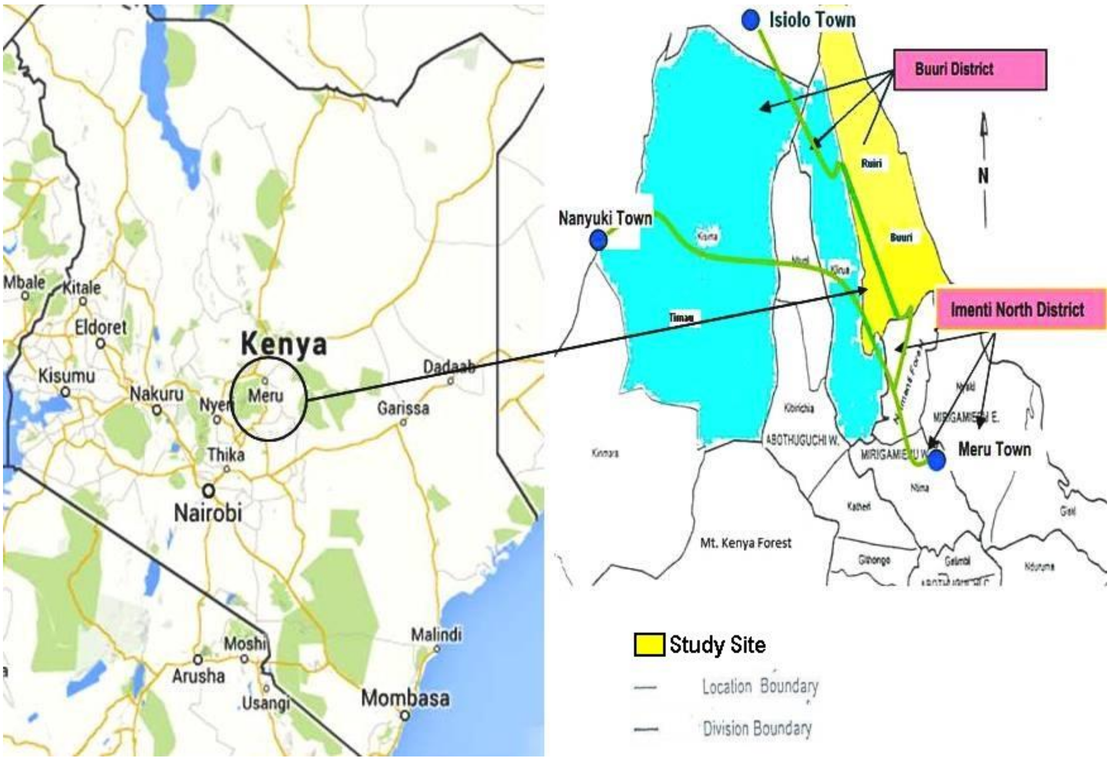


Figure 2:1: Map showing the study site; Buuri District in Meru County

Buuri district has a total area of 919 KM^2 with Buuri division covering about 26% of the area while Timau covering the rest. According to Meru Central District Development Plan (2002 -2008) prepared in 2002 total human population in 2008 was projected at 276000 with Buuri accounting for 70% of the population. The study area lies between 300 – 5199 meters above sea level (summit of Mount Kenya). While the South Eastern slopes of Mount Kenya (Meru North and Imenti North) receives ample rainfall amounting to between 1250 mm and 2500 mm per year, the leeward side of Mount Kenya, which includes Buuri division (the study site) receives low rainfall amounting between 380 mm and 1000 mm annually except for the regions closer to the Mountain. Rains come in two seasons with short rains in Mid-March to May and long rains October to December (Ministry of Planning and National Development, 2002).

2.2 Study Design

Stratified sample collection was used to study insect diversity and abundance from randomly selected farms of farmers who are known to be growing amaranth. The farms were grouped into homogenous units depending on the altitude and two farmers from each unit selected. For the ex-situ research completely randomized block design was used where treatments (two planting dates, three amaranth varieties, use of botanical pesticides and controls) were randomly assigned to plots where amaranth was grown. Each treatment was replicated three times.

2.3 Sampling and Sample Size

A pilot study was conducted between the February and March 2012 among the farmers in Buuri district to establish the optimum transect length for surveying of insects. There are 45 farmers who are confirmed by KAPAP to be growing amaranth regularly. These farmers are grouped into four zones (A, B, C and D) depending on altitude, topography and environmental conditions. Two farmers were selected from each zone (8 farmers). Amaranth insect pests were sampled twice per week from the selected farmers in Buuri District. This survey was repeated on two growing seasons of amaranth; April - September 2012 and October – December2012. The results on each sampling field and from each season were then compared.

2.4 Sampling of insect pest and natural enemies

2.4.1 Survey for natural enemies and insect pests of Amaranth

Sampling for insect pests and possible natural enemies was done at least once a week on eight unsprayed plots randomly selected from farmers growing amaranth in Meru County. Upon entering the field a quick visual examination was made to establish any typical areas that may affect the sampling pattern for example topographical variations in the field, varietal growth differences and areas with poor stand and necessary blocking was done to ensure un-biasness in sampling. To avoid the edging effect sampling began a few rows into the field. Also the type of damage on the plant was used to infer the type of insect pest likely to cause the damage (Clarke-Harris & Fleischer, 2008; Madhumitha *et al.*, 2013). The specimens were labeled, preserved in alcohol and taken to the Invertebrate laboratory at NMK for further identification, classification and archival.

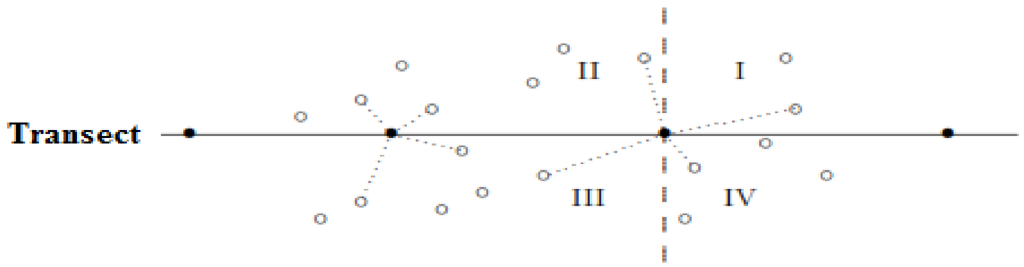


Figure 2:2: Sample points along a transect line

2.4.2 Methods of collecting insects

Slow moving and sedentary arthropods were collected by hand (Nderitu *et al.*, 2008). The plant was searched visually for possible insect pests which were then collected into vials, labeled and taken to the laboratory at NMK for identification, curation and archival. Healthy plants were also uprooted and stems and roots dissected to examine the presence of phytophagous insects that do not cause visible damage. A mild pesticide was sprayed on the plants to prevent the insect pests from escaping (Millar *et al*., 2000).

Beating sheets were used to collect well – camouflaged or hidden insect pests on plants that were missed during sampling by hand picking (Millar *et al*., 2000). A small sheet was placed beneath the plants preferably a white sheet and the insect pests were knocked down from the plant onto the sheet by beating with a stick. The insects were then picked up from the sheet with aid of a hand lens and forceps and placed into vials. This method was employed to collect sessile and wingless insect pests (Millar *et al*., 2000).

Flying insects were collected using aerial nets (Nderitu *et al*., 2008). Aerial net consist of a light weight frame made of soft durable material such as, aluminum with a net attached to it. Once the insect has been caught, the end of the net was flipped over to prevent it from escaping. Harmless insects were removed by hand, while harmful once were directed into a killing bottle (Millar *et al*., 2000).

Other insect pests that are ground dwelling such as, termites and weevils that attacked roots and stems of amaranth or those that moved to the ground to oviposit or spend one stage of their development cycle in the soil were collected using pitfall traps (Millar *et al*., 2000). Cylindrical containers were placed in holes dug at random within the amaranth plot with the upper rim of the container being flush with the ground surface. A killing agent, ethylene glycol was added to the trap to kill the insect after entering the trap. The traps was inspected weekly for possible insect pests and if available collected using forceps and placed in vials. The holes were distributed evenly within the plots (Millar *et al*., 2000).

2.4.3 Preserving the insect Pests

Most of the insect pests were killed using either ammonia (0.880) or ethyl acetate. An absorbent cotton wool was dampened with the killing agent then dropped to the bottom of a glass jar and then covered with a layer of non – absorbent cotton wool. Exposure to fumes for 10 – 15 minutes was sufficient to kill most insects (Nderitu *et* *al*., 2008). The insects were relaxed before pinning using a flat plastic container with an airtight lid. The base was lined with moist cotton wool covered with blotting paper. The dry insects were placed inside the relaxing dish in open containers and the container was sealed and left for at least a day (Millar *et al*., 2000).

Insects longer than about 8 mm were mounted on entomological pins pushed through the thorax (Nderitu *et al*., 2008). Entomological pins are made of stainless steel that does not rust. A No. 2 or No. 3 entomological pin was suitable for most insects, although those with delicate bodies required a size No. 0 or No. 00 (Millar *et al*., 2000). The mounting board made of polystyrene covered with paper or expanded polyethylene (EPX), at least 30 mm thick was used. The insects were pinned by pushing the pin vertically through the mesothorax, avoiding the legs as the point of the pin emerges on the underside of the body (Picker *et al*., 2004). The pin was inserted slightly to the right of the center of the mesothorax. The pin with the insect was then pushed into the mounting board until the underside of the body rests on the board. The legs and antennae close to the body were arranged to reduce the likelihood of damage and secured in their positions with bracing pins. Most insects were pinned with their wings folded (Picker *et al*., 2004).

Insects that were too small for mounting directly on standard pins were double-mounted on card points, card platforms, minuten pins or in gelatin capsules (Nderitu *et al*., 2008). A small drop of glue was placed on the tip of a card point mounted on an insect pin. Clear-drying, non-water-soluble project or wood glue is most suitable. The right side of the insect's thorax was pressed against the glue (Picker *et al*., 2004). Once mounted, insects were left to dry in a ventilated drying cabinet for a week (Miller *et al*., 2000).

Most arachnids and soft-bodied insects become much distorted when they dry up. Preserving the larvae in 70% ethanol discolors them. To avoid this, the larvae were preserved by dropping them in a vial containing 1 part 80% alcohol and 1 part glacial acetic acid. The addition of acetic acid helped to prevent discoloration. After 48 hours the specimens were then transferred to another vial containing 80% alcohol

(Holloway *et al*., 1987). Smaller specimens were mounted on microscope slides and studied under a compound microscope.

2.5 Determining the yield loss due to insect pest damage

Naturally occurring infestations are oftenly used to give a range of infestations or damage in a single plant, plot or field. The yield was determined per unit area in different plots with different degrees of pest infestation and correlation between the crop yield and degree of infestation was worked out to estimate crop yield loss (Odendo *et al*., 2003). This was used to identify the pests of economic importance to amaranth and require control interventions.

2.5.1 Insect sampling for crop loss assessment

Different activities of insects such as their population on the crop, damage inflicted to plants and insect stages present were surveyed on each plot. The decision on whether control interventions are needed depends upon the accurate estimation of insect pest numbers and the damage resulting to loss in yield on the crop.

2.5.2 Direct assessment of crop loss

Direct assessment of the number of insect on the crops randomly selected from each plot was taken. Aphids were counted per unit of leaf and bugs per panicle. Healthy looking stems were also uprooted and dissected to observe if they were infected by tunneling insects. The larvae collected from inside the stems were incubated on soil in a killing jar and small cuttings of amaranth stem added to provide food. The soil was kept moist by adding little water every after two days until the adult emerged.

Plate 2.1 a and b: Inoculation of the larval stage for further identification.

The number of insects in each species which were knocked down on the beating sheet were recorded versus the area surveyed (Saini, 2011).

2.5.3 Indirect assessment of crop loss

The difference between incidence (number of damaged plants) and intensity or severity (degree or extent of damage) in each plot was recorded. Soil pests, cutworms and borers may cause loss of plant stand and the number of plants that fail to germinate was also recorded. Holes, spots, mines, rolls or epidermis removal indicate attack by leaf caterpillars, leaf miners or leaf beetles and this damage was assessed by approximating the area damaged versus the undamaged area (Saini, 2011).

Crop loss can be defined as the difference between the potential yield Y (p) that is, the yield that would have been obtained in the absence of the pest under the study and the actual yield Y (a). It is convenient to express this proportionate to the potential yield, to obtain a proportional crop loss r (Odendo *et al*., 2003).

$$r = \frac{y_p - y_a}{y_p}$$

Equation 2:1: Calculation of the crop yield loss

The damage and the number of pests were given scores/rated and this scores were transformed and analyzed.

2.6 Effects of various control strategies on insect pest population

Planting dates, amaranth varieties and use of botanical pesticides were tested for efficacy in controlling insect pests of amaranth on demonstration plots at Meru University College of Science and Technology (MUCST).

2.6.1 Growing of amaranth

The area to be used as a plot for planting amaranth was manured using farm yard manure before primary cultivation was done. The area was thoroughly ploughed ensuring that manure mixed evenly with the soil and was well distributed on the entire plot (Schippers, 2000). Thirty plots were prepared each measuring 3 meters in length and 1.5 meters wide. The depth of preparation was 30cm during primary plough. This was followed by harrowing which encompasses breaking up of large particles of soil as well as raising the beds to 30cms above the ground surface. The beds were raked flat on the top maintaining the dimensions (Schippers, 2000).

Planting method was by direct seeding where seeds were mixed with sand, that is, 1 g of seed mixed with 100 g of sand to ensure uniform stand. Seeds were sawn in rows by making furrows 0.5 to 1.0 cm deep using a stick or finger. Inter-row spacing was 20 cm and thinning followed immediately after germination to achieve the desired within row spacing (Palada & Chang, 2003).

2.6.2 Testing the efficacy of pest control strategies

Two planting dates (April and May) and three amaranth varieties (A. dubius, A. cruentus and one local variety) were both assigned randomly to the prepared plots. On three plots neem leaf extracts (botanical pesticide) was used to control pest, a standard pesticide was used to control pest on other three plots and other plots were left unsprayed. All the treatments were replicated three times. The plots were then be surveyed for insect pests and crop yield loss evaluation done in all treatments. The mean number of pests occurring in each treatment and the percentage crop yield loss due to damage was compared and used to make judgment on the efficacy of these methods.

2.7 Controls

The standard pesticides used to control insect pests in amaranth were used as a positive control, that is, to control pests that damage roots granulated Furadan_5 G (carbofuran insecticide) was applied in doses of 25 kg ha-1 at the moment of first weeding and control foliage pests was carried out three weeks after planting by applying 1.0 kg ha-1 of Sevin _ 80 WP (carbaryl insecticide) and afterwards every 15 days, during the entire development of the plant and a field with no treatment or pest control mechanism was used as a negative control.

2.8 Data Collection

Various insects found feeding or ovipositing on amaranth were collected and recorded and further taken to the laboratory where correct identification and classification was conducted using relevant identification keys. The number of insects of each species was recorded in field data forms. The leaf index, diameter of stems, fresh biomass and dry biomass was also recorded. The number of insect pests in each treatment and their percentage damage were compared with that of controls.

2.9 Data Analysis

The data was tabulated in excel worksheets and field data sheets where the mean number of pest infestation in all the treatments was compared using Analysis of Variance (ANOVA). All significantly different means were separated using the Student least significant difference (LSD) at 0.05 level of significance (SAS Institute, 2009). The mean grain production in every treatment was also compared. The approximations of the pest damage were ranked using Arcsine transformation and compared using ANOVA. The data was presented using tables and graphs.

CHAPTER THREE

3.0 RESULTS

3.1 Diversity and abundance of insects associated with amaranth crop

A total of 1256 insect specimens were collected from amaranth during the period April 2012 and April 2013. The pest species were grouped into five orders, 15 families and 33 species (Table 3.1). The order with the greatest number of species was Heteroptera with 13 species, followed by coleopteran with 11 species.

Table 3.1: List of insect pests sampled from Amaranth between March 2012 and April 2013 in Meru County, Kenya

Order	Family	Scientific Name	Common Name*
Coleoptera	Curculionidae	*Baris massaica*	Stem-girdling Weevil
	Curculionidae	*Hypolixus nubilosus*	Amaranthus Weevil
	Tenebrionidae	*Lagria villosa*	Darkling Beetle
	Curculionidae	*Nematocerus perditor*	Shiny Cereal Weevils
	Coccinellidae	*Exochomus ventralis*	
	Coccinellidae	*Hippodamia variegate*	
	Cantharidae	*Lycus constrictus*	
	Cantharidae	*Idgia fulricollis*	
	Staphylinidae	*Paederus sabaeus*	
	Apionidae	*Apion africanum*	
	Chrysomelidae	*Strobiderus africanus*	
Heteroptera	Redunidae	*Rhinocoris segmentalis*	Assassin bug
	Pentatomidae	*Sphaerocoris annulus*	Shield-backed Bug
	Coridae	*Cletus indicator*	Horned Coreid Bug
	Pentatomidae	*Nezera virudala*	Green Stink Bug
	Pentatomidae	*Menida maculiventris*	
	Pentatomidae	*Agonoscelis versicolor*	
	Coreidae	*Cletus orientalis*	Horned Coreid Bug
	Coreidae	*Cletus capensis*	Horned Coreid Bug
	Pentatomidae	*Nysius binotatus*	
	Tingidae	*Dictyla nodipennis*	
	Coreidae	*Cletus ochraceus*	Horned Coreid Bug
	Miridae	*Eurystylus oldi*	African Head Bug
Lepidoptera	Pyralidae	*Herpetogramma bipunctalis*	Beet webworm
Orthoptera	Tettigonidae	*Microcentrum rhombifolium*	Angel-wing Grasshopper
	Gryllidae	*Velarifictorus micado*	Borrowing Cricket
	Caelifera	*Chortophaga viridifasciata*	Green Striped Grasshopper
	Acrididae	*Orphulella speciosa*	Slant faced Grasshopper

* Committee on the common names of insects. Entomological Society of America. (2011).

The pests were further divided into two broad groups depending on the damage they caused on the crop that is the grain pests and the stem and leaves pests. The most damaging grain pests were in the order Heteroptera causing upto 40% grain loss with the leading genus being Cletus. *Hepertogramma bipunctalis* (Coleoptera) feeds on the stems and leaves causing upto 27% foliage yield loss. Another significant pest that causes damage on stem and foliage was *Hypolixus nibiloscus* (Coleoptera).

Table 3.2: List of beneficial insects sampled from amaranth between March 2012 and April 2013 in Meru County, Kenya

Order	Family	Scientific Name	Common Name*
Coleoptera	Coccinelidae	*Cheilomenes sulphurea*	
	Coccinelidae	*Cheilomenes lunata*	Lunate Ladybird
	Coccinelidae	*Cheilomenes vicina*	
	Coccinelidae	*Cheilomenes propinqua*	
Hymenoptera	Ichneumonidae	*Dentichasmias busseolae*	Hymenoptera
	Braconidae	*Iphiulax varipalpis*	Braconid Parasite
	Sphecidae	*Philanthus triangulum*	Bee wolf
	Sphecidae	*Dolichurus* spp.	Sphecid Wasp

* Committee on the common names of insects. Entomological Society of America (2011).

The insect with potential of being conserved as natural enemies and parasitoids that were collected on amaranth were classified into two orders (Coleopteran and Hymenoptera), five families and eight species (Table 3.2).

Table 3.3: Summary of diversity of insects associated with *Amaranthus* sp. between 2012 and 2013 in Buuri District, Meru County, Kenya.

Diversity Indices	2012	2013	Remarks
Total Number of Organisms:	1138	1256	
Total Number of Species:	31	36	
Average population size:	37.32	41.18	
Simpson Index $\frac{\sum_i n_i(n_i-1)}{N(N-1)}$	0.1352	0.1453	Species are evenly distributed in the study site
Dominance Index $1-\left(\frac{\sum_i n_i(n_i-1)}{N(N-1)}\right)$	0.8648	0.8547	No species dominate the ecosystem in both years
Shannon Index $-\sum_i\left(\frac{n_i}{N}\cdot\log_2\left(\frac{n_i}{N}\right)\right)$	4.256	4.148	Species diversity is high in both years
Margalef Richness Index $\frac{S-1}{\ln N}$	3.884	3.83	Overall species richness is moderate
Menhinick Index $\frac{S}{\sqrt{\sum_i n_i}}$	0.8662	0.8246	Species richness per plot is high
Berger-Parker Dominance Index $\frac{n_{max}}{N}$	0.1502	0.1587	No species dominate the ecosystem in both years
Equitability Index $-\frac{\sum_i\left(\frac{n_i}{N}\cdot\ln\left(\frac{n_i}{N}\right)\right)}{\ln N}$	0.8853	0.8629	Even distribution within each family in both years

The summary of species diversity and abundance obtained from Species Diversity and Richness (SDR) Software 4.0 revealed that the species were highly diversified with Shannon Weaver Index of 4.256 and 4.148 during 2012 and 2013 respectively. Likewise the Simpson Index was low being 0.1352 and 0.1453 for 2012 and 2013 respectively indicating even distribution of species (Table 3.3)

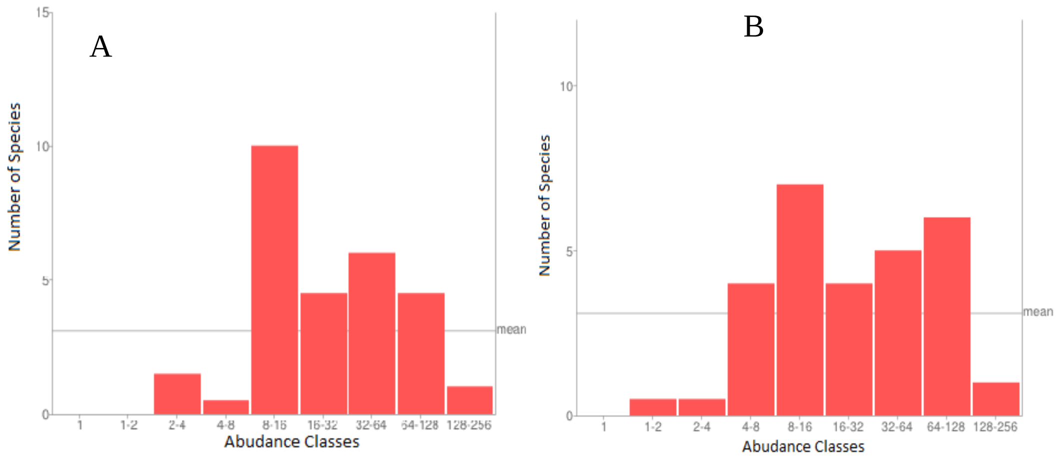


Figure 3:1: The Preston diagram showing the number of species in specified abundance classes during the two growing seasons.
Key: A- indicates the number of insect species in each abundance class during the first growing season (2012). B- Indicates the number of insect species in each abundance class during the second growing season (2013).

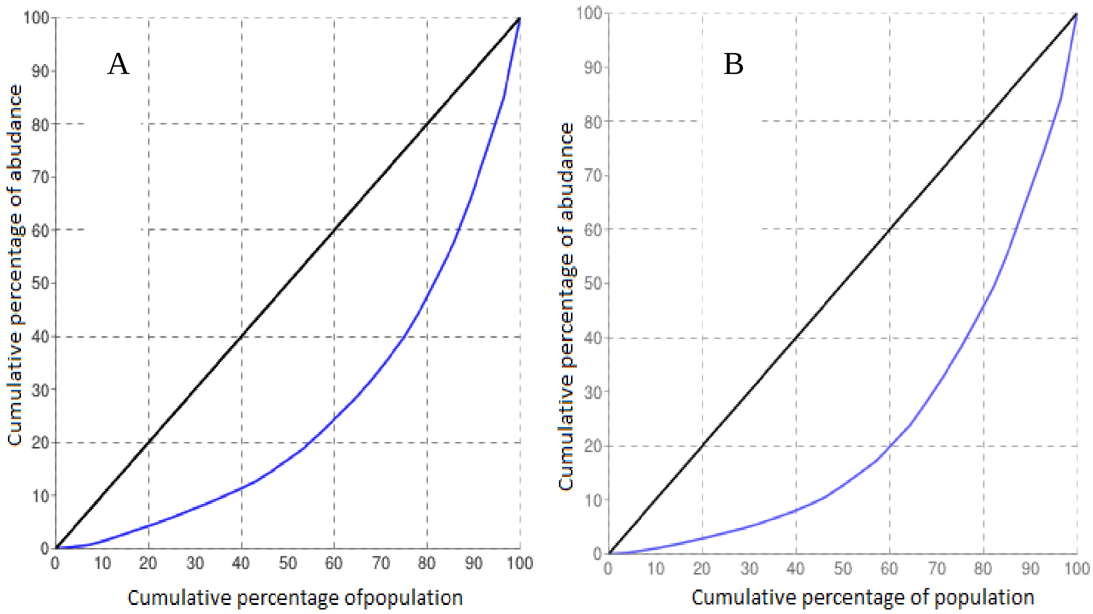


Figure 3:2: The Cumulative percentage of abundance verses cumulative percentage of the population expressed in a Lorenz graph
Key: A- First growing season (2012). B- Second growing season (2013).

The summary of species diversity was obtained using Species Diversity and Richness (SDR) software version 4.0.

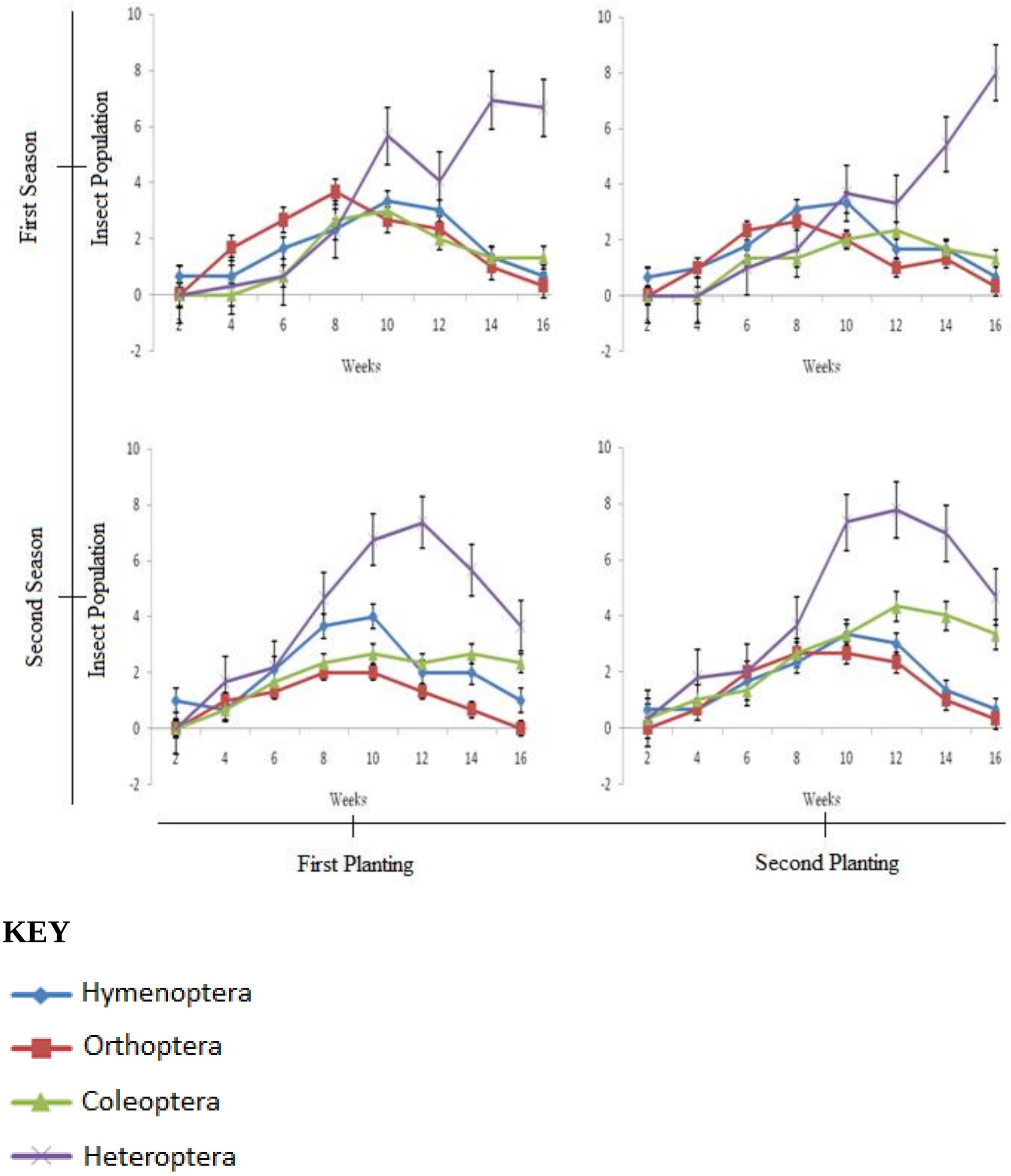


Figure 3:3: Population trends of insects associated with amaranth in relation to planting dates and seasons between April 2012 and April 2013.

The overall mean of insect population during the 2012 and 2013 growing periods are shown in Figure 3.3. The peak time was the tenth week where all the selected pest populations were high. The population of insects infesting the crop is low during the first planting weeks but increases as the crop grows.

3.2 Assessment of yield loss as a result of insect pest damage

From the data collected insects are key pests of amaranth causing considerable damage on stems, roots, leaves and grain. This insects cause windowing, folding of the leaves, necrosis, chlorosis among other damages as shown in plates 3.1, 3.2, 3.3, 3.4, and 3.5.

Plate 3.1: Mines caused by leaf miners

The larvae (first to third instar) of *Liriomyza sativa* tunnel inside the leaf epidermis feeding on the leaf tissues resulting to long slender mines (Plate 3.1) on the surface of the leaf. This reduces the photosynthetic capacity of the leaf and under severe infestation the whole leaf is lost.

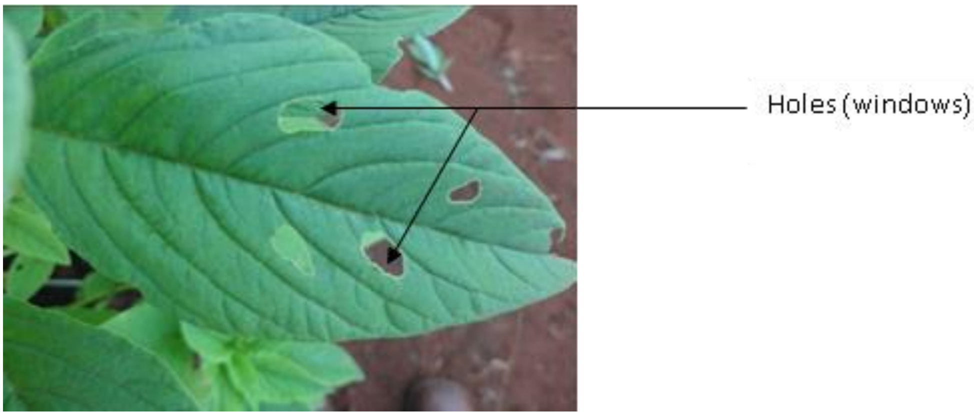


Plate 3.2: Windowing caused by caterpillars

The larvae of *Herpetogramma bipunctalis* and adults of leaf hoppers as well as weevils such as *Hypolixus* sp. feed on leaves causing small holes (Plate 3.2). If the feeding is severe the entire blade of the leaf is damaged leaving only the midrib

(Plate 3.3). This reduces the number and the quality of the leaves to be harvested. Cutting and windowing of leaves was observed in 100% of the plots.

Plate 3.3: Cutting of the leaves

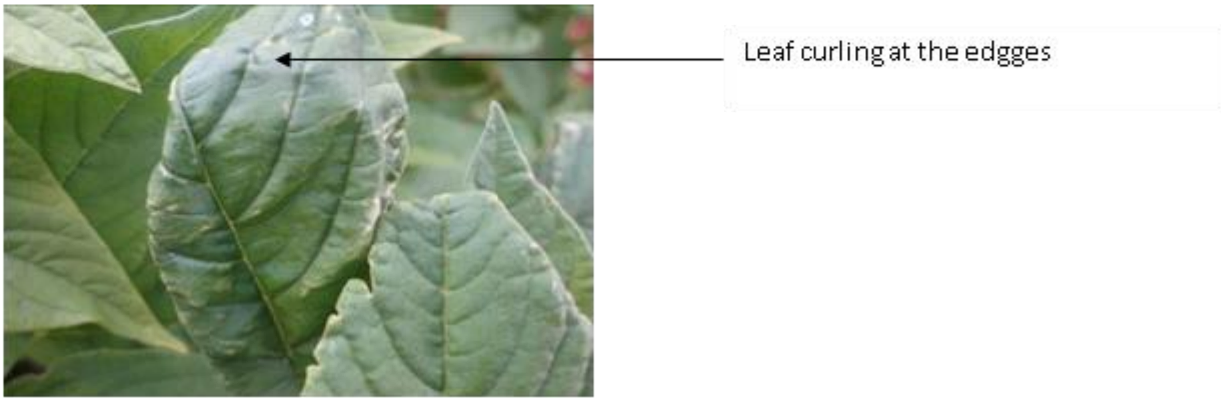


Plate 3.4: Folding of the leaves and necrosis due by aphids

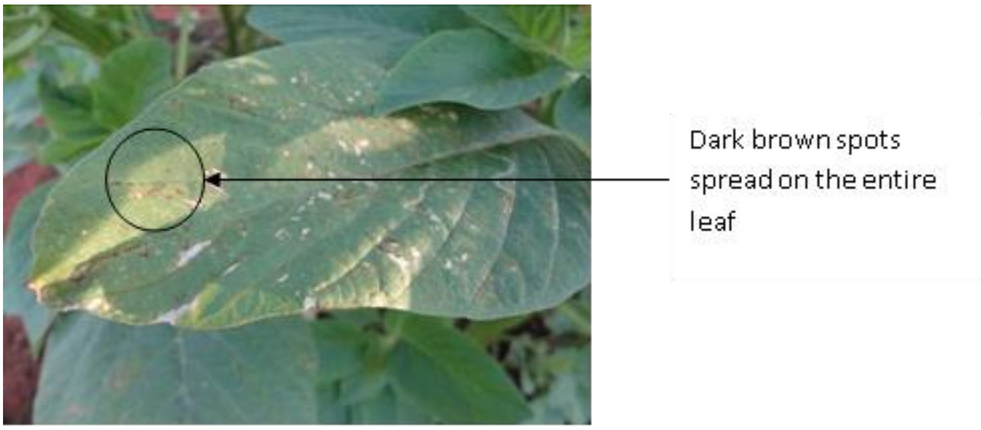


Plate 3.5: Necrotic lesion caused by feeding by bugs

Adult and nymphs of bugs feed by piercing plant tissue with slender needle-like mouth parts and removing plant juices. The area where the leaf is pierced forms a dark brown spots (necrotic lesions). Under heavy infestation the leaves dry up and fall. This affects the health and the vigor of the crop.

Plate 3.6: Tunnels and exit holes made by amaranth weevil

Other parts of the crop were damaged including stems and leaves. Weevils especially *Hypolixus* sp. and *Baris* sp. damaged the stem by tunneling both inside and on the surface of the stem as shown in Plate 3:6 and 3:8. Once they mature the leave the stem through an exit door they make while feeding.

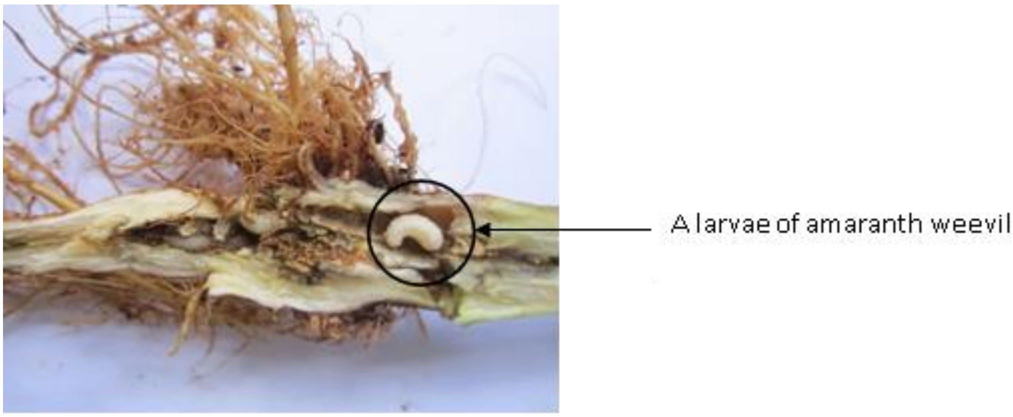


Plate 3.7: Stems of amaranth tunneled by white grabs of amaranth weevil

White larvae of *Hypolixus nubilosus* where isolated in 43% of all the healthy stems dissected (Plate 3.7). Some stems contained more than one larvae with a maximum of four larva isolated from one stem. *Amaranthus cruentus* and the local variety where more attacked compared to *Amaranthus dubius.* The stems where left hollow with dark brown colouring in the tunnels and even some tunnels contain fecal particles.

Plate 3.8: Lodging of amaranth stems as a result of damage by grabs of beet webworm (*Hepertogramma* spp.).

Larvae of *Herpetogramma bipunctalis* (Lepidoptera) were also isolated from the stems that were sampled and dissected. The caterpillars tunnel through the stem leaving behind gallaries as well as feed young leaves causing windowing and in some instances the total loss of the entire leaves.

Table 3.4: Means of production of amaranth grain under different treatments and analysis of losses due to pests of amaranth, as a function of the treatments in Meru County, Kenya.

TREATMENT	ACTUAL YIELD (Ya)	POTENTIAL YIELD (Yp)	YIELD LOSS ®	PERCENTAGE YIELD LOSS
***A. cruentus* 1st Planting**	0.2757±0.0164	0.5000	0.4486±0.0329[b]	44.86
***A. cruentus* 2nd Planting**	0.2507±0.0288	0.5000	0.4987±0.0574[b]	49.87
Neem extract	0.3863±0.0080	0.5000	0.2273±0.0160[a]	22.73
Chemical treatment	0.4210±0.0030	0.5000	0.1580±0.0060[a]	15.80

*Yield loss is indicated by r and superscript indicates the significant difference where similar letters indicate there is no significant difference in the means

The potential yield was obtained from KAPAP extension officers in Meru County where from the records it is expected that under optimum growth conditions the yield for the grains is 3300kg/ha and 5500kg/ha for the leaves. This was then used to calculate the potential yield for the area of each demonstration plot. The grain loss is at 44.86% during the first planting and 49.87% during the second planting (Table 3.4). Further analysis of this data show no significant difference between the two planting dates. The grain loss when neem extracts are used to control the pest reduces to 22.73% and 15.80% when chemical treatment is used(Table 3.4). These results indicate that there is no significant difference in the mean grain loss under neem extract and chemical treatment.

Table 3.5: Means of production of amaranth leaves under different treatments and analysis of losses due to pests of amaranth, as a function of the treatments in Meru County, Kenya.

TREATMENT	ACTUAL YIELD (Ya)	POTENTIAL YIELD (Yp)	YIELD LOSS ®	PERCENTAGE LOSS
***A. cruentus* 1st Planting**	0.4889±0.0123	0.8	0.3892±0.0154^{c}	38.92
***A. cruentus* 2nd Planting**	0.4600±0.0020	0.8	0.4250±0.0025^{c}	42.50
Neem extract	0.5663±0.0120	0.8	0.2921±0.0150^{b}	29.21
Chemical treatment	0.6977±0.0180	0.8	0.1279±0.0224^{a}	12.79
***A. dubius* 1st Planting**	0.5933±0.0071	0.8	0.2583±0.0089^{a}	25.83
***A. dubius* 2nd Planting**	0.5640±0.0078	0.8	0.2950±0.0098^{b}	29.50

*Yield loss is indicated by r and superscript indicates the significant difference where similar letters indicate there is no significant difference in the means

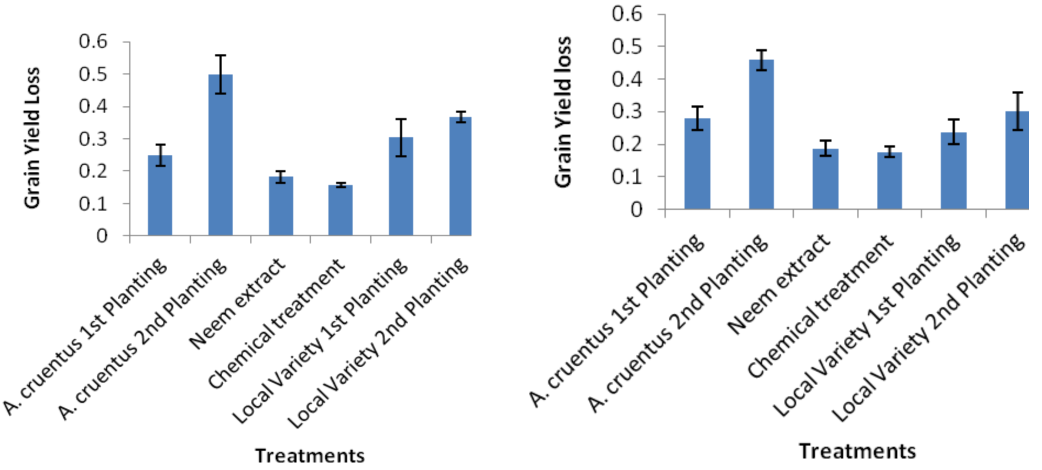


Figure 3:4: Analysis of grain losses due to pests of amaranth, as a function of the treatments in Meru County during the first and second planting seasons.

3.3 Screening the effects of various pest control strategies on pest population

Evaluation of these control mechanisms was done by comparing the population of the major pests in all plots with different treatments throughout the growing period as well as evaluation of the crop yield from all plots.

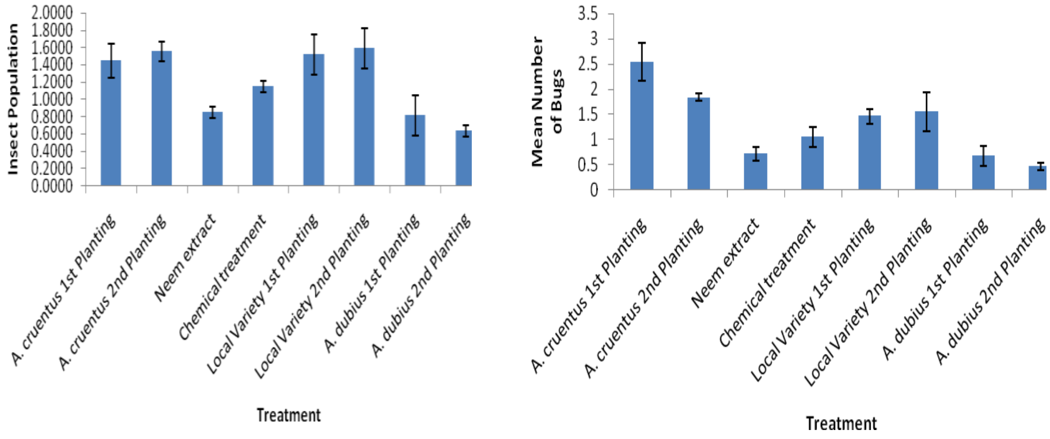
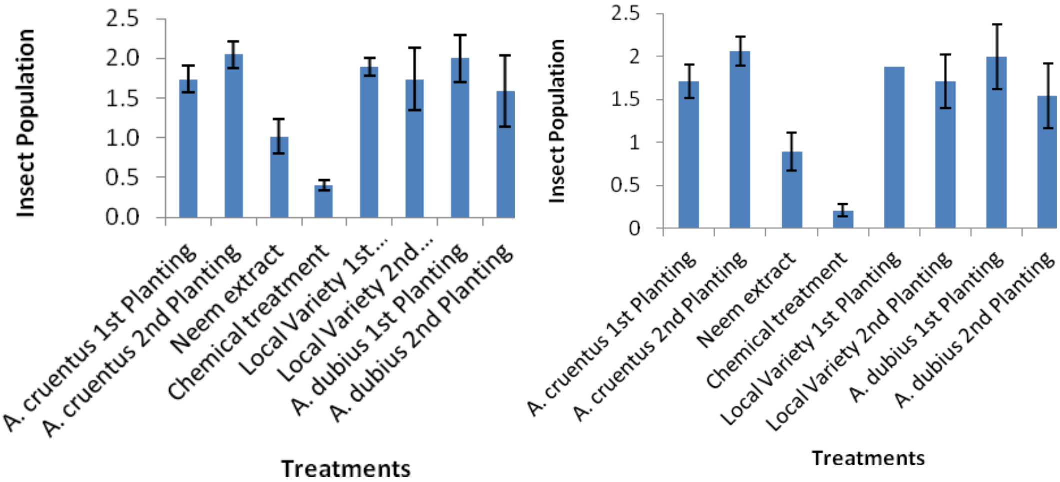


Figure 3:5: Mean number of bugs under various control strategies during the two growing seasons

Effect of insect infestations on susceptible Amaranthus plant under different control treatments is presented in Figure 3.5, 3.6 and 3.7. There was significant decrease (P<0.05) in the bug population per plant pinnacle and the number of leaves damaged (Figure 3.5) in plots treated with neem extracts compared to other treatments in the



two seasons.

Figure 3:6: Mean number of weevils under various control strategies during the two growing seasons

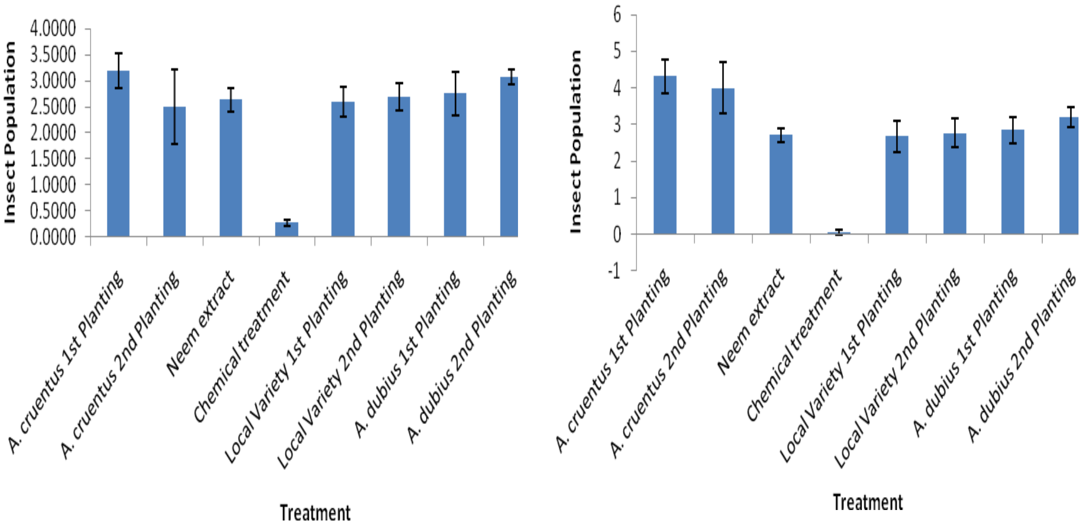


Figure 3:7: Mean number of hymenopterans under various control strategies during the two growing seasons

The results show that there is significant difference in the population of bugs and weevils collected from amaranth plots during the two growing period (P>0.05). The population of the pests reduces under neem extract and chemical treatments (Figure 3.5 and Figure 3.6). The population of bugs is low in plots planted with *Amaranthus dubius* during the two growing periods (Figure 3.5)

The impact of control strategies on hymenopterans population which are the major order of beneficial insects was investigated. There was significant difference in the mean population (P-value < 0.05) with a further separation of means indicating significant difference between chemical treatment and neem treatment (Table 3.6).

Table 3.6: Separation of means of hymenopterans population under each control strategy using least significant difference

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	1.741e+00	1.528e-01	11.390	4.36e-09 ***
TreatmentA. cruent2	3.111e-01	2.161e-01	1.439	0.16937
TreatmentA. dubius1	2.592e-01	2.161e-01	1.199	0.24784
TreatmentA.dubius2	-1.482e-01	2.161e-01	-0.686	0.50283
TreatmentChem Treat	-1.333e+00	2.161e-01	-6.169	1.35e-05 ***
TreatmentLocal Var1	1.481e-01	2.161e-01	0.685	0.50293
TreatmentLocal Var2	-3.333e-05	2.161e-01	0.000	0.99988
TreatmentNeem	-7.260e-01	2.161e-01	-3.359	0.00399 **

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1, Residual standard error: 0.2647 on 16 degrees of freedom, Multiple R-squared: 0.8568, Adjusted R-squared: 0.7941, F-statistic: 13.67 on 7 and 16 DF, P-value: 1.119e-05.

CHAPTER FOUR

4.0 DISCUSSIONS, CONCLUSIONS AND RECOMMENDATIONS

4.1 Discussion

4.1.1 Diversity and abundance of insects associated with amaranth crop

4.1.1.1 Diversity of insect pests

The results from this study show diversity in the number of insect species associated with cultivated amaranth in Meru County. These results concur with the findings from similar survey carried out in Puebla, Mexico (López *et al*., 2011). From the results Heteroptera is the order with greatest number of species, that is, 13 species, which causes significant damage to grains. The most significant genus in this Order was Cletus with four species. This genus was the most occurring with infestations of 100% in all plots. This may be as a result of amaranth being a suitable host for heteropterans. Other studies by López *et al*., (2011) in Mexico and Aderolu *et al*., (2013) in Nigeria also recorded high number of heteroptera species attacking amaranth.

The most abundant species were *Cletus* sp. (Heteroptera), *Eurystulus* spp. (Heteroptera), *Hypolixus nubilosus* (Coleoptera), *Microcentrum rhombifolium* (Orthoptera) and *Herpetogramma* spp. (Lepidoptera). Aderolu *et al*., (2013) reported *Hymenia recurvalis* and *Hypolixus truncatulus* as the most abundant pests in Nigeria. This shift in the species in the two studies may be due to geographical difference in the two study areas. From the results there was high diversity of amaranth pest species with a Shannon-Weaver index of 4.256 during the first growing season and 4.148 during the second growing season which was not significantly different ($P>0.05$). This trend of insect species confirms the insect species previously reported on amaranth by López *et al*., (2011) and Torres *et al*., (2011).

There was moderate species richness and even across all the growing the growing seasons with a Simpson Index of 0.1352 and 0.1452 in the first and second growing seasons respectively. The level of infestation increased gradually from planting to maturity of the crop (Figure 3). The diversity of insect species also increased as the crop grew to maturity. The population of stem and leaf pests was high during the early stages of the crop growth but reduced as the plant attained maturity. The population of grain pests started accumulating at the milking stage of the crop and increased considerably as the crop reached maturity. This can be observed on the population trend of Cletus sp. and other bug population which were the major pests of attacking the grains. These findings agree with the research results of Oke and Ofuya (2011) on population dynamics of Cletus sp. on amaranth crop in Nigeria. Which demonstrate that the infestation of *Cletus* sp. starts at milking stage and continues to accumulate as the crop grows.

4.1.1.2 Significance of pest species collected

Adults of amaranth weevils are all leaf and stem feeders. There were three significant species that included *Hypolixus nubilosus*, *Nematocerus* sp. and *Baris massaica*. They chew semi-circles out of the leaf edges and windows in the leaf lamina. They target mostly the soft stems and leaves. Adult defaecation was visible all over the plants as small brown blotches. Their larvae on the other hand utilizes a number of feeding niches with *Nematocerus* sp. and *Baris massaica* boring endophytically in the above ground parts such as meristems and larger side stems and plant crowns, while *Hypolixus nubilosus* bore endophytically in stems and roots (Louw *et al.*, 1994).

The results of this study revealed that the infestation by the weevils took place throughout the growing period of the crop, with the number increasing gradually as the crop grew but began to drop as it matured. The females oviposited in the stems where eggs hatched into larvae which fed while tunneling through the stem. This pest resulted to significant crop loss especially through foliage damage. Other studies have also reported that this pest was found to cause considerable damage on amaranth leaves and stems (Torres *et al.*, 2011 & López *et al.*, 2011).

All plants examined in the laboratory presented galleries throughout the main stem. The galleries had occasional interruptions, dark coloration and the presence of chewed plant material mixed with feces of *Herpetogramma* spp. larvae. This is consistent with reports from amaranth crop fields in Mexico where the pupae were observed in the soil nearby host plants (Torres *et al*., 2011). *Herpetogramma bipunctalis* larvae have been observed feeding on several plant species (Solis, 2006; Oliveira *et al*., 2012). In Mexico this species was observed feeding on leaves and grains of Amaranthus spp. plant (Torres *et al*., 2011) as well as boring and building galleries inside the plant stems as observed in this study.

The galleries and exit holes make the stem weak and if the weather is windy it causes lodging of the crop resulting to yield loss if the crop is not yet mature (Plate 15). If the weather is not windy the crop continues to grow without significant loss on yield. Oliveira *et al*. (2012) observed that 100% of the crop examined presented galleries of up to 5mm in diameter throughout the main stems which was an indication of the presence of *H. bipunctalis* larvae. This larvae was also observed feeding and building galleries in stems of amaranth in Puebla, Mexico (López *et al*., 2011).

In the present study *Cletus* sp. was observed and collected in all plots and farms visited. It was found to be a major grain pest of amaranth and in high infestation, caused total loss of yield. These insects are observed mostly at the beginning of milking stage and the population increases as the grain matures (Figure 2). This was also observed by Oke and Ofuya (2011) in their study on amaranth in Ibadan, Nigeria. They observed that the population of *Cletus* sp. increases gradually from the start of milking stage to maturity, with the highest population being recorded slightly before harvesting.

Among the insects that damage the foliage we found grasshoppers which were observed in all the plots. The order Orthoptera was a significant order with four families and four species. This order consists of grasshoppers which is the only group of insects in this order collected during the research period. The most significant species was *Microcentrum rhombifolium* which infested the leaves of the crop especially during the early stages of crop development cutting the leaves and causing windowing. The number of species recorded in this study is higher compared to one species recorded by Gracia *et al.*, (2012) in their study in Brazil and López *et al.*, (2011) in their study in Mexico which recorded two species. Grasshoppers were using grass close to the amaranth plots as an alternative host and therefore were difficult to control. This has also been reported by Capinera *et al.*, (2007) and Basset (1999) in USA and New Guinea respectively.

4.1.1.3 Diversity of potential natural enemies

Most hymenopterans and some coleopterans observed in this study were classified as natural enemies or parasitoids of amaranth pests. *Dentichamias busseolae* which was sampled during the second season of planting has been reported as a pupal parasitoid of lepidopterans. The female parasitoid oviposits only in a borer pupa without a cocoon in a stem (Mailu *et al*., 1984).

Braconid parasite (*Bracon* sp.) was also observed occurring on amaranth during both the first and second season (Figure 2). Similarly, this insect was recorded in the survey conducted by López *et al*., (2011) in Mexico. *Bracon sp*. is a gregarious ectoparasitoid of weevils (Coleoptera) pest larvae (Dillon *et al*., 2008 and Evarard *et al*., 2009). Female braconid respond to the stumuli associated with the grab of the weevil actively feeding on or inside the stem of the crop (Faccoli and Henry, 2003). The female then inserts its ovipositor through the back of the stamp, to inject the larva with paralyzing venom prior to depositing a cluct of eggs on or near the body of the host (Evarard *et al*., 2009). This is the first study in Kenya which has reported the naturally occurring enemies and parasitoids of amaranth insect pest.

4.1.1.4 Seasonality of the insects

The results in this study showed that there was no significant difference ($P>0.05$) in the diversity of insects between all growing seasons. There was also no significant difference in population of insects between the growing seasons. Insect abundance and distribution are regulated by several biotic and abiotic factors and their interactions (Salvopoulou-Soultani *et al*., 2012). This biotic and abiotic factors are bound to change from season to season (Southwood *et al*., 2004) hence affecting the diversity and abundance of insects. The diversity and abundance of insects in this study did not change probably because the biotic factors in both seasons did not vary. The only thing that changed in both seasons was the level and period of rainfall whose impact on the diversity and species population is minimal.

4.1.2 Assessment of yield loss as a result of insect pest damage

The pest resulted in significant damage to the crop yield both grains and leaves (Table 1 and Table 2). The damage was as high as 49% in plots with *Amaranthus cruentus* with no control strategy used (Table 1). The attack to the leaves by pests is high during the first weeks of crop growth but reduces considerably as the crop matures (Figure 1). The loss in yield on the leaves was 42.5% (Table 2).

Bugs constitute major pests of amaranth causing considerable damage to mostly grains and leaves. The major genus of importance that was identified was *Cletus*. These were coreid bugs which began attacking the crop at milking stage that hampered seed development hence resulting to significant grain loss. In Meru most farmers prefer harvesting the grain hence grain loss to have major economic losses to the farmers. López *et al*., (2011) and Torres *et al*., (2011) in their studies in Mexico also observed that insect pests cause a significant damage to amaranth crop at all stages and there was need to design a comprehensive pest management strategy to control them.

4.1.3 Screening the effects of various pest control strategies on pest population

4.1.3.1 Tolerance of different crop lines to pest damage

Local variety of amaranth had a higher pest population and diversity compared to the other two hybrid varieties. This could probably be due to its fast growth and large leaves which makes it more preferable to pests than the other two lines. However, the damage by pests to this line compared to the other lines was not significant. This was due to its quick recovery from damage making the loss less significant. The major pest species was *Hepertogramma* sp. which resulted to lodging of stems (Plate 3.8) after severe attack and contributed to 20% loss of the crop during the second growing season.

Amaranthus dubius is majorly grown for its leaves. As observed in this research the growth characteristics of this line make it less attractive to insect pests hence no significant damage. Its shiny black grains are not attractive to insect pests hence the population of insect pests on this crop was very low. This line grows to about one meter above ground making it shorter than the other two lines. For this reason even under the attack of *Hepertogramma* sp. there was no loss due to lodging of the stems. Niveyro *et al*., (2008) in their study in Argentina affirms these findings that various genotypes or varieties had different numbers of insect pest species attacking them. They found out that *A.cruentus* had the highest number of insect species with *A. hypochondriacus* having the least number of insects.

Major losses on both the grain and leaves were observed on plots with *Amaranthus cruentus*. This plant line attracts a high population of insect pests second to the local variety. It has bright green leaves and golden-cream grains. It is mainly grown for grains but the leaves can also be harvested as the plant grows. This attributes makes this line more vulnerable to pest damage. The recovery of this line after pest damage is slow hence any slight attack to crop is detrimental. The grains were attacked mainly by *Cletus* sp. This pest attacked the crop at milking stage and if the attack was severe the crop ended up not producing any mature grains. The crop takes a shorter time to mature (70-90 days) compared to other varieties and if well managed the yield can be higher.

4.1.3.2 Impact of planting dates and growing seasons on insect population

There was no significant difference in the pest population and yield loss between the first planting date and second planting date. The first planting date was a week before the onset of the rains while the second planting date was two weeks after the onset of rains. The two experiments were conducted on the same farm hence it could have made it easier for the insects to migrate and establish in the plots during the second planting date. The insects were observed in the second planting period much earlier compared to the first planting season. The damage as a result of stem pests was higher in the plots planted at the onset of the rains than in delayed planting. This can be due to the fact that most stem and root pests lay on the ground and hatch when there is sufficient moisture thus attacking the first crop on the ground. By the second planting date most eggs had hatched and the insects established in other crops hence the damage is reduced. This method can be effective in control of ground and stem pests.

The pest population and damage was also compared over two seasons; long rains (September to December) and short rains (May – August). There was no significant difference in the pest diversity and yield loss over the two seasons. The occurrence of the insects was not seasonal but there was slight build-up in pest population during the second planting season especially of grain pests *Cletus* sp. These results concur with the finding of Oke and Ofuya (2011) in Nigeria. They observed that during the subsequent planting of amaranth on the same plots there was a build-up in *Cletus* sp. population from the previous season.

4.1.3.3 Botanical verses Chemical control

An effective control strategy is the one that reduces the population of the insect pests such that the overall yield loss is not economically significant and causes little or no damage to other beneficial insects or organisms. There was significant difference in the leaf yield loss between chemical control and neem extract treatments with plots treated with neem extract having a higher loss.

The neem leaf extracts were effective in causing significant reduction in leaf damage (70.79±1.5%) and grain damage (77.27±1.6%) compared to the untreated controls but comparatively less effective to chemical control by 6%. This implies the suitability of employing this method as an environmentally safe control measure. This assertion has been corroborated by Aderolu and Okelana (2013) who found that modified aqueous neem leaf extracts was effective in reduction of leaf damage by 72% and overall field infestation by 78%. Plots treated with neem extracts and pesticides recorded the lowest bug population therefore we can conclude that neem extracts can be employed in designing an integrated pest management plan for this pest. Other plant etracts (botanical extracts) have also been employed to manage amaranth insect pests. Arivudainambi *et al*., (2010) in their study found out that application of *Cleistanthus collinus* extracts on amaranth crop reduce population of beat web leaf caterpillar (*Hymenia recurvalis*).

4.1.3.4 Impact of the control strategies on beneficial insects

A control strategy cannot be said to be good if the effect on the beneficial insects which are supposed to aid in biological control as well pollination is detrimental. In this study the major beneficial insects belonged to the order hymenoptera which consisted of mainly the wasps of which are majorly parasitoids or parasites and order Coleoptera consisted of mainly the lady bird beetles which are predators.

Results on assessment of the impact of the control strategies on the population of this insects indicated that there was significant difference in the mean population of the insects under all treatments ($P>0.05$). Further separation of means using the Student Least Significant Difference (LSD) indicated a significant difference between the mean population in plots treated with chemical pesticides and all other treatments. Chemical treatment significantly reduces the population of natural enemies as compared to all other treatments. Agrios (2012) asserts that the broad effect nature and persistence of chemical pesticides has a lasting impact on beneficial insects and microbes. Any control strategy should be geared towards the reduction of pest population to a number that will not result to economic damage. In the design of a good integrated pest management system conservation of natural enemies is key and judicious use of chemical pesticides is only permitted once this system is not sustainable.

4.2 Conclusions

From this study it is concluded that there is a diverse number of insect species occurring in cultivated amaranth in Buuri district, Meru County, Kenya. The insect pests resulted to a consolidated loss of 50% of the total yield with 49% being attributed to grain pests and 42.5% caused by stem and foliage pests. The pests that caused significant grain yield loss were coreid bugs (*Cletus* sp.) which were found to attacks the grain, Amaranth weevil (*Hypolixus nubilosus*) caused damage on stems and leaves and Webworm (*Hepertogramma bipunctalis*) attacked stems and leaves. The pests results to significant yield loss on both the grain and leaves which are the harvestable parts of amaranth in this region necessitating control.

Neem (*Azadirachta indica*) leaf extracts are effective in the reduction of pest population and have little impact on the beneficial insects. Chemical control reduces the pest population considerably but reduces also the population of beneficial insects. Planting lines can also be used to reduce the yield loss as a result of pest damage. The local variety exhibited tolerance and quick recovery to pest damage resulting to low yield loss compared to other varieties. This can be employed by plant breeders to breed for varieties that have traits from this line.

A considerable number of naturally occurring enemies, parasites and parasitoids were collected indicating there is potential to conserve these insects for biological control. The beneficial insects belonged to two orders; Coleoptera and Hymenoptera. These insects can be reared artificially and introduced when the pest population reaches economic injury level (EIL) or can be conserved naturally as the crop grows and integrated with other control strategies.

From the present study it can be concluded that, an effective integrated pest management strategy can be achieved with correct planting lines, use of botanical pesticides (*Azadirachta indica* extract), and judicious use of specific/less potent chemical pesticides. Planting dates and seasons do not have an effect on pest population and diversity.

4.3 Recommendations

1. Further work should be done to investigate the potential of rearing the beneficial insects collected for biological control of amaranth pest and the impact on pest population dynamics.
2. Breeding for superior lines and varieties of amaranth that are pest resistant, faster growing and high yielding.
3. More sampling and identification of amaranth insect in other regions of the country should be done to increase the database of available information.
4. Farmers should employ crop rotation as a major pest management strategy to reduce the pest build up from the previous seasons.

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APPENDICES

Appendix A: Mean of production of amaranth grain under different treatments and analysis of losses due to pests of amaranth from Ex-situ plots in MUCST.

TREATMENT	REPLICATE	PLOT NUMBER	ACTUAL YIELD (Ya)	POTENTIAL YIELD (Yp)	YIELD LOSS (r)
***A. cruentus* 1st Planting**					
	1	05	0.388	0.5	0.224
	2	20	0.357	0.5	0.286
	3	23	0.382	0.5	0.236
***A. cruentus* 2nd Planting**					
	1	06	0.277	0.5	0.446
	2	13	0.22	0.5	0.56
	3	18	0.255	0.5	0.49
Neem extract	1	02	0.378	0.5	0.244
	2	16	0.394	0.5	0.212
	3	25	0.387	0.5	0.226
Chemical treatment					
	1	07	0.421	0.5	0.158
	2	15	0.424	0.5	0.152
	3	26	0.418	0.5	0.164
Local Variety 1st Planting	1	11	0.38	0.5	0.24
	2	19	0.343	0.5	0.314
	3	21	0.322	0.5	0.356
Local Variety 2nd Planting	1	14	0.318	0.5	0.364
	2	22	0.307	0.5	0.386
	3	27	0.324	0.5	0.352

Appendix B: Mean of production of amaranth leaves under different treatments and analysis of losses due to pests of amaranth from Ex-situ plots in MUCST.

TREATMENT	REPLICATE	PLOT NUMBER	ACTUAL YIELD (Ya)	POTENTIAL YIELD (Yp)	YIELD LOSS ®
***A. cruentus* 1st Planting**	1	05	0.475	0.8	0.40625
	2	20	0.492	0.8	0.385
	3	23	0.499	0.8	0.37625
***A. cruentus* 2nd Planting**	1	06	0.462	0.8	0.4225
	2	13	0.458	0.8	0.4275
	3	18	0.46	0.8	0.425
Neem extract	1	02	0.554	0.8	0.3075
	2	16	0.567	0.8	0.29125
	3	25	0.578	0.8	0.2775
Chemical treatment	1	07	0.684	0.8	0.145
	2	15	0.718	0.8	0.1025
	3	26	0.691	0.8	0.13625
Local Variety 1st Planting	1	11	0.627	0.8	0.21625
	2	19	0.618	0.8	0.2275
	3	21	0.612	0.8	0.235
Local Variety 2nd Planting	1	14	0.594	0.8	0.2575
	2	22	0.58	0.8	0.275
	3	27	0.611	0.8	0.23625
***A. dubius* 1st Planting**	1	01	0.587	0.8	0.26625
	2	17	0.601	0.8	0.24875
	3	09	0.592	0.8	0.26
***A. dubius* 2nd Planting**	1	24	0.56	0.8	0.3
	2	10	0.573	0.8	0.28375
	3	04	0.559	0.8	0.30125

Appendix C: Comparison of mean population of individual pest species using ANOVA

Analysis of Variance Table

Response: Grass Hopper Population

	Df	Sum Sq	Mean Sq	F value	Pr (>F)
Treatment **	7	2.4260	0.34657	4.0342	0.009912
Residuals	16	1.3745	0.08591		

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Analysis of Variance Table

Response: Bug Population

	Df	Sum Sq	Mean Sq	F value	Pr (>F)
Treatment ***	7	3.11713	0.44530	16.028	3.898e-06
Residuals	16	0.44453	0.02778		

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Analysis of Variance Table

Response: *Hypolixus* sp. Population

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment ***	7	6.7070	0.95814	13.673	1.119e-05
Residuals	16	1.1212	0.07007		

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Analysis of Variance Table

Response: Hymenoptera Population

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment ***	7	17.7673	2.53818	19.708	9.486e-07
Residuals	16	2.0606	0.12879		

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Appendix D: Summary of diversity of insects associated with Amaranthus species between May and September 2012 in Buuri District, Meru County, Kenya.

Dataset Totals

Total Number of Organisms:	1045	Total Number of Species:	28
Average population size:	37.32	Decimal Accuracy:	4
Total Number of Regions:	1	Total Number of Region Sets:	1

Alpha Biodiversity

Simpson Index $\frac{\sum_i n_i(n_i-1)}{N(N-1)}$	0.1352	Simpson Index Approximation $\frac{\sum_i n_i^2}{N^2}$	0.06851
Dominance Index $1-\left(\frac{\sum_i n_i(n_i-1)}{N(N-1)}\right)$	0.8648	Dominance Index Approximation $1-\left(\frac{\sum_i n_i^2}{N^2}\right)$	0.9315
Reciprocal Simpson Index $\frac{1}{\left(\frac{\sum_i n_i^2}{N^2}\right)}$	7.394	Alternate Reciprocal Simpson Index $\frac{1}{\left(\frac{\sum_i n_i(n_i-1)}{N(N-1)}\right)}$	14.6
Shannon Index $-\sum_i\left(\frac{n_i}{N}\cdot\log_2\left(\frac{n_i}{N}\right)\right)$	4.256	Berger-Parker Dominance Index $\frac{n_{max}}{N}$	0.1502
Shannon Index $-\sum_i\left(\frac{n_i}{N}\cdot\ln\left(\frac{n_i}{N}\right)\right)$	2.95	Inverted Berger-Parker Dominance Index $\frac{N}{n_{max}}$	6.656
Shannon Index $\sum_i\left(\frac{n_i}{N}\cdot\log_{10}\left(\frac{n_i}{N}\right)\right)$	-1.281	Margalef Richness Index $\frac{S-1}{\ln N}$	3.884
Menhinick Index $\frac{S}{\sqrt{\sum_i n_i}}$	0.8662	Rényi Entropy/Hill Numbers (r=0,1,2,∞) $\frac{1}{1-r}\cdot\ln\left(\sum_i p_i^r\right)$	28, 19.13, 14.6, ≈∞
Buzas and Gibson's Index $\frac{e^{-\sum_i\left(\frac{n_i}{N}\cdot\ln\left(\frac{n_i}{N}\right)\right)}}{S}$	0.6824	Gini Coeffificient	10.68
Equitability Index $-\frac{\sum_i\left(\frac{n_i}{N}\cdot\ln\left(\frac{n_i}{N}\right)\right)}{\ln N}$	0.8853	ln() of Hill Numbers (0,1,2,∞):	3.332, 2.951, 2.681, ≈-∞

Beta Biodiversity

Absolute beta Value $((S_0-c)-(S_1-c)...)$:	27	Whittaker's Index (S/alpha):	1

Sørensen's similarity index:	1	Alternate Whittaker's Index (S/alpha-1):	0
Sørensen's similarity index (%):	100%	Jaccard Index:	-1
Routledge beta-R Index:	9.333	Jaccard Index (%):	-100%
Mountford Index:	-0.07692	Number of Common Species:	28
Mountford Index (%):	-7.692%	Bray Curtis dissimilarity	0

Gamma Biodiversity

Absolute gamma (S_0+S_1...-c):	0		

Appendix E: Summary of diversity of insects associated with Amaranthus species between February and May 2013 in Buuri District, Meru County, Kenya.

Dataset Totals

Total Number of Organisms:	1153	Total Number of Species:	28
Average population size:	41.18	Decimal Accuracy:	4
Total Number of Regions:	1	Total Number of Region Sets:	1

Alpha Biodiversity

Simpson Index $\frac{\sum_i n_i(n_i-1)}{N(N-1)}$	0.1453	Simpson Index Approximation $\frac{\sum_i n_i^2}{N^2}$	0.07346
Dominance Index $1-\left(\frac{\sum_i n_i(n_i-1)}{N(N-1)}\right)$	0.8547	Dominance Index Approximation $1-\left(\frac{\sum_i n_i^2}{N^2}\right)$	0.9265
Reciprocal Simpson Index $\frac{1}{\left(\frac{\sum_i n_i^2}{N^2}\right)}$	6.882	Alternate Reciprocal Simpson Index $\frac{1}{\left(\frac{\sum_i n_i(n_i-1)}{N(N-1)}\right)}$	13.61
Shannon Index $-\sum_i\left(\frac{n_i}{N}\cdot\log_2\left(\frac{n_i}{N}\right)\right)$	4.148	Berger-Parker Dominance Index $\frac{n_{max}}{N}$	0.1587
Shannon Index $-\sum_i\left(\frac{n_i}{N}\cdot\ln\left(\frac{n_i}{N}\right)\right)$	2.876	Inverted Berger-Parker Dominance Index $\frac{N}{n_{max}}$	6.301
Shannon Index $\sum_i\left(\frac{n_i}{N}\cdot\log_{10}\left(\frac{n_i}{N}\right)\right)$	-1.249	Margalef Richness Index $\frac{S-1}{\ln N}$	3.83
Menhinick Index $\frac{S}{\sqrt{\sum_i n_i}}$	0.8246	Rényi Entropy/Hill Numbers (r=0,1,2,∞) $\frac{1}{1-r}\cdot\ln\left(\sum_i p_i^r\right)$	28, 17.76, 13.61, ≈∞
Buzas and Gibson's Index $\frac{e^{-\sum_i\left(\frac{n_i}{N}\cdot\ln\left(\frac{n_i}{N}\right)\right)}}{S}$	0.6334	Gini Coeffificient	10.08
Equitability Index $-\frac{\sum_i\left(\frac{n_i}{N}\cdot\ln\left(\frac{n_i}{N}\right)\right)}{\ln N}$	0.8629	ln() of Hill Numbers (0,1,2,∞):	3.332, 2.877, 2.611, ≈∞

Beta Biodiversity

Absolute beta Value ((S_0-c)-(S_1-c)...):	27	Whittaker's Index (S/alpha):	1

Sørensen's similarity index:	1	Alternate Whittaker's Index (S/alpha-1):	0
Sørensen's similarity index (%):	100%	Jaccard Index:	-1
Routledge beta-R Index:	9.333	Jaccard Index (%):	-100%
Mountford Index:	-0.07692	Number of Common Species:	28
Mountford Index (%):	-7.692%	Bray Curtis dissimilarity	0

Gamma Biodiversity

Absolute gamma (S_0+S_1...-c):	0