PHENOTYPIC VARIATION IN MORPHOLOGY, YIELD AND SEED QUALITY IN SELECTED ACCESSIONS OF LEAFY AMARANTHS

BY

OMONDI, JOSHUA OTIENO

A THESIS SUBMITTED IN PARTIAL FULFILLMENT

OF THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE IN GENETICS AND PLANT BREEDING

DEPARTMENT OF APPLIED PLANT SCIENCES

MASENO UNIVERSITY

DECLARATION

Declaration by the candidate

This thesis is my original work and has not been presented for a degree award in Maseno University or any other university.

Signature……Date…….

OMONDI, JOSHUA OTIENO

(PG/AF/00005/2012)

This thesis has been presented for examination by our approval as the University supervisors

PROF. MATHEWS DIDA

School of Agriculture and food security

Department of Applied plant Sciences

Maseno University.

Signature…….Date……

PROF. BARRACK OWUOR

School of Agriculture and food Security

Department of Applied plant Sciences

Maseno University

Signature……..Date……..

DR. PATRICK MUTHOKA

Senior Research scientist

National Museums of Kenya

Signature……Date……

ACKNOWLEDGEMENT

My utmost gratitude to the Almighty God for the good health and His providence throughout the study period. This far He has brought me He is my Ebenezer.

The completion of this work could have been a more daunting task were it not for the support, encouragements and useful suggestions extended to me by my friends, colleagues and supervisors.

I am especially grateful for my supervisors, Prof Mathews Dida, Prof Barrack Owuor and Dr. Patrick Muthoka whose consistent guidance, advice and support saw this piece of work push through.

I would like to appreciate Dr. Phoebe Sikuku and Mr. Ajwang Joseph whose constant encouragements gave me the impetus to further my studies. Were it not for them, masters studies would have remained a mirage.

May I also express my gratitude to my colleagues at Ngere High school, Mr. K'otieno, and Madam Linet for covering up for me whenever I left my working station for my studies, Mr. Okone for his great assistance in typesetting and compiling this work, Mr. Awuor for being very resourceful during this study and the director of studies, Mr Imbuye, who factored in my program within the school schedule.

Special thanks to my wife, Faith, for her profound understanding and sacrifice to accommodate my studies within our little family income. My children Emerald, Kayla and Eldad cannot go without being appreciated for when I looked at their faces every morning I saw a people yearning for a better future. This gave me the drive to work harder.

Thanks are due to KAPAP through the National Museums of Kenya fellowship whose financial support was of great importance during my research work.

Finally, my appreciation goes to Pastor Sika, Pastor Odong'a, Pastor Ogeda and the REFAM family led by Pastor Sammy and Pastor Rajula for standing with me in prayers. God granted me a great favour during this study period courtesy of their prayers.

DEDICATION

To my dear mum, Liz, who instilled the value of education in me and whose hard work and unrelenting support catapulted me to this level of education.

ABSTRACT

Vegetable amaranths are highly valued for being rich in proteins and micronutrients such as iron, calcium, zinc, vitamin C and vitamin A. In spite of the crop's exceptional nutritional qualities, very little effort has been put in to improve the foliage yield potential in Kenya. Reports on morphological phenotypic variation analysis in *Amaranthus* are rare and detailed agronomic recommendations for leaf and seed yields and quality enhancement are scanty. Research on the extent of the phenotypic variation of amaranths is of great significance in the choice of some of the amaranths accessions as progenitors for useful traits. It was on this background that this study assessed the phenotypic variation in morphology, yields and seed quality in five amaranth accessions commonly grown for leaf consumption in Kenya. The specific objectives of the study were; to evaluate growth and morphological variation, evaluate leaf and seed yields and to assess seed quality in the five accessions vegetable amaranths. The five accessions were planted in randomized complete block design (RCBD) with three replicates. The amaranth accessions were provided with uniform agronomic treatments. Data was collected on growth and morphological traits, leaf and seed yields and seed quality parameters from ten plants per plot. Seed moisture content was determined using the fresh weight basis as per the international seed testing association (ISTA) standards. Seed quality as measured by germination was conducted in four replicate samples of 25 seeds each. The seeds were sown on plain agar held in 90mm sterilin petri-dishes and incubated at temperatures of 24-26^{0}C. Data collected from the study on the quantitative traits were subjected to analysis of variance (ANOVA) at 5% level of significance. Clustering was done using agglomerative hierarchical clustering method. This study revealed that there was significant variation among the accessions in most of the growth and morphological characteristics. This could probably be attributed to lack of selection pressure on amaranths. There was also great diversity in leaf and seed yields, the most outstanding being *Amaranthus hybridus* (AH). An overall multiple regression model indicated significant positive correlation (R^2=0.7378) of the growth and morphological characteristics to leaf yield. The model accounted for 73.78% of the variation in leaf yield per plant. This implies that the greater the value of the growth and morphological characteristics the higher the leaf yield. Morphological characteristics thus contributed directly to leaf yield hence selection could be done on these traits to achieve leaf yield improvement. Significant variation was observed in germination tests with accessions AH exhibiting the highest germination percentage. There was also significant differences in the moisture content among the five accessions. Cluster dendogram grouped the accessions into three clusters with agglomerative co-efficient of 0.81. All the landrace variety (LV) were grouped in cluster 1, Evergreen variety (EG), accession from gene bank of Kenya (GBK) and simlaw (SIM) were grouped in cluster 2 and *Amaranthus hybridus* (AH) grouped in cluster 3. Accessions EG, GBK and SIM clustered together because they are of the same species even though they were sourced from different collections. The study concluded that accession AH is the best source of growth and morphological traits for a breeding programme, the best for selection for both vegetable and seed production and the best producer of quality seeds. Accession AH can thus be recommended to Kenyan farmers as the most suitable cultivar for agro-ecologies similar to Mumias sub-county. Accession AH can also serve as a dual purpose cultivar to farmers in Western Kenya. Landrace variety (LV) was found to contain early maturity traits hence suitable for selection for earliness.

TABLE OF CONTENTS

TITLE……...i

DECLARATION……ii

ACKNOWLEGEMENT…….iii

DEDICATION……iv

ABSTRACT……....v

TABLE OF CONTENTS……vi

ABBREVIATIONS AND ACRONYMS…….....x

LIST OF TABLES…….xii

LIST OF FIGURES……..xiii

LIST OF APPENDICES……...xiv

CHAPTER ONE: INTRODUCTION……..1

1.1 Background information……1

1.2 Statement of the problem……...3

1.3 Justification……4

1.4 Objectives of the study……..4

1.4.1 General objective……....4

1.4.2 Specific objectives……..4

1.5 Null hypothesis……..5

CHAPTER TWO: LITERATURE REVIEW…….....6

2.1 Amaranthus…….....6

2.1.1 Origin and domestication……6

2.1.2 Botany…….7

2.1.3 Cultivated varieties of amaranth…….7

2.1.4 Cytogenetics of amaranths……..9

2.1.5 Agronomic practices on amaranth……. 9

2.1.6 Amaranth distribution in Kenya……14

2.2 Morphological variability of amaranths…….....14

2.3 Yield performance in vegetable amaranth……18

2.4 Pollination and seed viability testing……....21

2.4.1 Pollination…….21

2.4.2 Seed viability testing……22

CHAPTER THREE: MATERIALS AND METHODS……...23

3.1 Experimental site…….23

3.2 Seed acquisition……...25

3.3 Agronomic practices……....25

3.4 Experimental design…….26

3.5 Data collection…….29

3.5.1 Growth and morphological traits……..……29

3.5.2 Yields……30

3.5.3 Seed quality parameters……31

3.6 Data analysis……35

CHAPTER FOUR: RESULTS……...36

4.1 Growth and morphological variation…….....36

4.1.1 Qualitative characteristics…….36

4.1.2 Plant architectural traits……37

4.1.3 Leaf character traits……...41

4.1.4 Phenological traits…….....46

4.1.5 Cluster analysis……49

4.2 Yields……...52

4.2.1 Leaf yields……52

4.2.2 Seed yields……54

4.3 Seed quality parameters……...56

CHAPTER FIVE: DISCUSSION……...60

5.1 Growth and morphological variation……...60

5.1.1 Qualitative traits……....60

5.1.2 Plant architectural traits……60

5.1.3 Leaf character traits……...62

5.1.4 Phenological traits…….....64

5.1.5 Cluster analysis……65

5.2 Yields……...65

5.2.1 Leaf yields……65

5.2.2 Seed yields……67

5.3 Seed quality……..67

CHAPTER SIX: SUMMARY, CONCLUSIONS AND RECOMMENDATIONS……69

6.1 Summary…….....69

6.2 Conclusions……..70

6.3 Recommendations……..……..70

6.3.1 Recommendations from the present study……....70

6.3.2 Recommendations for further research……71

REFERENCES……72

ABBREVIATIONS AND ACRONYMS

$^{\circ}C$	-	Degrees centigrade
a.s.l	-	above sea level
ANOVA	-	Analysis of Variance
cm	-	centimetres
cm^2	-	square centimetres
DAFFSA	-	Department of Agriculture, Fisheries and Forestry of South Africa
DAP	-	Diammonium phosphate
DNA	-	Deoxyribonucleic acid
FAO	-	Food Agriculture Organization
GBK	-	Gene bank of Kenya
GCV	-	Genotypic co-efficient of variation
GS	-	Genetic Similarity
IPGRI	-	International Plant Genetics Resource Institute
ISTA	-	International Seed Testing Association
KAPAP	-	Kenya Agricultural Productivity and Agri-business Programme
LSD	-	Least significance difference
m	-	metres
MC	-	Moisture content
m^2	-	square metres

MDDP	-	Mumias District Development Plan
mm	-	Millimetres
NMK	-	National Museums of Kenya
RAPD	-	Random Amplified Polymorphic DNA
RCBD	-	Randomised complete block design
RH	-	Relative humidity
SSR	-	Simple Sequence Repeats

LIST OF TABLES

Table 1: Summary of traits examined and method of data collection…….....33

Table 2: Plant qualitative traits…….…….…….....36

Table 3: Plant height…….…….38

Table 4: Number of branches on the main stem…….……...…39

Table 5: Number of internodes on the main stem.....…....40

Table 6: Leaf blade ratio…….……...42

Table 7: Number of leaves per plant……..……...…….44

Table 8: Total leaf area per plant…….……..46

Table 9: Days to 50 % flowering…….……..……47

Table 10: Days to 50 % maturity…….……..49

Table 11: Leaf yields per plant…….…….....53

Table 12: Pearson's moment correlation co-efficient……54

Table 13: Seed yield per plant…….…….…….....55

Table 14: Percent seed germination…….....57

Table 15: Seed moisture content…….…….…….....59

LIST OF FIGURES

Figure 1(a): Map of Kenya showing the location of mumias sub-county…….24

Figure 1(b): Map of Mumias sub-county and its administrative units……...24

Figure 2: Dendogram of five amaranth accessions following the agglomerative hierarchical Clustering method……..51

APPENDICES

Appendix I: ANOVA for the different morphological variables among the accessions in season 1……78

Appendix II: ANOVA for the different morphological variables among the accessions in season 2……79

Appendix III: ANOVA for the different morphological variables among the accessions in season 1 and 2 combined……80

Appendix VII: Result of multiple regression model of leaf yield per plant……..82

CHAPTER ONE

INTRODUCTION

1.1 Background information

Amaranth is a herbaceous annual plant in the family *Amaranthaceae.* Plants in the genus *Amaranthus* have green or red leaves and branched flower stalks (heads). Mature plants bear small seeds, variable in colour from cream to gold to pink to shiny black. The genus *Amaranthus* consists of up to 70 species (in the form of cosmopolitan weed or cultivated plant) and is widely spread in all tropical and subtropical regions of the world (Espitia, 1994). In Kenya, amaranths exhibit the highest diversity of species exploited as traditional vegetables (Wambugu and Muthamia, 2009). Among the common species include *Amaranthus hybridus, A. dubius, A. spinosus, A. blitum, A. caudatus, A. graecizans, A. lividus, A. tricolor* and *A. viridis* (Wambugu and Muthamia, 2009).

Amaranths are usually distinguished as grain, vegetable, ornamental, or weedy (Brenner *et al*., 2000). The grain and the vegetable types, whose grain and leaves respectively are highly appreciated for human consumption, are the two major types of cultivated amaranths. The uncultivated amaranths are mostly weedy, including those that have not yet been cultivated or those that escape out of cultivation (Pal, 1972). Many amaranth species are collected from the wild for subsistence, while only few are cultivated or occur as protected weeds in backyards and home gardens (Stallknecht and Schulz-Schaeffer, 1993; Keller, 2004).

Amaranth vegetables contribute greatly to nutritional well-being of rural people by providing the essential nutrients required for body development and for prevention of diseases associated with

nutritional deficiencies, such as blindness due to vitamin A deficiency (Varalakshmi, 2011). The vegetables are also rich sources of vitamin C, protein, fibre and minerals such as potassium, phosphorous, calcium and zinc (Akindahunsi and Salawu, 2005; Orech *et al*., 2005). Vegetable amaranths are therefore highly recommended as food of high nutritional value with medicinal properties for young children, lactating mothers and for patients with constipation, fever, haemorrhage, anaemia or kidney complaints (Grubben and Denton, 2004).

Even though amaranth vegetables contribute greatly to nutritional well-being of humans, very little studies have been done to increase its foliage and seed yields potential in Kenya. There are thus few improved varieties of amaranths in Kenya unlike widely domesticated high yielding crops like maize or rice. This could probably be because amaranths are considered as a poor people's resource, and the plants are often reported as weeds hence ignored. This explains why it is to a larger extent grown for subsistence in the so called "kitchen" gardens or otherwise found in places near villages, roadsides, short grasslands sites, stony hillsides and cleared forest areas or silty riversides (Polhill, 1985). A good basis of improvement on foliage yield of any vegetable crop would be variation in the phenotypic traits hence the need for the study in morphological variation among selected vegetable amaranths in Kenya. Clean quality seeds for the crop are lacking in the market since most farmers grow their own seeds and sell seedlings in the local markets. Farmers do not therefore have good supply of seeds for vegetable amaranths (Shukla *et al*., 2010). Uniform stand of any variety hardly exist since most of the plots planted with landraces, tend to be highly heterogeneous. The viability of seeds produced on-farm is often low (Schippers, 2000). The technology of quality seed production is poorly understood and only a few of the stored seeds are viable beyond one season (Schippers, 2000).

An understanding on the extent of the diversity of amaranths would enable identification of some of the amaranth accessions as prospective genetic resources for useful traits such as variation in leaf size, leaf shape, branching, bolting pattern, growth and regrowth ability and color. Indeed with the vast wide geographical spread of amaranths, there is a more huge genetic diversity than that of numerous better understood crops such as rice, wheat and maize. The huge gene pool in widely separated areas can be tapped for the development of the crop. It is on this premise that this study evaluated the phenotypic variation in morphology, leaf and seed yields and the seed quality parameters in five amaranth accessions commonly grown in Kenya. Assessment of genetic diversity is invaluable in a crop-breeding programme, as it helps in the identification of diverse parental combinations to create segregating progenies with optimum genetic variability.

1.2 Statement of the problem

In spite of the high nutritional value and medicinal qualities in amaranth, very little research has been done on the crop's genetic improvement to increase foliage and seed yields potential in Kenya. The leaf yield potential for most amaranth cultivars in Kenya is hardly known, though recent research indicates that fresh leaf yield of up to 40 tonnes per hectare is possible (Anjali *et al*., 2013). There is thus scanty information on the crop's phenotypic variation in morphology, leaf and seed yields and seed quality parameters. Studies by modern plant breeders focus on variation at the molecular level but farmers are more concerned with phenotypic and agronomical variations and how these can be exploited to improve their livelihoods. Seeds for farmer selected varieties are the only ones available in the market hence farmers grow their own low yielding local cultivars. Farmers need better varieties but have no access to a good supply of quality seeds. Plots planted using seeds from landraces exhibit a mixture of different genotypes. This study provides an assessment of phenotypic variation in morphology, leaf and seed yields and seed quality traits in

five vegetable amaranth accessions. This is considered as a significant step towards the crop's selection and breeding programme in Kenya and the East Africa region.

1.3 Justification of the study

There is need for information on phenotypic variability of vegetable amaranth accessions commonly grown in Kenya. Most studies so far conducted on genetic diversity of amaranths are on grain amaranths and variability on morphological traits at molecular level. It is important to establish leaf and seed yields in vegetable amaranths commonly grown in Kenya. This will lead to identification and multiplication of accessions with outstanding performance in leaf and seed yields. There is also a need to provide farmers with good quality seeds to support amaranths production on-farm.

1.4 Objectives of the study

1.4.1 General objective

To determine the phenotypic and agronomic variation among selected amaranth accessions grown in Kenya.

1.4.2 Specific objectives

i) To evaluate the growth and morphological variation of five vegetable amaranth accessions
ii) To evaluate the leaf and seed yield of the amaranth accessions
iii) To assess the seed quality of the amaranth accessions

1.5 Null Hypotheses

- There is no growth and morphological variation among the five vegetable amaranth accessions.
- There are no differences in leaf and seed yield in the five amaranth accessions.
- There is no difference in seed quality among the five amaranth accessions.

CHAPTER TWO

LITERATURE REVIEW

2.1 AMARANTHUS

The genus *Amaranthus* consists of up to 70 species (in the form of cosmopolitan weed or cultivated plant) and is widely spread in all tropical and subtropical regions of the world (Espitia, 1994). Amaranth is an excellent versatile crop which can grow over a wide range of agro-climatic zones showing resistance to different environmental stresses and thereby may readily adapt to new environments (Brenner *et al*., 2000). Amaranth is a multi-purpose crop popularly grown as leafy vegetables with high nutrient values both for humans and animals (Mlakar *et al*., 2009; Khanam and Oba, 2013) and as grain amaranth (Brenner *et al*., 2000). In addition, amaranths having attractive inflorescence and leaf color are grown as ornamental plants (Mlakar *et al*., 2009).

2.1.1 Origin and domestication

Amaranth originated in America and is one of the oldest food crops in the world, with evidence of the crop's cultivation dating back as far as 6700 BC (DAFFSA, 2010). Evidence of domesticated amaranth seeds comes from the Tehuacan valley of Mexico and dates as early as 4000 BC (Sauer, 1967). Amaranth was eaten by hunter-gatherers in both North and South America before the domestication for agriculture (Sauer, 1967). The largest area ever grown was during the height of the Aztec civilisation in Mexico during the 1400s (Armillas 1971). After the arrival of the Spanish conquistadors in Mexico in the early 1500s, amaranth almost disappeared in America as a crop. Research was later started on amaranth in the US in the 1970s. Meanwhile, amaranth had spread around the world and was established for food (the grain or leaves) in places such as Africa, India

and Nepal. During the past two centuries, grain amaranth has been grown in various regions of the world, including Mexico, Central America, India and Nepal.

2.1.2 Botany

According to Agnew (2013), Amaranths are generally monoecious, erect and simple to freely-branched annual plants. They bear one to several stems that are able to grow to a height of up to 2 metres (m). The stems are striate and reddish, usually glabrous below the inflorescence. Leaves are alternate, the blade lanceolate or ovate to deltoid-elliptic, 2-10 centimetres (cm) long. Usually leaves are glabrous and narrowed abruptly to petioles. Flowers are numerous in crowded, spike-like, terminal or axillary clusters that are usually compound and up to 15 centimetres long, subtended by several linear-lanceolate, spine-tipped bracts 2.5-5 millimetres (mm) long. Sepals are somewhat unequal, those of the pistillate flowers about equal to the fruit, 2-3 mm long, narrowly oblong, acute to obtuse. Flowers have no petals. Stamens are usually three. Carpels are also usually three in number. Fruits are a one seeded capsules. The vegetable amaranths have small seeds which are usually shiny black in colour, in contrast to those of grain types which are cream-colored (O'Brien and Price, 2008) .

2.1.3 Cultivated species of Amaranth

Amaranths consist of 60–70 species (Xu and Sun, 2001) and include at least 17 species with edible leaves and three grain amaranths grown for their seeds (Grubben and Denton 2004). According to Das (2012) amaranth species can be classified into three categories, which represent more or less use-groups; Vegetable amaranths which includes *Amaranthus tricolor variety tricolor*, *Amaranthus tricolor variety tristis*, Grain amaranths which includes *Amaranthus hypochondriacus*, *Amaranthus caudatus*, *Amaranthus cruentus*, Weed amaranths with members such as *Amaranthus*

spinosus, *Amaranthus viridis*, *Amaranthus retroflexus*, *Amaranthus graecizans*, *Amaranthus dubius* and *Amaranthus hybridus*.

Vegetable amaranths can be easily distinguished from grain amaranths by inflorescence features. Vegetable amaranths mostly have inflorescence with axillary short spikes, flower bud originating from leaf axil, three petal lobes, three stamens, brownish black seed and indeterminate growth habit (Das, 2012). Grain Amaranthus are characterized by apical large to moderately large complex inflorescence comprising aggregates of cymes, five petal lobes, five stamens, seed with variable seed coat colour and well defined flange (Das, 2012). Other amaranths species adopted as vegetables are represented by *Amaranthus dubius*, *A. blitum* and *A. cruentus* (purple amaranth) (O'Brien and Price, 2008).

The utilization of amaranths as grain or vegetable depends on the regional preferences, as some grain species (*A. hypochondriacus, A. caudatus, and A. cruentus)* are also utilized as vegetables in Asian and African countries (Hauptli and Jain, 1983). The prominent vegetable species is *A. tricolor,* whose leaves are served as an affordable protein source in South-East Asia (Grubben, 1994).

The most commonly used amaranth species in Kenya are *Amaranthus hybridus, A. dubius*, *A. spinosus, A. blitum, A. caudatus*, *A. graecizans*, *A. lividus*, *A. tricolor* and *A. viridis*. (Wambugu and Muthamia, 2009).

2.1.4 Cytogenetics of amaranths

Karyotypical studies in the genus *Amaranthus* have indicated that there are two basic chromosome numbers, n = 16 and n = 17 (Khoshoo and Pal, 1972). Information on chromosome number of 30 species of *Amaranthus* show that all are diploids with 2n=32 or 2n=34 except *Amaranthus dubius* which is tetraploid (2n=64) (Grant, 1959). This study targeted *Amaranthus hybridus* which has 32 chromosomes, *Amaranthus lividus* which can either have 32 or 34 chromosomes and different accessions of *Amaranthus dubius* which are tetraploids.

Studies carried out on chromosome morphology of some species in the genus indicated extensive variation in number of chromosome pairs with satellites. Palomino and Rubí (1991) reported the karyotypic formula in some cultivars of *Amaranthus hypochondriacus* and *Amaranthus cruentus*, suggesting the existence of six to ten pairs of chromosomes with satellites in different cultivars.

2.1.5 Agronomic practices on amaranths

2.1.5.1 Propagation

Amaranth grows naturally from wild dispersed seeds which farmers routinely utilize. The crop is however propagated from seeds. Seedlings are fragile at young stage, so it is important to have a fine well drained media for propagation. Amaranth seedlings can easily be blocked from emergence by a thin crust on the soil which forms after rain (DAFFSA, 2010).

2.1.5.2 Site selection and soil preparation

In site selection, the field history especially past weed populations needs to be taken into account. It is best to avoid fields with weeds such as weedy amaranth, which germinate at soil temperatures similar to the amaranths (Weber, 1987). Since amaranths require shallow planting, their seeds are

susceptible to washing, or being buried by soil in the event of heavy rains before or during emergence. Such losses can be minimized by selecting fields that are level, and have plant residue from the previous crop on the soil surface. (Weber, 1987). Results have shown that the best growth in amaranth is achieved at soil pH above 6.0. (Singh and Whitehead, 1993). However, their growth decreases with the increase in soil acidity (Singh and Whitehead, 1993).

2.1.5.3 Planting

Propagation is generally by direct seeding. The small seeds is broadcast on prepared beds. The tiny seeds are covered with a little soil at a depth of less than a centimeter (National research council, 2006). Seeds may also be planted in seed trays then transplanted when the plants are about 15 cm tall (DAFFSA, 2010). Transplanting is done into rows 30 cm apart and with a spacing of 15 cm within the row. When transplanting seedlings, water is poured into the furrow or hole into which the plant is to be placed. The poured water is given time to seep into the soil. The plants are placed into the holes with roots in the mud-water mixture and then covered with soil. Seeds can also be sown in shallow rows 30 cm apart. The seeds are then covered lightly with soil (DAFFSA, 2010).

Seeding rate recommendations range from 1.2 to 3.5 kilograms per hectare depending on the type of soil and soil moisture (O'Brien and Price, 2008). Standard recommended seeding rate for commercial growers is 2 kilograms of seed per hectare. This rate produces so many seedlings that a large number can be lost without reducing yield. For dryland production, 0.5 to 1 kilograms of seeds per hectare is recommended (O'Brien and Price, 2008).

Putnam (1990) argued that amaranth seed germination is controlled by soil temperature. Myers (1996) found that temperature at or above 24^0C day/21^0C at night were needed for above optimum

amaranth germination in controlled environment tests. Weber (1987) noted that amaranth germination rate increases with thermogradient plate and 21.3^0C to 33.8^0C was the optimum temperature range for seedling emergence. Best results in germination is therefore obtained when seedlings are planted in warm temperatures (Whitehead *et al*., 2002).

2.1.5.4 Fertilizer application

Vegetable amaranth requires Diammonium phosphate fertilizer (DAP) at the rate of 200 kilograms (kg) per hectare during planting (Waithaka and Chweya, 1991). One of the essential elements, nitrogen, is an indispensable requirement for normal plant growth. High levels of nitrogen are essential for the re-growth of leaves after harvesting. To promote better re-growth, a top dressing of Calcium Ammonium Nitrate (CAN) can be given at monthly intervals. Nitrogen is the most limiting nutrient in most environments. Nitrogen requirement is approximately 200 kilograms per hectare. The requirement differs, depending on the species. Plants can be fertilized by using cow manure at 6 tonnes per hectare in combination with commercial fertilizers with high nitrogen contents. Higher yields are also obtained from plots fertilized with composted chicken manure, which has considerable quantities of nitrogen, a mineral that plays a key role in the development of the plant (especially leaf growth). A side dressing of compost is sometimes applied during active growth, especially if plants are grown for seed production (DAFFSA, 2010).

2.1.5.5 Weed control

Weeds are the biggest problem in amaranth production. Examples of weeds commonly found in amaranth fields include lambsquarter, redroot pigweed, kochia, cheatgrass and various other grasses (DAFFSA, 2010). Early weed control is important as amaranth seeds are small in size and

relatively slow to germinate (Ebert *et al*., 2011). The first step in effective weed control is to avoid planting into fields with heavy weed populations (Myers, 2011). Thorough land preparation is thus essential for effective initial weed control. A clean seedbed gives amaranth seedlings a head start on weeds and the plantlets may then establish a dense canopy that suppresses the emergence of weed seedlings. Mulching is recommended to reduce soil compaction and erosion, to conserve soil moisture, and to suppress weed competition (Ebert *et al*., 2011). Organic mulching materials should be free of weed seeds. Herbicides should only be used if absolutely necessary.

2.1.5.6 Pest and disease control

There is a wide range of insect pests that attack amaranths. These include snout beetles, moth larvae, fleas, stinkbugs and blowflies. Tarnished plant bug and amaranth weevil are regarded as potentially significant insect pests of amaranth (DAFFSA, 2010). Kioko *et al*. (2013) in a study on the insect abundance and diversity on cultivated amaranth species in Meru-Kenya found out that the most damaging insect pest on vegetable amaranth were *Cletus spp., Hepertogramma bipunctalis and Hypolixus nubilosus.* Other insects that can cause damage to developing amaranth include fall armyworm (*Spodoptera frugiperda*), cabbage looper (*Trichoplusia ni*), corn earworm (*Heliothis zea*) and the cowpea aphid (*Aphis craccavora*). The amaranth weevil (*Conotrachelus seniculus*) can damage roots, resulting in lodging or other root diseases. There are no synthetic insecticides labeled for amaranth, but various organic insecticides can be used to control these insect pest (DAFFSA, 2010).

No significant disease problems have been conclusively identified for amaranths. However according to O'Brien and Price, (2008) amaranth will contract some fungal diseases, particularly

seedling damping-off disease caused by *Pythium*, *Rhizoctonia* and *Aphanomyces* spp. and cankers caused by either *Phoma* or *Rhizoctonia*. Various root and stem rots can occur later in the season if the soils are wet, thereby contributing to lodging. *Alternaria* leaf spot is the most serious foliar disease. It is therefore advisable to use disease-free seeds and avoid both overwatering and dense planting (DAFFSA, 2010).

2.1.5.8 Harvesting

Vegetable harvesting

Most amaranth cultivars grow rapidly and may be harvested from 30 to 55 days from sowing, when they reach a height of 0.6 meters (DAFFSA, 2010). Where plants are harvested at regular intervals, picking of leaves begins eight weeks after sowing or four weeks after transplanting. When harvesting by repeated clippings, a two- or three-week interval is common through to the end of the season (O'Brien and Price, 2008). Leaf production can be sustained by the removal of flowers (Awe and Onsunlola, 2013). When the vegetative stage ends and flowering begins, subsequent harvests are lower in both quality and quantity (O'Brien and Price, 2008).

Seed harvesting

According to DAFFSA (2010) amaranth harvesting involves cutting the seed heads just before they become dry and brittle, laying the seed heads on a cloth or placing them inside paper or cloth bags with the heads down and leaving in the shade to finish drying. When the seed heads are dry, the seeds can be removed in several ways; by rubbing gently with your hands (wearing gloves is recommended), by enclosing the seed heads between two cloths and treading on them without shoes on and by beating the seed heads off a bag or by beating them together over cloth.

2.1.6 Amaranths distribution in Kenya

Chweya and Eyzaguire (1999) described the distribution of amaranths in Kenya as follows:

Amaranthus dubius is mostly common in the urban centers along roadsides at an altitude of below 2000 metres above the sea level. *Amaranthus graecizans* is most common in drylands but may also be found in more humid regions of Kenya. It is collected from the wild. It has not been found cultivated. It is a common plant in sandy areas, especially along the river banks and roadsides. *Amaranthus sparganiocephalus* is a common species in dry areas occupied by the pastoral groups. The plant is mostly found in pastoral settlements in semi-arid areas especially in the Northern and Southern parts of Kenya. It is found growing at 100-1600 metres above sea level. *Amaranthus hybridus* is mainly found as a weed of cultivation in degraded land and built up areas in humid to sub-humid lands. It is widely distributed in Kenya at an altitude of 900 to over 2600 metres above sea level. *Amaranthus spinosus* is a widely distributed species in Kenya being found in most areas below 1900metres above sea level. It is a common plant near the livestock enclosures. *Amaranthus blitum* is found in the Central and Western parts of Kenya at an altitude of about 800-2000 metres above sea level.

2.2 MORPHOLOGICAL VARIABILITY OF AMARANTHS

In view of the enormous nutritional benefits of the crop, there is a definite need for its genetic improvement to develop high foliage yielding varieties. In the process of genetic improvement of any crop, phenotypic variation among germ-plasm plays a major role. This is because it opens the way to determine the most divergent parents based on the contribution of different qualitative and quantitative traits, for feasible utilization in any hybridization program (Shukla *et al*., 2010).

Shukla *et al*. (2010) evaluated 39 strains of vegetable amaranth (*Amaranthus tricolor*) for eight morphological and seven quality traits in two test seasons to study the extent of genetic divergence among the strains. Cluster analysis grouped the strains into six clusters that displayed a wide range of diversity for most of the traits. They concluded that strains of a particular cluster having desirable genes for specific traits can be hybridized with other promising strains of different divergent clusters, which can facilitate the accumulation of favorable genes in hybrids. The obtained hybrids may then be fixed by recurrent selections of their selected transgressive segregants in advanced generations, which may lead to the development of high-foliage-yielding varieties rich in nutritional components. Rita *et al*. (2013) assessed the variations in morphology and protein content of Indonesian amaranths and compared them with the worldwide variation. They also evaluated the relative potential of Indonesian amaranths for improvement of vegetable production. They found that the variation in average values of most morphological traits and protein content in the Indonesian accessions were similar to those of the worldwide germplasm, but the important parameters that influence vegetable yield (e.g., number of leaves and stem diameter) were superior in the Indonesian accessions. Protein content showed a positive correlation with the number of leaves, whereas a negative correlation was observed with leaf thickness. The Indonesian accession of *Amaranthus viridis* and *A. dubius* showed a great potential for further selection as parental lines for high protein content and number of leaves. Simmonds, (2014) carried out a study on characterization of the phenotypic and genotypic diversity of amaranth species in response to drought stress. Trait screening was carried out on six local Malaysian cultivars and four Tanzanian landraces to assess suitable phenotypic characteristics for drought tolerance selection. Amaranth water use efficiency was carried out through a dry down experiment while genotypic characterization was carried out through simple sequence repeats (SSR) molecular

markers. Results revealed that amaranth is a drought tolerant crop variety. A morphological assessment of genetic variability among five accessions of *Amaranthus hybridus* by Akaneme and Ani (2013) revealed high significant differences for leaf width, hypocotyls length, days to 50% flowering, 500 seed weight and leaf length. The range of the co-efficient of variability, phenotypic and genotypic co-efficient of variability also revealed high variability for each quantitative trait.

Gerrano *et al.* (2010) carried out an evaluation on agro-morphological variability of thirty two *Amaranthus* genotypes in South Africa. The analysis of variance showed highly significant ($p \leq 0.01$) differences among the *Amaranthus* species for all phenotypic traits like plant height, number of branches on the main stem, number of leaves per plant among others. The differences in the phenotypic traits indicates existence of high genetic variability. Assessment of genetic interspecies relationships among five selected *Amaranthus* species using phenotypic and RAPD markers by Odigie-Tony (2012), exhibited a high degree of interspecies variability. Two common grain amaranths (*A. caudatus* and *A. cruentus*) and three major weedy types (*A. hybridus*, *A. spinosus* and *A. viridis*) were studied. Quantitative characters exhibited wide interspecies variation. Morphological cluster analysis showed that the five species were entirely distinct with a similarity coefficient of 0 except for *A. cruentus* and *A. hybridus* which shared very low coefficient of 0.093. Hasan *et al*., (2013) studied genetic variability, correlation and path analysis in stems of amaranth *(Amaranthus tricolor)* genotypes. Seventeen genotypes of amaranth (*Amaranthus tricolor*) were evaluated to determine the genetic variability, degree of association between yield and its component characters. High heritability with high genetic advance as percent of mean was registered for number of leaves, leaf weight and marketable yield which demonstrated the presence of additive gene effects. The correlation studies revealed strong positive association of yield with leaf weight, stem weight, stem diameter. The result of path analysis indicated that stem weight had

maximum direct effect on marketable yield followed by leaf weight, leaf number and dry weight without rind.

Ramesh *et al*. (2013) studied the genetic parameters in grain amaranthus (*Amaranthus hypochondriacus* l.) as influenced by plant densities. Ten genotypes were evaluated for twelve characters under four plant density levels, very high, high, normal and low plant density. The results revealed that the genotypic coefficient of variation (GCV) was maximum in high plant density when compared to very high, normal and low plant density levels for the characters, fresh weight of the inflorescence, length of the rachis per inflorescence, grain yield per plant and total carbohydrates. Leaf area at 50 per cent flowering, fresh weight of the inflorescence, number of secondary branches per inflorescence and total carbohydrates recorded high magnitude of genetic variability in combination with high heritability and genetic advance as per cent of mean in all the four plant density levels. An experiment on morphological and genetic variation of *Amaranthus spinosus* as an evidence of climate differences and gene interaction in indonesia by Arik *et al*. (2013) indicated that *A. spinosus* from tropical zones had a higher genetic variability than temperate zones. They therefore concluded that *A. spinosus* that adapt to different habitat have different morphological character and genetic variability. An investigation in the diversity of amaranth germplasm collection at the national plant genetic resources laboratory (NPGRL) in Philippines by Lavernee *et al*. (2016) revealed a high diversity in 17 characters out of the 34 evaluated. Five clusters were generated from the morphological characters. A study on genetic variation and character association in vegetable amaranth (*Amaranthus tricolor L*) in India by Pan *et al*. (2008) revealed a highly significant differences for the quantitative characters evaluated on indigenously collected germplasm lines of vegetable amaranth (*A. tricolor*). The maximum extent of genetic variability was exhibited by leaf-

stem ratio followed by total grain yields per plot, girth of stem and length of leaf. An estimation of genetic parameters, inter-relationships and genetic diversity of Indian vegetable amaranths by Chattopadhyay *et al*. (2013) showed significant variation among the genotypes entered for the experiment. The findings of the study pointed out that emphasis should be given to shoot weight per plant, stem-diameter and leaf-shoot ratio in selecting high yielding genotypes. Results further indicated that shoot weight per plant and leaf weight per plant were the greatest contributors towards genetic divergence.

The review shows substantial amount of work done on the characterization of amaranths in various countries. Most of these studies were on the grain amaranths and not vegetable amaranth commonly grown in Kenya. Studies on the variations of amaranths species cultivated in Kenya and their potential in breeding program has not been reported.

2.3 YIELD PERFORMANCE IN VEGETABLE AMARANTHS

Several studies have been carried out about the origin and interrelationship of different species of amaranths, germplasm characterization, their reproduction and hybridization. These studies have generally focused on grain amaranths which are selected for a high grain yield to the detriment of leaf production. Expanding research to vegetable amaranths strengthens the background information necessary for any breeding work. This requires collection, testing and diffusion of local communities' knowledge on the value of neglected amaranths species and an effective collaboration between farmers and scientists (Enoch *et al*., 2014).

Information on leaf yields in relation to the genotypes is hardly available. The few studies directed on

amaranth leaf yield, instead focus on the effect of different parameters on the leaf yield at the expense of leaf yields with respect to individual plant genotypes. Olowoake and Ojo (2014) evaluated the effect of fertilizer types on growth and yield of *Amaranthus caudatus* in southern Guinea savannah zone of Nigeria. The results indicated that the amaranth yield of 18.9 t/ha produced from organomineral fertilizer was significantly ($p<0.05$) higher than 17.6 t/ha obtained from NPK fertilizer. Amaranth growth parameters such as plant height, number of leaves, and yield values obtained from organomineral fertilizer was also significantly ($P<0.05$) higher than that of NPK and compost. Whitehead *et al.* (2002) researched on the effect of planting date on vegetable amaranth leaf yield, plant height and gas exchange in south eastern of United States. Results indicated that vegetative growth of June seeded amaranth that took place during the warmest part of summer had the maximum CO_2 exchange rate (CER), plant height and leafy fresh and dry yields. Awe and Onsunlola (2013) studied the influence of induced growth patterns on green yield components of *Amaranthus cruentus*. The findings in this study indicate that *Amaranthus cruentus* growers could adopt the method of cutting back the stem at 10 cm from the base at 21 days after transplanting in order to take full advantage of the yield potential of the crop. Svirkis (2003) investigated amaranth cultivation technology, such as, time, seed rate, row spacing etc. on amaranth yields. The highest yield was produced when amaranth had been sown in the middle of May, at a seed rate of 2–4 kg ha-1, with row spacings of 50 cm. Law-Ogbomo and Ajayi (2009) findings on growth and yield performance of *Amaranthus cruentus* influenced by planting density and poultry manure application in Benin showed that plant density and poultry manure significantly ($P = 0.05$) affected the number of leaves, leaf area index, total dry matter and the crop growth rate positively leading to higher herbage yield. An investigation into the influence of row spacing and nitrogen fertilizer on yield in vegetable amaranth (*Amaranthus cruentus* L) in Mubi northern Guinea savannah zone of Nigeria by

Mohammed (2016) revealed that fresh weight, dry matter weight, absolute crop growth rate per plant of vegetable amaranth increased significantly (P = 0.05) as row spacing and applied Nitrogen (N) rate was increased. On unit area basis however, fresh yield increased as the applied N increased and row spacing decreased. The optimum N rate and row spacing for the maximum yield of vegetable amaranth (*Amaranthus cuentus* L.) is 120 kg N ha-1 at 20 cm inter row spacing and was judged the best combination for the production of vegetable amaranth in the Northern Guinea Savannah zone of Nigeria. Afolayan *et al*. (2004) findings on the effect of tillage, namely, no-tillage (NT), slashing (SH), ploughing (PHO), ploughing plus harrowing (PHA), ploughing plus harrowing plus bedding (PHB) on growth and shoot yield of large green leafy amaranth (*Amaranthus ssp*.) in Ibadan, Nigeria, showed leaf area and stem girth performed significantly better under PHO and PHB respectively. Soil types and fertilizer regimes were evaluated on growth, yield, and quality of *Amaranthus tricolor* lines, IB (India Bengal), TW (Taiwan), BB (Bangladesh B), and BC (Bangladesh C) by Masanobu *et al*. (2014) in developing management practices in Okinawa, Japan. Growth and yield of all amaranth lines were higher in gray soil (pH 8.4) than in dark red soil (pH 6.6) and red soil (pH 5.4). The combined NPK fertilizer resulted in highest growth parameters and yield of amaranths in all soils. These studies mainly focus on how varied factors influence yields but do not put into perspective the leaf yields in relation to the individual plant genotypes.

Studies conducted on leaf yields so far show very little information on amaranth genotypes commonly grown in Kenya. Mbwambo *et al*. (2015) evaluated the performances of elite amaranth in grain and leaf yields in Northern Tanzania with the main objective of identifying cultivars which can be grown for dual purpose (both grain and leaf yield). The accessions with the gene bank names of TZMN102 and RVI00007 emerged to be the high yielding varieties in terms of both grain and leaf

yield. A study on agro-morphological diversity of *Amaranthus* species in central Malawi where 37 accessions were characterized using morphological traits revealed the highest yielding varieties as *Amaranthus hypochondriacus* and *Amaranthus tricolor* for seed and leafy vegetables respectively. Leaf yield ranged between 1.13 to 18.3 tonnes per hectare while seed yield ranged between 78 to 685 kilograms per hectare (Mwase *et al*. 2014).

2.4 POLLINATION AND SEED VIABILITY TESTING

2.4.1 Pollination

All monoecious species of *Amaranthus* are self-compatible and probably are primarily self-pollinated (Brenner *et al*., 2000; Costea *et al*., 2001). The flowers lack nectar glands, and pollination occurs predominantly by wind or gravity (Costea *et al*., 2001; Franssen *et al*., 2001). The pollen grains of *Amaranthus* species contain 1.2–7.5 percent (%) starch, which may play a role in protecting the pollen against desiccation. The pollen grain is covered with granules or spinules that facilitate adherence to the stigma hairs. The gynoecium of *Amaranthus* species does not have a style and consists of two or three united carpels. The unilocular ovary is sometimes narrowed toward the apex to form a ‘‘beak’’ filled with ramified cells and many intercellular spaces that are penetrated by the pollen tube during fertilization. The receptive part of the stigma is dry and covered with 2–4 rows of uni- or bicellular hairs (Costea *et al*., 2001). Amaranth is not only self-pollinating, but will also cross-pollinate (possibly even between different species). Wild amaranths are common in most areas worldwide. Individual heads of amaranths can be bagged to allow growing several varieties in proximity or to ensure that wild plants don't cross the plants you're growing. From ½ mile (green amaranths) to two miles (grain amaranths) are needed for reliable distance isolation (Suzanne, 2002).

2.4.2 Seed viability testing

Seed viability is usually assessed by means of a germination test, although other test procedures (such as the topographical tetrazolium test) may be required in order to clarify whether the non-germinating seeds in these tests are non-viable or whether their dormancy has not been broken during the test. Any empty seeds should be removed before beginning the germination test (FAO/IPGRI, 1994). The minimum standard is that accession viability monitoring tests be carried out at, or soon after, receipt of seeds and subsequently at intervals during storage. The initial germination test should be carried out on a minimum of 200 seeds drawn at random from the accession (FAO/IPGRI, 1994). The period between viability monitoring tests will vary among species and will also depend upon seed storage conditions. Gene banks should regularly conduct monitoring tests. Under the preferred storage conditions for base collections, the first monitoring test should normally be conducted after ten years for seeds with high initial germination percentage. Species known to have poor storage life or accessions of poor initial quality should be tested after five years and where necessary re-generated.

A crucial step in the promotion of amaranths is the production and supply of quality seeds. Seeds represent an important factor in food production, and their quality determines the performance of a crop (Achigan-Dako *et al.,* 2014). The seed supply system is still weak for many major crops and worse for neglected and under-utilized species including amaranths crops (Enoch *et al.,* 2014). This situation calls for the development of local seed programmes including commercial seed supply by small-scale seed enterprises, and community based seed supply systems that will ensure production and marketing of quality seed. In this regard, this study focused on the assessment of seed quality parameters with a view to produce quality seeds for the sustained cultivation of vegetable amaranths.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Experimental site

This study was conducted in Ekambara village in Matawa sub-location, Lureko location within Mumias sub-county in Kakamega county, western Kenya (Figure 1a and 1b). The experimental site lies at a longitude of 00 degrees 19.790' North and a latitude of 0.34 degrees 25.556' East. Ekambara village is situated at an altitude of 1264 metres above the sea level. The site has predominantly black cotton soils with some patches of loamy soils. Adjacent to the experimental site is the Nzoia River giving the area a good water resource. This, combined with good climate offer a high potential for crop development all the year round. Generally, Mumias sub-county has a few hills and valleys dissected by a number of other small rivers and streams. The sub-county has high temperatures all the year round ranging between 24^0C to 30^0C with mean maximum being about 30^0 C. The sub-county experiences high rainfall all the year round but it becomes less between December and February of each year. The annual rainfall ranges between 1597mm-2873mm per year with slight variations across the entire region (MDDP, 2012). The experiment was conducted in this site between the months of August to November, 2014 and February to May, 2015.

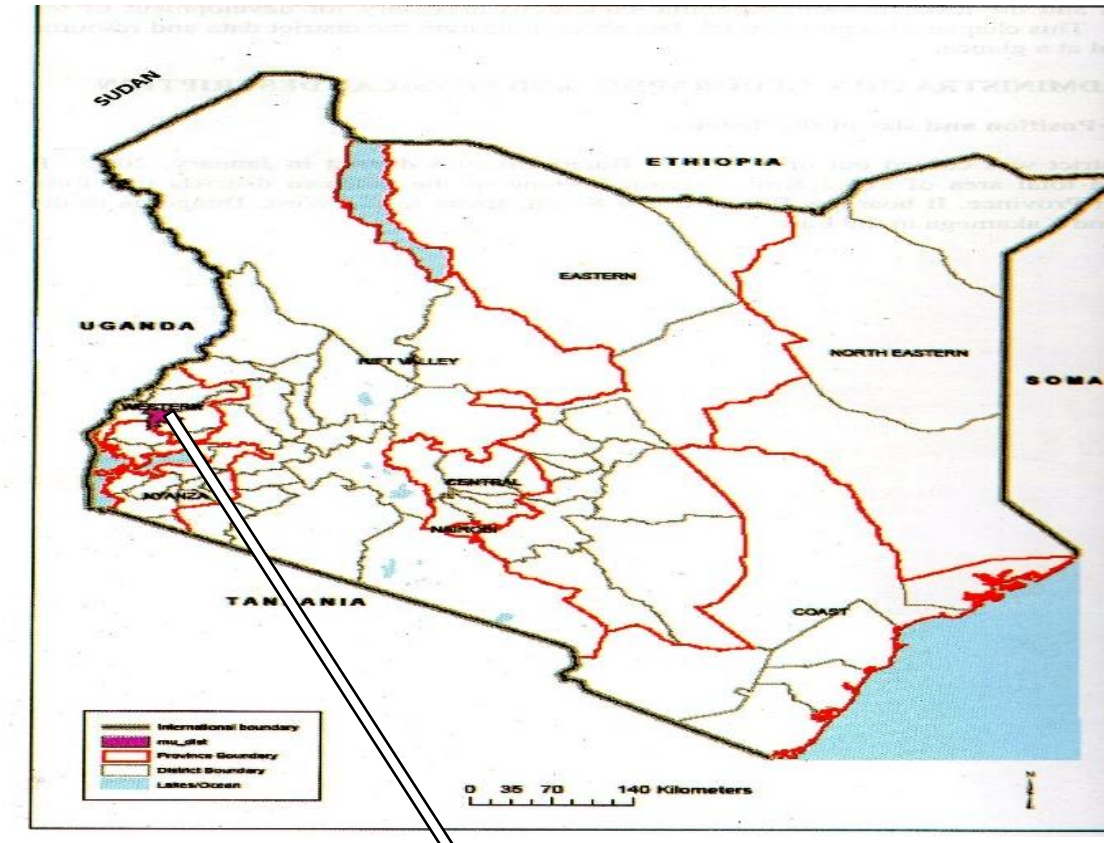

Figure 1(a): Map of Kenya showing the location of Mumias sub-county

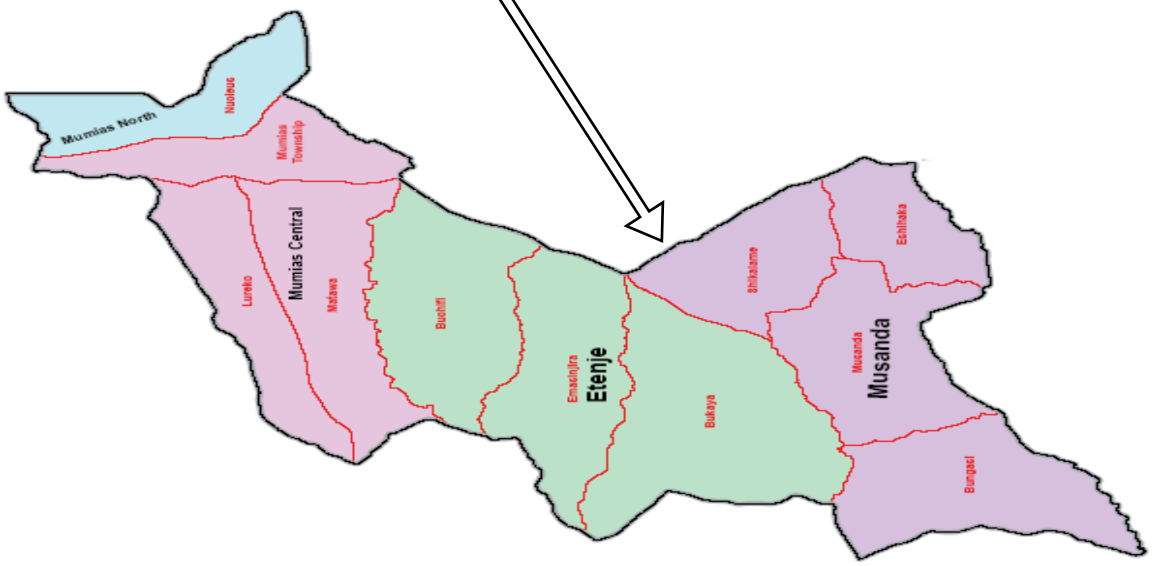

Figure 1(b): Map of Mumias sub-county and its administrative units

(Maps were obtained from Mumias district development plan-2012)

3.2 Seed acquisition

Seeds were acquired from several places. Two seed accessions, landrace (*Amaranthus lividus ssp lividus*) and evergreen varieties (*Amaranthus dubius* from Maseno) were sourced from farmers in western Kenya and confirmed as belonging to the species specified at national museums of Kenya using plants from the first season. *Amaranthus hybridus ssp cruentus* was sourced from Eastern Kenya farmers through National Museums of Kenya. Seeds of *Amaranthus dubius* was sourced by the National Museums of Kenya (NMK) from Simlaw seeds, Kijabe Street in Nairobi. Another accession of *Amaranthus dubius* (GBK 050699) was sourced from national gene bank of Kenya. The seeds were delivered to Maseno packed in airtight containers and paper bags.

3.3 Agronomic practices

Land preparation was carried out in the experimental field by hand digging. Farm yard manure was applied in the experimental site at a rate of 6 tonnes per hectare. This was followed by harrowing to a fine tilth since amaranth is a small seeded crop. Diammonium phosphate (DAP) fertilizer was applied at the rate of 200 kilograms per hectare. Planting was done through direct sowing on shallow drills at an inter-row spacing of 30 cm. First weeding was done within the second week after germination between the rows to reduce weed competition. Thinning was done after the third week making the distance between plants within rows to be 15 cm. During thinning Calcium Ammonium Nitrate (C.A.N) top-dress fertilizer was applied at the rate of 0.24 kilograms per experimental unit (200 kilograms per hectare). This fertilizer was applied uniformly to each plant using the ring application method.

3.4 Experimental design

The experiment was laid out as a Randomized Complete Block Design (RCBD). The blocking was against soil heterogeneity and edge effects. There were five accessions entered for this study. Each accession was sown in a separate plot. The experiment was replicated three times making a total of fifteen experimental units. Each experimental unit measured 3metres by 2metres. The experiment was conducted in two seasons, August to November, 2014 and February to May, 2015. Season one was characterized by cool and dry weather conditions while season two had warm and wet weather conditions. The accessions planted were:

LV- *Amaranthus lividus ssp lividus* (LV)

EG- *Amaranthus dubius* from Maseno (EG)

SIM- *Amaranthus dubius* from Simlaw (SIM)

GBK-*Amaranthus dubius* from gene bank of Kenya (GBK 050699)

AH-*Amaranthus hybridus* ssp *cruentus* (AH)

Accessions EG, GBK and SIM though belonging to the same species, were entered for this study since there germplasms were sourced from different places and therefore belong to different collections.

Grubben and Denton, (2004) described the morphological features of the amaranth accessions entered for this experiment as follows;

Amaranthus lividus ssp lividus (LV)

It is an annual herb which can grow to a height of up to 100 cm. Its stem may be erect or branched and glabrous. It has simple leaves, arranged spirally and without stipules. Leaf petiole is 1-10 cm long. Leaf lamina is angular and ovate measuring 1-10 cm long by 0.5-6 cm wide. Lamina is shortly cuneate at the base, notched at apex, have entire margin, glabrous, green or purple and pinnately veined. Inflorescence is characterized by many-flowered clusters, forming a false spike at the apex of plant, with male and female flowers intermixed. Bracts are able to grow up to 1 mm long. Flowers are unisexual, sub-sessile, with 3-5 tepals which can develop up to 1.5 mm long. Male flowers are made up of 3 stamens while female flowers have superior, one-celled ovary crowned by 2-3 stigmas. Fruits are sub-globular to broadly ovoid-ellipsoid capsules that are approximately 2 mm long. Fruits are one seeded, indéhiscent or bursting irregularly and crowned by stigmas. It produces glossy dark brown to black seeds, lenticular in shape and usually 1.5 mm in diameter.

Amaranthus dubius (EG, SIM and GBK)

Amaranthus dubius is an erect annual herb that can grow up to 150 cm tall. Its stems are slender to stout, branched, glabrous, especially in the inflorescence, with short to rather long hairs. Leaves are simple, spirally arranged and without stipules. Leaf petiole can grow up to a length of between 8.5cm to 12 cm. Leaf lamina is ovate or rhomboid-ovate measuring approximately 1.5-12 cm long by 0.7-8 cm wide. The lamina is cuneate at the base, blunt or refuse at apex, mucronate, entire, glabrous or shortly pilose and sometimes the centre is blotched red. Inflorescence is spike like or paniculate and can be axillary or terminal. Terminal inflorescence are usually 25 cm long, consisting of glomerules more or less isolated at base and agglomerated towards apex. Bracts are

able to develop up to 2.5 mm long. Flowers are normally unisexual, sub-sessile, with 4-5 tepals developing up to 2.5 mm long. Male flowers are usually found near apex of inflorescences, with 5 stamens which are 2 mm long. Female flowers have superior, one-celled ovary crowned by 3 stigmas. Its fruits are one seeded ovoid urceolate capsules that are about 1.5 mm long. The fruits have a short inflated beak below the stigmas, dehiscing circularly and the lid strongly rugulose below the beak. Seeds are black, lenticular in shape and approximately 1 mm long.

Amaranthus hybridus ssp cruentus (AH)

This is an annual herb mostly erect able to grow up to a height of 200 cm. Stems are stout, branched, angular, glabrous or thinly to moderately furnished with multicellular hairs. Leaves are simple, arranged spirally with long petiole but without stipules. Leaf lamina is broadly lanceolate to rhombic-ovate with an approximate measurement of 2-18 cm long by 2-15 cm wide. The lamina is shortly cuneate at the base, obtuse to sub-acute at the apex, mucronate, entire, glabrous to sparsely pilose and pinnately veined. Inflorescence consists of numerous agglomerated cymes arranged in axillary and terminal racemes and spikes. The terminal one can grow up to 45 cm long, with many lateral, perpendicular and thin branches. Bracts grow up to approximately 2-3 mm long, with a long awn. Flowers are usually unisexual, sub-sessile, with 5 tepals that are 1-2 mm long. Male flowers usually have 5 stamens 1 mm long while female flowers are characterized with superior, one-celled ovary crowned by 3 stigmas. Fruit capsules are one-seeded, obovoid to rhombic in shape and normally 2-2.5 mm long. Seeds are obovoid to ellipsoid in shape, compressed, whitish to yellowish or blackish and 1 mm long.

3.5 Data collection

Ten plants of each accession were randomly selected from each replication and tagged before taking agronomical data. From these tagged randomly selected plants, data were recorded in each replication for morphological traits, leaf and seed yields and seed quality parameters (Table 1). Data on growth and morphological traits were collected four weeks after planting, at 50% flowering and at 50% maturity from the ten tagged plants of each accession per replication.

3.5.1 Growth and morphological traits

Morphological traits examined were qualitative traits, plant architectural traits, leaf character traits and phenological traits.

3.5.1.1 Qualitative traits

Qualitative traits evaluated under this study were growth habit and seed colour. Data on the qualitative traits were collected from the ten tagged plants per plot through visual observation and recorded on a categorical scale.

3.5.1.2 Plant architectural traits

Plant architectural traits examined were plant height, number of branches per plant and number of internodes per plant. Data on plant height were collected by taking measurements of the height of each of the ten tagged plants per plot from the soil surface to the top of the apical inflorescence using a metre rule. Counts of number of branches and internodes on the main stem were done on each of the ten tagged plants per plot to establish the average numbers per plant. Data on plant architectural traits were collected twice in each season, at 50 % flowering and at 50 % maturity.

3.5.1.3 Leaf character traits

Leaf blade ratio per plant, number of leaves per plant and the total leaf area per plant were evaluated as leaf character traits. Leaf blade ratio was determined by taking measurement of length and width of five fully expanded leaves from each of the ten tagged plants per plot. Number of leaves per plant was determined by physically counting number of leaves along the main stem of each of the ten tagged plants per plot. The total leaf area per plant was determined by estimating the surface area of one fully expanded leaf using a graph paper from each of the ten tagged plants per plot and then multiplying by the number of leaves per plant. Data on leaf character traits were collected thrice in each season, at first harvesting which was done four weeks after planting, at 50 % flowering and 50 % maturity.

3.5.1.4 Plant phenological traits

Traits examined under this category were number of days to 50 % flowering and number of days to 50 % maturity. Days to 50 % flowering was determined by counting the number of days from planting time to 50 % flowering per plot. Data on number of days to 50 % maturity were collected by taking counts of number of days from planting time to 50% maturity per plot. Seeds were considered mature when changes were observed on the inflorescence color from green to brown.

3.5.2 Yields

The yield parameters studied were leaf and seed yields per plant.

3.5.2.1 Leaf yield

Leaf yield was determined by measuring fresh weight of fully expanded leaves from the ten tagged plants per plot. Leaf harvesting was done thrice, four weeks after planting, at 50 % flowering and

at 50 % maturity. Data from the three measurements were pooled together and used to calculate the average leaf yield per plant.

3.5.2.2 Seed yield

Seeds from the ten tagged plants per plot were taken as representative sample for the whole plot and weighed immediately after harvesting. Data from all the plots were consolidated and used to establish the average seed yield per plant.

3.5.3 Seed quality parameters

Seed moisture content and germination percentage were determined as measures for seed quality. Seeds used were taken from the ten plants tagged at the beginning of the experiment. After harvesting, the seeds were threshed by hand. The threshed seeds were cleaned by winnowing and air dried. Seed moisture content and % germination were then determined as follows:

i) Moisture content (M.C)

Tests for seed moisture content were conducted 2 days after harvesting in both seasons. A sample of 4 grams of seed for every accession was taken to be tested for moisture content. Moisture content was determined by low temperature oven method following ISTA (1985; 1996) procedure for oily seeds and expressed on fresh weight basis. A heat resistant container together with the cover was weighed and the measurement was recorded as measurement 1 (M1). Seeds were placed in the container and weighed together. This was recorded as measurement 2 (M2). Seeds were placed in an oven at 103^0C for 17 hours. After drying, the seeds were placed in dessication chamber while cooling to avoid re-absorption of moisture from the atmosphere. After cooling the

seeds and container were weighed again and recorded as measurement 3 (M3). The % moisture content was then calculated using the following formula

$$M.C. = \frac{(M2-M3) \times 100}{(M2-M1)}$$

Where; M.C = Moisture content, M1 = Measurement one, M2 = Measurement two**,** M3 **=** Measurement three**.**

ii) Seed germination tests

Germination tests were conducted 2 days after harvesting in both seasons one and two. Four replicate samples of 25 seeds each were sown on plain agar held in sterilin petridishes. Germination tests were incubated in cooled incubators at temperatures of 24-26^{0}C. Germination was recorded when radicles were at least 2millimetres (mm) in length. Scoring for germination was continued until no further germination was occurring. Germination % was calculated using the formula below;

$$\frac{\text{Number of seeds that germinated}}{\text{Total number of seeds sown}} \times 100$$

The aspects examined under this study and the methods of data collection are summarized in table 1 below.

Table 1: Summary of traits examined and method of data collection

Morphological traits		**Method of data collection**	**Data-type**
Qualitative traits	Growth habit	Visual observation	Category
	Seed colour	Visual observation	Category
Plant architectural traits	Plant height (cm)	Measurement of the height of a plant from the soil surface to the top of the apical inflorescence using a metre rule.	Numerical
	Number of branches on the main stem	Counts of number of branches on the main stem from each of the ten tagged plants at maturity stage.	Numerical
	Number of internodes on the main stem	Counts of number of internodes on the main stem from each of the ten tagged plants at maturity growth stage.	Numerical
Leaf character traits	Leaf blade ratio (length:width)	Measurement of length and width of one fully expanded leaf blade from each of the ten tagged plants per plot.	Numerical
	Number of leaves per plant	Counts of number of leaves along the main stem of each of the ten tagged plants per plot.	Numerical
	Total leaf area (cm^2)	Area of one fully expanded leaf estimated using a graph paper and multiplied by the average number of leaves.	Numerical

Phenological traits	Days to 50% flowering	Counts of number of days from germination to 50% flowering per plot	Numerical
	Days to 50% maturity	Counts of number of days to 50% maturity. Seeds are mature when the inflorescence changes its color from green to brown.	Numerical
Yields	Leaf yield	Measuring fresh weight of leaves from 10 plants per plot at 50 % flowering and 50 % maturity	Numerical
	Seed yield	Measuring weight of seeds from 10 plants per plot immediately after harvesting	Numerical
Seed quality parameters	Seed moisture content	A sample of 4 grams of seed for every accession was taken to be tested for moisture content. Moisture content was determined by low temperature oven method following ISTA (1985; 1996) procedure for oily seeds and expressed on fresh weight basis	Numerical
	% germination	Four replicate samples of 25 seeds each were sown on plain agar held in sterilin petridishes. Germination tests were incubated in cooled incubators at temperatures of 24-26^{0}C. Germination was recorded at regular intervals when radicles were at least 2millimetres (mm) in length.	Numerical

3.6 Data analysis

Data collected on quantitative characters was subjected to Analysis of Variance (ANOVA) using the general linear model of SAS statistical package with 5% level of significance used to test the difference between accessions. Separation of means was done only for those parameters where the ANOVA was significant using least significant difference at 5% level ($LSD_{5\%}$). Linear correlation was done to compare the relationship between morphological characteristics and leaf yield (Gomez and Gomez, 1984). Data from the quantitative characteristics was used for clustering the accessions using the agglomerative hierarchical clustering method. Data on qualitative traits were recorded on a categorical scale.

CHAPTER FOUR

RESULTS

4.1 Growth and morphological variation

The variation in phenotypic traits were grouped into five categories namely, qualitative traits, plant architectural traits, leaf character traits and plant phenological traits.

4.1.1 Qualitative traits

All the genotypes studied possessed an upright stature as their growth habit. The seed colour was black for all the genotypes except *Amaranthus hybridus* ssp *cruentus* whose seeds were brown in colour.

Table 2: Plant qualitative traits

Accession	Growth habit	Seed colour
AH	Upright	Brown
EG	Upright	Black
GBK	Upright	Black
LV	Upright	Black
SIM	Upright	Black

NB: AH=*Amaranthus hybridus ssp cruentus*, EG=*Amaranthus dubius* from Maseno, GBK=*Amaranthus dubius* from gene bank of Kenya, LV=*Amaranthus lividus ssp lividus*, SIM=*Amaranthus dubius* from simlaw.

4.1.2 Plant architectural traits

These traits were plant height (PH), number of branches on the main stem (NBMS) and number of internodes on the main stem (NIMS).

4.1.2.1 Plant height

A significant variation ($P<0.05$) was observed in mean plant height among the accessions for both seasons (Table 3). In the first season, *Amaranthus hybridus ssp cruentus* (AH) was significantly different ($P<0.05$) from *Amaranthus lividus ssp lividus* (SIM) and the tallest with a mean of 90.57 cm. It however showed insignificant difference ($P>0.05$) to the other accessions (Table 3). There was also an insignificant difference ($P>0.05$) among all the remaining accessions in plant height in this season. Accession LV was the shortest with a mean height of 34.97 cm. *Amaranthus dubius* from Maseno (EG), *Amaranthus dubius* from gene bank of Kenya (GBK) and *Amaranthus dubius* from simlaw (SIM) posted mean heights of 58.03 cm, 58.17 cm and 52.7 cm respectively. In the second season, accession AH was significantly different ($P<0.05$) from all the other accessions with a mean height of 96.97cm (Table 3). There was however insignificant difference ($P>0.05$) in mean plant height among the remaining accessions, EG (59.38 cm), GBK (57.12 cm), LV (56.15 cm) and SIM (40.98 cm). Combined seasons results also indicated accession AH as being significantly different ($P<0.05$) from all the other accessions.

Table 3: Plant height

Accession	Plant height (cm)		
	Season 1	Season 2	Mean
AH	90.57a	96.97a	93.77a
EG	58.03ba	59.38b	58.71b
GBK	58.17ba	57.12b	57.64b
LV	34.97b	56.15b	45.56b
SIM	52.70ba	40.98b	46.84b
Overall mean	58.89	62.12	60.50
LSD value$_{(0.05)}$	40.86	18.86	20.23
CV (%)	36.85	16.13	27.57

NB: AH=*Amaranthus hybridus ssp cruentus*, EG=*Amaranthus dubius* from Maseno (Evergreen variety), GBK=*Amaranthus dubius* from gene bank of Kenya, LV=*Amaranthus lividus ssp lividus* (Landrace variety), SIM=*Amaranthus dubius* from simlaw, CV=Co-efficient of variation, LSD=Least significant difference at $P<0.05$, Means followed by the same letter within the column are not significantly different at $P<0.05$.

4.1.2.2 Number of branches on the main stem (NBMS)

Results for mean number of branches on the main stem (NBMS) is presented in Table 4. It indicates that the number of branches on the main stem was significantly different ($P<0.05$) among the accessions in both seasons 1 and 2. There was however insignificant variation ($P>0.05$) between accessions AH and LV, SIM and GBK and EG and GBK in both the first and second season. In the first season, accession LV recorded the highest mean NBMS of 16.03 while accession EG had the least mean NBMS of 9.2. In the second season accession AH had the highest mean number of branches on the main stem with a mean of 30.73 while accession SIM had the

least mean number of branches on the main stem with a mean of 16.23. Results across the seasons showed significant differences (P<0.05) among the accessions. There was however insignificant variation between accessions AH and LV, EG, GBK and SIM.

Table 4: Number of branches on the main stem

Genotype	Number of branches on the main stem		
	Season 1	Season 2	Mean
AH	13.87a	30.73a	22.3a
EG	9.2c	20.93b	15.07b
GBK	10.97bc	17.13bc	14.05b
LV	16.03a	27.33a	21.68a
SIM	11.03bc	16.23c	13.6b
Overall mean	12.22	22.47	17.35
$LSD_{(0.05)}$	4.15	4.26	2.62
CV (%)	18.02	10.08	12.47

NB: AH=*Amaranthus hybridus ssp cruentus*, EG=*Amaranthus dubius* from Maseno (Evergreen variety), GBK=*Amaranthus dubius* from gene bank of Kenya, LV=*Amaranthus lividus ssp lividus* (Landrace variety), *Amaranthus dubius* from simlaw, CV=Co-efficient of variation, LSD=Least significant difference at P<0.05, Means followed by the same letter within the column are not significantly different at P<0.05.

4.1.2.3 Number of internodes on the main stem (NIMS)

Presented in Table 5 is the results of mean number of internodes on the main stem by accession. It indicates that there was a significant variation (P<0.05) in the mean number of internodes among the accessions in both seasons. In the first season, accession LV recorded the highest mean number of internodes on the main stem of 15.03. This was significantly different (P<0.05) from accessions

GBK (9.97), EG (8.2) and SIM (10.03) but insignificantly different (P>0.05) to accession AH (12.87). An insignificant difference was also observed between accessions EG and GBK, GBK and SIM and LV and AH in both seasons 1 and 2.

Table 5: Number of internodes on the main stem

Accession	Number of internodes on the main stem		
	Season 1	Season 2	Mean
AH	12.87ba	29.73a	21.3a
EG	8.2c	19.93b	14.07b
GBK	9.97bc	16.13bc	13.05b
LV	15.03a	26.33a	20.68a
SIM	10.03bc	15.23c	12.63b
Overall mean	11.22	21.47	16.35
$LSD_{(0.05)}$	4.1	4.2	2.62
CV (%)	19.62	10.54	13.23

NB: AH=*Amaranthus hybridus ssp cruentus*, EG=*Amaranthus dubius* from Maseno (Evergreen variety), GBK=*Amaranthus dubius* from gene bank of Kenya, LV=*Amaranthus lividus ssp lividus* (Landrace variety), *Amaranthus dubius* from simlaw, CV=Co-efficient of variation, LSD=Least significant difference at P<0.05, Means followed by the same letter within the column are not significantly different at P<0.05.

4.1.3 Leaf character traits

Leaf character traits examined under this study were leaf blade ratio, number of leaves per plant and the total leaf area per plant.

4.1.3.1 Leaf blade ratio

Table 6 presents the result of leaf blade ratio by accession. It shows that accession AH was significantly different ($P<0.05$) from all the other accessions in both seasons 1 and 2. There was however insignificant difference ($P>0.05$) among accessions EG, GBK, LV and SIM in both seasons. Accession AH had the highest mean leaf blade ratio of 1.78 and 1.84 in seasons 1 and 2 respectively while accession SIM recorded the least mean leaf blade ratio of 1.34 and 1.39 in seasons 1 and 2 respectively. Accessions EG, GBK and LV had mean leaf blade ratio of 1.37, 1.36 and 1.39 respectively in season 1 and 1.43, 1.54 and 1.50 respectively in season 2.

Table 6: Leaf blade ratio

Accession	Leaf blade ratio		
	Season 1	Season 2	Mean
AH	1.78a	1.84a	1.81a
EG	1.37b	1.43b	1.41b
GBK	1.35b	1.54b	1.45b
LV	1.39b	1.50b	1.44b
SIM	1.34b	1.39b	1.37b
Overall mean	1.45	1.53	1.49
$LSD_{(0.05)}$	0.11	0.14	0.08
CV (%)	3.93	4.93	4.65

NB: AH=*Amaranthus hybridus ssp cruentus*, EG=*Amaranthus dubius* from Maseno (Evergreen variety), GBK=*Amaranthus dubius* from gene bank of Kenya, LV=*Amaranthus lividus ssp lividus* (Landrace variety), *Amaranthus dubius* from simlaw, CV=Co-efficient of variation, LSD=Least significant difference at $P<0.05$, Means followed by the same letter within the column are not significantly different at $P<0.05$.

4.1.3.2 Number of leaves per plant

A significant variation ($P<0.05$) on the mean number of leaves per plant was observed among the accessions in both seasons (Table 7). In the first, season accession LV showed significant difference ($P<0.05$) to accessions EG, GBK and SIM but an insignificant difference ($P>0.05$) to accession AH (Table 7). Accessions AH, EG, GBK and SIM had insignificant difference ($P>0.05$)

among themselves in the mean number of leaves per plant. In this season, accession LV recorded the highest number of leaves per plant with a mean of 16 followed by accession AH with a mean of 13.67 then GBK, SIM and EG with mean number of leaves per plant of 11, 11 and 9.67 respectively. In the second season accession AH had the highest mean number of leaves per plant of 30.73 which was significantly different ($P<0.05$) from accessions EG (21), GBK (17) and SIM (16.33) but insignificantly different ($P>0.05$) from accession LV (27.37). There was also a significant difference ($P<0.05$) between accessions EG and SIM in this season. There was however insignificant difference ($P>0.05$) between accessions EG and GBK and GBK and SIM. A combined analysis of the two seasons revealed significant variation ($P<0.05$) between accession AH (22) and accessions EG (15), GBK (14) and SIM (13.67). An insignificant difference ($P>0.05$) in the mean number of leaves per plant was observed between accessions AH (22) and LV (21) and among accessions EG, GBK and SIM.

Table 7: Number of leaves per plant

Accession	Number of leaves per plant		
	Season 1	Season 2	Mean
AH	13.67ba	30.73a	22a
EG	9.67b	21b	15b
GBK	11b	17bc	14b
LV	16a	27.37a	21a
SIM	11b	16.33c	13.67b
Overall mean	12.27	22.49	17.38
$LSD_{(0.05)}$	4.02	4.35	2.62
CV (%)	17.39	10.27	12.45

NB: AH=*Amaranthus hybridus ssp cruentus*, EG=*Amaranthus dubius* from Maseno (Evergreen variety), GBK=*Amaranthus dubius* from gene bank of Kenya, LV=*Amaranthus lividus ssp lividus* (Landrace variety), *Amaranthus dubius* from simlaw, CV=Co-efficient of variation, LSD=Least significant difference at $P<0.05$, Means followed by the same letter within the column are not significantly different at $P<0.05$.

4.1.3.3 Total leaf area per plant

Presented in Table 8 is the result of mean total leaf area per plant by accession. It indicates that there was a significant variation ($P<0.05$) between accessions AH and all the other accessions in both seasons. There was however insignificant difference ($P>0.05$) among accessions EG, GBK, LV and SIM in both seasons. Accession AH recorded the largest total leaf area with a mean of 1795.8 cm^2 while accession LV had the smallest mean total leaf area of 591 cm^2 in the first season.

Accessions EG, GBK and SIM recorded mean total leaf area of 1042 cm^2, 1018.3 cm^2 and 1050.2 cm^2 respectively. In the second season, accession AH was significantly different ($P<0.05$) from the rest of the other accessions. There was however no significant difference ($P>0.05$) among accessions EG, GBK, LV and SIM. Accession AH had the largest mean total leaf area of 3908.43 cm^2 while accession LV had the lowest mean total leaf area of 753.06 cm^2. Mean total leaf area for accessions EG, GBK and SIM in the second season were 1630.81 cm^2, 1325.31 cm^2 and 1658.15 cm^2 respectively. A combined season 1 and 2 results showed significant difference ($P<0.05$) in the mean total leaf area among the accessions. An insignificant variation ($P>0.05$) was however observed between accessions EG, GBK and SIM and between accessions GBK and LV.

Table 8: Total leaf area per plant

Accession	Total leaf area per plant (cm^2)		
	Season 1	Season 2	Mean
AH	1095.8a	3908.4a	2501.1a
EG	542.0ba	1630.8b	1086.4b
GBK	518.3b	1325.3b	921.8bc
LV	89.7b	753.1b	421.4c
SIM	550.3ba	1658.2b	1104.2b
Overall mean	559.21	1855.16	1204.18
$LSD_{(0.05)}$	616.49	997.63	552.32
CV (%)	58.55	28.56	37.72

NB: AH=*Amaranthus hybridus ssp cruentus*, EG=*Amaranthus dubius* from Maseno (Evergreen variety), GBK=*Amaranthus dubius* from gene bank of Kenya, LV=*Amaranthus lividus ssp lividus* (Landrace variety), *Amaranthus dubius* from simlaw, CV=Co-efficient of variation, LSD=Least significant difference at $P<0.05$, Means followed by the same letter within the column are not significantly different at $P<0.05$.

4.1.4 Plant phenological traits

These were days to 50% flowering and days to 50% maturity.

4.1.4.1 Days to 50% flowering

Results of days to 50% flowering is presented in Table 9. It shows that the difference in number of days to 50% flowering was significant ($P<0.05$) among all the accessions in both seasons. Accession LV took the shortest time to attain 50% flowering of 36 days while accession EG took

the longest time to attain 50% flowering of 57 days in season 1. Days to 50% flowering for accessions AH, GBK and SIM were 42 days, 55days and 54 days respectively in this season. In the second season, accession LV took the shortest time of 35 days to attain 50% flowering while accession GBK took the longest time of 60 days to attain 50% flowering. The rest of the accessions took 52 days, 56 days and 57.3 days for accessions AH, EG and GBK respectively. Combined season 1 and 2 result also indicate a significant variation ($P<0.05$) in days to 50 % flowering among the accessions. An insignificant variation ($P>0.05$) was however noted in days to 50% flowering between accessions EG and SIM.

Table 9: Days to 50% flowering

Accession	Days to 50 % flowering		
	Season 1	Season 2	Mean
AH	43d	52d	47.5c
EG	57a	56c	56.5b
GBK	56b	60a	58a
LV	36e	35e	35.5d
SIM	55c	57b	56.1b
Overall mean	49.4	51.2	50.73
$LSD_{(0.05)}$	0.91	0.97	1.04
CV (%)	0.9	0.99	1.7

NB: AH=*Amaranthus hybridus ssp cruentus*, EG=*Amaranthus dubius* from Maseno (Evergreen variety), GBK=*Amaranthus dubius* from gene bank of Kenya, LV=*Amaranthus lividus ssp lividus* (Landrace variety), *Amaranthus dubius* from simlaw, CV=Co-efficient of variation, LSD=Least

significant difference at P<0.05, Means followed by the same letter within the column are not significantly different at P<0.05.

4.1.4.2 Days to 50% maturity

A significant variation (P<0.05) in days to 50 % maturity was observed among the accessions in both seasons 1 and 2 (Table 10). Accession LV was the first to reach 50 % maturity in both seasons 1 and 2 at 80 days and 75 days respectively (Table 10). It was followed by accession AH which took approximately 84 days and 83 days to attain 50 % maturity in the first and second seasons respectively (Table 10). Accession EG took the longest time to mature at 109 days in the first season while accession GBK was the last to mature after 90 days in the second season. A combined season 1 and 2 results also revealed that the accessions were significantly different (P<0.05) from one another in the number of days to 50 % maturity. Accessions EG, GBK and SIM generally took a much shorter time to mature in the second season than the first season (Table 10).

Table 10: Days to 50% maturity

Accession	Days to 50 % maturity		
	Season 1	Season 2	Mean
AH	83.67d	83.33d	83.5d
EG	109a	85c	97b
GBK	107b	90a	98.5a
LV	80e	75e	77.5e
SIM	105c	86.67b	95.8c
Overall mean	96.93	84	90.47
$LSD_{(0.05)}$	0.49	1.65	0.84
CV (%)	0.27	1.04	0.76

NB: AH=*Amaranthus hybridus ssp cruentus*, EG=*Amaranthus dubius* from Maseno (Evergreen variety), GBK=*Amaranthus dubius* from gene bank of Kenya, LV=*Amaranthus lividus ssp lividus* (Landrace variety), *Amaranthus dubius* from simlaw, CV=Co-efficient of variation, LSD=Least significant difference at $P<0.05$, Means followed by the same letter within the column are not significantly different at $P<0.05$.

4.1.5 Cluster analysis

A cluster dendogram was used to estimate the morphological diversity among the five accessions giving an idea of how closely related different accessions were. The result presented in figure 2 shows a dendrogram from agglomerative hierarchical clustering. The dendrogram groups the five accessions into three clusters from a single linkage. The dissimilarities occur at an approximate height of 4 resulting into three clusters. Cluster 1 consist of *Amaranthus lividus ssp lividus* (LV)

with dissimilarities at a height of 2 forming two sub-clusters and several groupings at a height less than 2. *Amaranthus dubius* from Maseno (EG), *Amaranthus dubius* from the gene bank of Kenya (GBK) and *Amaranthus dubius* from simlaw (SIM) are grouped into cluster 2 which is classified into two sub-groups at a height of 3.8. One of the sub-groups has only GBK while all the three accessions, EG, GBK and SIM were classified in the other sub-cluster. This sub-cluster has dissimilarities at a height of 3.5 further grouping into two, both splitting into many groups between height 2 and 1, but fails to completely separate EG, GBK and SIM. Cluster 3 had only AH with dissimilarities at a height of 3.6 forming two sub-clusters and many sub-groups below a height of 2.

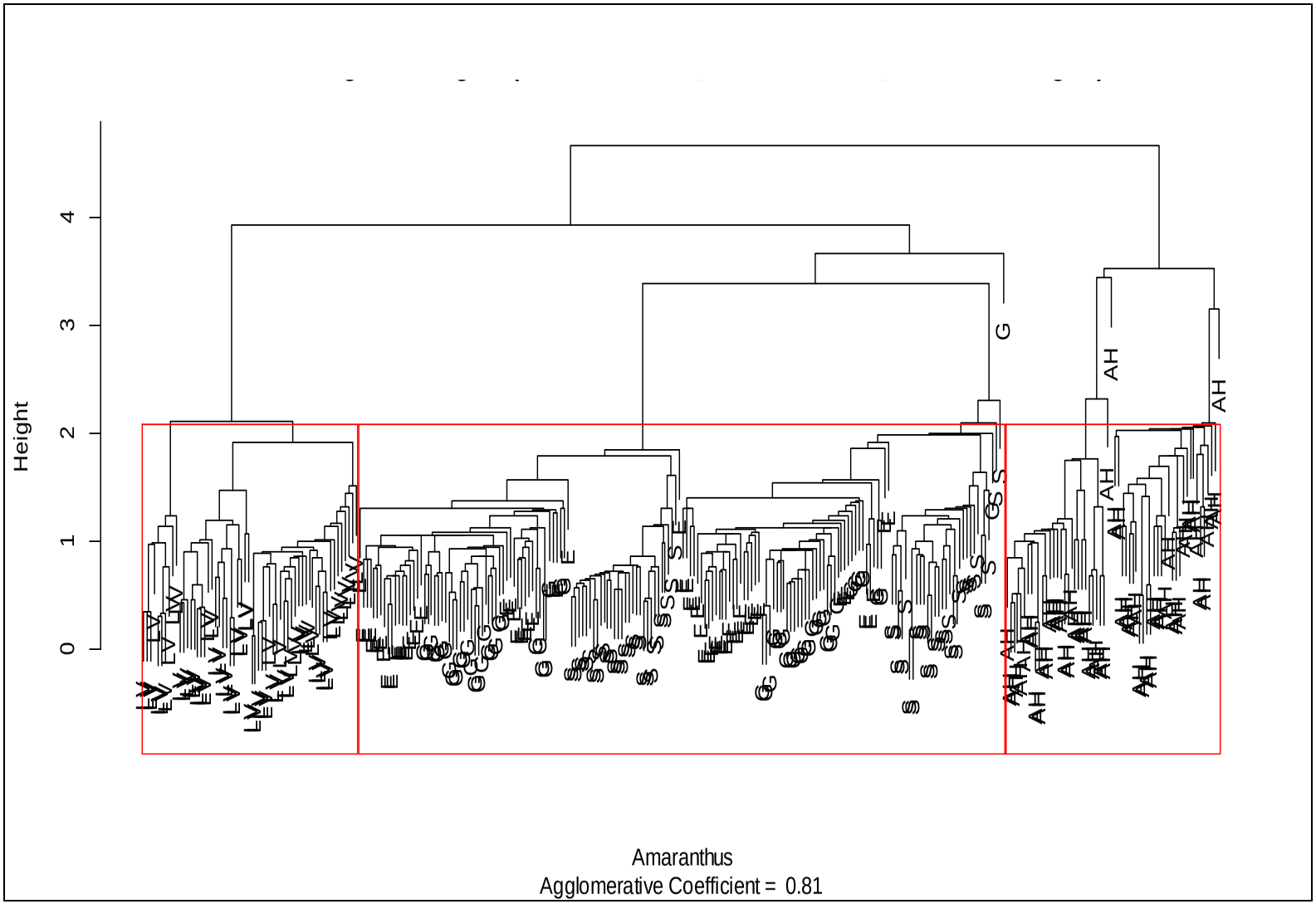

Figure 2: Dendogram of the five accessions following agglomerative hierarchical clustering method.

NB: AH=*Amaranthus hybridus ssp cruentus*, EG=*Amaranthus dubius* from Maseno, GBK=*Amaranthus dubius* from gene bank of Kenya, LV=*Amaranthus lividus ssp lividus,* SIM=*Amaranthus dubius* from simlaw

4.2 Yields

Measurements were taken on leaf and seed yields and results presented as follows:

4.2.1 Leaf yield

Presented in Table 11 is the result for mean leaf yield per plant for every accession. It shows that there was a significant variation ($P<0.05$) in mean leaf yield per plant among the accessions in the two seasons. In the first season, accessions AH and LV were significantly different ($P<0.05$) from each other and from accessions EG, GBK and SIM in leaf yield per plant. Accessions EG, GBK and SIM showed no significant variation ($P>0.05$) among themselves. Accession AH recorded the highest leaf yield per plant with a mean of 67.74g while accession LV recorded the lowest mean leaf yield per plant with a mean of 10.17g. Accessions EG, GBK and SIM had mean leaf yield per plant of 41.02g, 44.89g and 42.22g respectively. In the second season, accession AH had the highest leaf yield per plant of 135.99g which was significantly different ($P<0.05$) from all the other accessions. Accession LV recorded the lowest leaf yield per plant of 22.61g which was also significantly different ($P<0.05$) from accession EG but insignificantly different ($P>0.05$) from accessions GBK and SIM. No significant difference ($P>0.05$) was observed in leaf yield per plant between accessions EG (65.88g), GBK (38.28g) and SIM (47.45g). Combined result shows a significant difference ($P<0.05$) between accessions AH (101.86g) and LV (16.39g) in leaf yield per plant. The two accessions were significantly different from accessions EG, GBK and SIM. There was however no significant variation ($P>0.05$) in leaf yield per plant between accessions EG (52.45g), GBK (41.58g) and SIM (44.84g). A correlation analysis between growth and morphological characteristics and leaf yield indicated a significantly positive correlation between each of the growth and morphological traits and leaf yield (Table 12). The result demonstrated that there was a highly significant and positive correlation of leaf yield to plant height ($r=0.706$,

r^2=0.4988) and total leaf area per plant (r=0.839, r^2=0.7038). A significant and positive correlation was also observed between leaf yield and number of branches on the main stem (r=0.567, r^2=0.3220), leaf blade ratio (r=0.551, r^2=0.3040) and number of leaves per plant (r=0.567, r^2=0.3218).

Table 11: Leaf yield per plant

Accession	Leaf yield (g)		
	Season 1	Season 2	Mean
AH	67.74a	135.99a	101.86a
EG	41.02b	65.88b	53.45b
GBK	44.89b	38.28bc	41.58b
LV	10.17c	22.61c	16.39c
SIM	42.22b	47.45bc	44.84b
Overall mean	41.21	62.04	51.62
$LSD_{(0.05)}$	18.56	35.73	18.21
CV (%)	23.93	30.58	29.07

NB: AH=*Amaranthus hybridus ssp cruentus*, EG=*Amaranthus dubius* from Maseno (Evergreen variety), GBK=*Amaranthus dubius* from gene bank of Kenya, LV=*Amaranthus lividus ssp lividus* (Landrace variety), *Amaranthus dubius* from simlaw, CV=Co-efficient of variation, LSD=Least significant difference at P<0.05, Means followed by the same letter within the column are not significantly different at P<0.05.

Table 12: Pearson's moment correlation coefficients

Variable	Leaf yield per plant		
	Correlation coefficient, r	95% CI on r	r^2
PH	0.7063	0.6157 - 0.7784	0.4988
NBMS	0.5674	0.4479 - 0.6670	0.3220
BR	0.5514	0.4291 - 0.6539	0.3040
NLP	0.5673	0.4477 - 0.6669	0.3218
TLAP	0.8389	0.7840 - 0.8808	0.7038

NB: PH=Plant height, NBMS=Number of branches on the main stem, NIMS=Number of internodes on the main stem, BR=Blade ratio, NLP=Number of leaves per plant, TLAP=Total leaf area per plant.

4.2.2 Seed yield

Table 13 presents the results for seed yield per plant for each accession. It indicates a significant variation ($P<0.05$) among the accessions in seasons 1 and 2. Accessions EG, GBK and SIM however showed insignificant differences ($P>0.05$) among themselves in both seasons. Accession AH produced significantly ($P<0.05$) the highest seed yield of 85g and 66.77g in both seasons 1 and 2 respectively. Accession LV was the second highest seed yielding variety with a mean seed weight per plant of 29.4g and 18.2g in the first and second seasons respectively. Accession EG produced the lowest seed yield of 12.97g in the first season and 3.13g in the second season. Accessions GBK and SIM had seed yield per plant of 13.43g and 13.87g respectively in the first season and 5.70g and 5.77g respectively in the second season. A combined analysis of season 1 and 2 revealed a significant variation ($P<0.05$) among the accessions in seed yield. Accessions AH

(76.35g) and LV (23.8g) were significantly different from each other and from accessions EG (8.05g), GBK (9.57g) and SIM (9.82g).

Table 13: Seed yield per plant

Accession	Seed yield per plant (g)		
	Season 1	Season 2	Mean
AH	85.93a	66.77a	76.35a
EG	12.97c	3.13c	8.05c
GBK	13.43c	5.7c	9.57c
LV	29.4b	18.2b	23.8b
SIM	13.87c	5.77c	9.82c
Overall mean	31.12	19.91	25.52
$LSD_{(0.05)}$	7.72	8.12	4.92
CV (%)	13.18	21.65	15.87

NB: AH=*Amaranthus hybridus ssp cruentus*, EG=*Amaranthus dubius* from Maseno (Evergreen variety), GBK=*Amaranthus dubius* from gene bank of Kenya, LV=*Amaranthus lividus ssp lividus* (Landrace variety), *Amaranthus dubius* from simlaw, CV=Co-efficient of variation, LSD=Least significant difference at $P<0.05$, Means followed by the same letter within the column are not significantly different at $P<0.05$.

4.3 Seed quality parameters

Seed germination and seed moisture content were determined for each of the accessions as a measure of seed quality.

4.3.1 Seed germination

Table 14 presents % germination by accession. It shows a significant variation ($P<0.05$) between accession AH and accessions EG and GBK in the first season. There was however no significant variation ($P>0.05$) in % germination among accessions AH (95.67%), LV (72.33%) and SIM (76 %) and among accessions EG (61.33%), GBK (64.33%), LV (72.33 %) and SIM (76 %) in the first season. Results from the second season revealed a significant difference ($P<0.05$) between accessions EG and GBK and insignificant difference ($P>0.05$) among all the other accessions. Combined season 1 and 2 result indicates accession AH as being significantly different ($P<0.05$) from accessions GBK and LV with a germination percentage of 91.67. Accession GBK performed the lowest in germination test with a mean germination % of 66.33. This was insignificantly different ($P<0.05$) from accessions LV with % germination of 74.67, EG with % germination of 77.33 and SIM with % germination of 82.67.

Table 14: Percent seed germination

Accession	% germination		
	Season 1	Season 2	Mean
AH	95.67a	87.67ba	91.67a
EG	61.33b	93.33a	77.33bac
GBK	64.33b	68.33b	66.33c
LV	72.33ba	77ba	74.67bc
SIM	76.0ba	89.33ba	82.67ba
Overall mean	73.93	83.13	78.53
$LSD_{(0.05)}$	29.01	22.05	16.25
CV (%)	20.8	14.09	17.06

NB: AH=*Amaranthus hybridus ssp cruentus*, EG=*Amaranthus dubius* from Maseno (Evergreen variety), GBK=*Amaranthus dubius* from gene bank of Kenya, LV=*Amaranthus lividus ssp lividus* (Landrace variety), *Amaranthus dubius* from simlaw, CV=Co-efficient of variation, LSD=Least significant difference at $P<0.05$, Means followed by the same letter within the column are not significantly different at $P<0.05$.

4.3.2 Seed moisture content

Presented in table 15 is the result for seed moisture content by accession. It indicates that there was no significant variation ($P>0.05$) among all the accessions in the first season. Seed moisture content in season 1 were 22.19 % for AH, 19.73 % for EG, 22.47 % for GBK, 17.31 % for LV and 16.67 % for SIM. In the second season, accession AH and EG were significantly different ($P<0.05$) from each other and from each of the accessions GBK, LV and SIM in seed moisture content. There was however no significant difference ($P>0.05$) in seed moisture content among accessions GBK, LV and SIM. Seed moisture content of 8.84 % for accession AH, 7.49 % for accession EG, 5.87 % for accession GBK, 5.49 % for accession LV and 5.92 % for accession SIM were recorded in the second season. Results from the two seasons combined showed a significant variation ($P<0.05$) between accessions AH (15.51 %) and each of the accessions LV (11.40 %) and SIM (11.3 %). An insignificant difference was noted among accessions AH, EG and GBK and between accessions LV and SIM. Seed moisture content for the accessions in the second season were very low compared to first season (Table 15)

Table 15: Seed moisture content

Accession	Seed moisture content (%)		
	Season 1	Season 2	Mean
AH	22.19a	8.84a	15.51a
EG	19.73a	7.49b	13.61ba
GBK	22.47a	5.87c	14.17a
LV	17.31a	5.49c	11.40b
SIM	16.67a	5.92c	11.23b
Overall mean	19.67	6.72	13.2
$LSD_{(0.05)}$	5.83	1.11	2.72
CV (%)	15.75	8.76	17

**NB:* AH=*Amaranthus hybridus ssp cruentus*, EG=*Amaranthus dubius* from Maseno (Evergreen variety), GBK=*Amaranthus dubius* from gene bank of Kenya, LV=*Amaranthus lividus ssp lividus* (Landrace variety), *Amaranthus dubius* from simlaw, CV=Co-efficient of variation, LSD=Least significant difference at $P<0.05$, Means followed by the same letter within the column are not significantly different at $P<0.05$.

CHAPTER 5

DISCUSSION

5.1 Growth and morphological variation

5.1.1 Qualitative traits

All the five amaranth accessions were found to have an upright growth stature and black seed color except accession AH which produced brown seeds (Table 2). Amaranth seeds are reportedly brown to black color (Lanta *et al.*, 2003). A study on morphological assessment of genetic variability among accessions of *Amaranthus hybridus* by Akineme and Ani (2013) also reported erect growth stature of amaranths and brown to black seeds. The observations made were purely due to genetic differences since environmental influence has no effect on the qualitative characteristics.

5.1.2 Plant architectural traits

Amaranthus hybridus ssp cruentus (AH) was significantly different ($P<0.05$) from all the other four accessions in plant height in both seasons 1 and 2 (Table 3). Combined season 1 and 2 result indicated a range of 45.56 cm to 93.77 cm (Table 3) with accession AH being the tallest and *Amaranthus lividus ssp lividus* (LV) being the shortest. This is in tandem with DAFFSA report of 2010 which described height of amaranth to be ranging between 0.3m to 2m (DAFFSA, 2010). Similar findings were also reported by Chattopadhyay *et al*. (2010) in an experiment to estimate the genetic parameters, interrelationships and genetic divergence of vegetable amaranths in India which showed a plant height range of 36.30 cm to 97.6 cm. Plant heights were not significantly different ($P>0.05$) between the two seasons hence the variation reported among the accessions could largely be attributed to genetic effect.

Number of branches and internodes on the main stem were significantly different ($P<0.05$) among the accessions in season 1, season 2 and across the seasons (Table 4 and 5). In season 1, accession LV had the highest number of branches and internodes on the main stem with a mean of 16.03 and 15.03 respectively while *Amaranthus dubius* from Maseno (EG) had the lowest number of branches and internodes on the main stem with a mean of 9.2 and 8.2 respectively (Table 4 and 5). In season 2 accession AH had the highest number of branches and internodes on the main stem with a mean of 30.73 and 29.03 respectively while *Amaranthus dubius* from simlaw (SIM) had the lowest number of branches and internodes on the main stem with a mean of 16.23 and 15.23 respectively (Table 4 and 5). Significantly higher ($P<0.05$) mean values of number of branches and internodes on the main stem were generally recorded in season 2 than season 1 (Table 4 and 5). This could be due to warm and wet weather conditions that characterized season 2 thereby providing optimum conditions for growth of the amaranths accessions entered in this study. Vegetable amaranth has been reported to achieve optimum growth when air temperatures are above 25^0C (Whitehead *et al.,* 2002). Amaranths are known to grow very rapidly, particularly under bright sunlight and high temperature (Larvanee *et al.,* 2016). Season 1 however had cool weather conditions hence the low number of branches and internodes on the main stem for the accessions. The environment can thus be postulated as having had a greater influence on the variation in the number of branches and internodes on the main stem among the accessions. The mean number of branches and internodes on the main stem across the seasons ranged from 13 to 22 and 12 to 21 respectively (Table 4 and 5). These findings compare well with that of a similar study conducted on different strains of *Amaranthus tricolor* which revealed that the average number of branches per plant ranged between 13 to 29 (Shukia *et al*., 2010). An insignificant differences ($P>0.05$) in the number of branches and internodes on the main stem observed for

Amaranthus dubius species; from simlaw (SIM), from gene bank of Kenya (GBK) and from Maseno (EG) (Tables 4 and 5), was because they are of the same species and thus similar in their genetic constitution. In spite of LV being far much shorter than AH, it had insignificant difference (P>0.05) to AH in the number of branches and internodes on the main stem in both seasons and across the seasons. This was because the distance between its internodes was shorter than in AH. Accession AH showed remarkably high performance in plant architectural traits and could therefore be the best progenitor for these traits.

5.1.3 Leaf character traits

Amaranthus hybridus ssp cruentus (AH) was significantly different (P<0.05) from all the other accessions in leaf blade ratio in seasons 1 and 2 and across the seasons (Table 6). Blade ratio of all the accessions ranged between 1.34 to 1.78 in the first season, 1.39 to 1.84 in the second season and 1.37 to 1.81 across the seasons (Table 6). This is slightly below that of a similar study by Rita *et al*. (2010) on *Amaranthus* genetic resources of Indonesia that reported a blade ratio range of 1.5 to 2.0. This could be due to differences between the genotypes of the accessions studied and the cultivars in the previous study. The blade ratios in season 1 were not significantly different (P>0.05) from the blade ratios in season 2 for all the accessions except *Amaranthus dubius* from gene bank of Kenya (GBK) that showed a significant difference (P<0.05) (Table 6). The difference noted on GBK did not however make its blade ratio significantly different from the other accessions. Variation observed between accession AH and the other accessions could thus be attributed to genetic influence since findings for season 1 were the same as season 2. Accession AH can serve as the best source of this trait for selection in a breeding programme.

Number of leaves per plant was significantly different ($P<0.05$) among the accessions in both seasons and across the seasons (Table 7). The mean number of leaves per plant of between 13 and 22 (Table 7) corroborates the findings of a similar study on the phenotypic diversity of different strains of *Amaranthus tricolor* that reported the number of leaves per plant to be ranging from 12 to 22 (Shukia *et al*., 2010). Similar results were also shown in a study on Indian amaranths by Chattopadhyay *et al*. (2013) which reported the number of leaves per plant to be ranging from 15 to 45. Accessions LV and AH were significantly different from accessions EG (*Amaranthus dubius* from Maseno), GBK (*Amaranthus dubius* from gene bank of Kenya) and SIM (*Amaranthus dubius* from simlaw). The variation in the number of leaves per plant among the accessions could have been greatly influenced by the environment since the number of leaves per plant were significantly higher in season 2 than season 1 for all the accessions (Table 7). This was perhaps due to warmer weather conditions that favored amaranth growth in season 2 than season 1. Murua (2002) reported that effects of planting date is correlated with the temperature and ultimately affect the number of leaves and development of plant covering. There was however no significant variation ($P>0.05$) between accessions AH and LV in the number of leaves per plant despite AH being far much taller than LV. This was probably because accession LV had very many smaller leaves. Rita *et al*. (2013) indicated in a study of Indonesian amaranths that the more number of leaves amaranth produced the smaller they were. An insignificant variation ($P<0.05$) was also observed between accessions EG, GBK and accession SIM in the pooled data from the two seasons (Table 7). This was due to close genetic ties between them being accessions of the same species.

Accession AH posted significantly higher ($P<0.05$) mean total leaf area of 1795.8 cm^2 and 3908.43 cm^2 in the first and second seasons respectively. On the other hand accession LV had the lowest

mean total leaf area of 591 cm^2 and 753.06 cm^2 in the first and second seasons respectively. The mean total leaf area per plant by genotype (Table 8) supports the findings of a study by Rita *et al*., (2013) that reported a mean total leaf area ranging from 525.36cm^2 to 2987.37cm^2 for different clusters of amaranth studied. The lower mean total leaf area for accession LV can be attributed to its genotype which codes for its characteristic smaller leaves. Total leaf area per plant was significantly higher ($P<0.05$) in the second season than the first season (Table 8). This is an indicator that environmental factors could have played a major role in the variation observed in total leaf area per plant. An assessment of morphological diversity in *Amaranthus tricolor* and *A. viridis* by Reema (2015) showed a positive correlation between leaf area and plant height. It can therefore be argued that accession AH could have had the largest total leaf area courtesy of being the tallest plant among all the accessions. Accession AH could be considered as the best in terms of leaf production for fresh market since it had the highest total leaf area compared to the rest of the accessions. Accession AH had the largest total leaf area and could thus serve as the best progenitor for leaf size.

5.1.4 Phenological traits

A significant variation ($P<0.05$) was observed among the accessions in days to 50 % flowering (Table 9) and days to 50% maturity (Table 10) in both seasons and across the seasons. Accession LV (*Amaranthus lividus ssp lividus*) took the shortest time to attain 50% flowering of averagely 35.5 days (Table 9) and therefore matured the earliest within a period of averagely 78.5 days (Table 10). Accession LV can thus be considered as the best for this region in terms of selection for earliness. Accessions EG (*Amaranthus dubius* from Maseno), GBK (*Amaranthus dubius* from gene bank of Kenya) and SIM (*Amaranthus dubius* from simlaw) took a significantly shorter time to mature in season 2 than season 1. This could be due to more favourable environmental

conditions for their growth and development in season 2 that was warmer than season 1. Grubben (1980) reported rapid growth and high yields of amaranth at 30-35^{0}C.

5.1.5 Cluster analysis

A dendogram constructed based on the growth and morphological traits studied revealed three clusters from a single linkage (Figure 2). The dendrogram showed that the accessions that were similar in most of their growth and morphological characteristics clustered together. *Amaranthus dubius* species (Accessions EG, GBK and SIM) were placed in the same cluster. This is an indication they are of the same species hence closely related genetically. Each of the accessions EG, GBK and SIM failed to completely separate into their own sub-groups, an indication that amaranths show variations even among the same species. Accessions LV and AH were found in completely different clusters. This shows that accessions LV and AH probably have little genetic association between them hence the dissimilarity in most of their phenotypic traits.

5.2 Yields

5.2.1 Leaf yield

A significant difference ($P<0.05$) in mean leaf yield per plant was observed among the accessions in the two seasons (Table 11). There was however an insignificant variation ($P>0.05$ in leaf yield among accessions EG (*Amaranthus dubius* from Maseno), GBK (*Amaranthus dubius* from gene bank of Kenya) and SIM (*Amaranthus dubius* from simlaw). This is due to the fact that they are of the same species. Pooled data from the two seasons revealed the highest leaf yield per plant (135.99g) for accession AH (*Amaranthus hybridus ssp cruentus*) while accession LV (*Amaranthus lividus ssp lividus*) recorded the least leaf yield (22.61g) per plant (Table 11). This was way above the findings of a similar study on phenotypic diversity and nutritional traits of *Amaranthus tricolor*

by Shukia *et al*. (2010) which reported 3.61-5.15g/plant. This difference was perhaps due to variation in environment or accessions or interaction between accession and environment. Higher leaf yield was noted for all the accessions except GBK in season 2 than season 1 (Table 11). This could be due to warm-wet weather conditions that characterized the second season thereby enhancing more vegetative growth in the second season compared to first season. Whitehead *et al*. (2002) in their study of effect of planting date on vegetable amaranth leaf yield, suggested that warm weather conditions promote vegetative growth in amaranth. This is because amaranth is a C_4 plant and therefore grows well in warm temperature (El-sharkawy *et al*., 1968). Correlation studies revealed a significantly positive association between plant height ($r=0.706$, $r^2=0.4988$), number of branches on the main stem ($r=0.567$, $r^2=0.3220$), leaf blade ratio ($r=0.551$, $r^2=0.3040$), number of leaves per plant ($r=0.567$, $r^2=0.3218$) total leaf area per plant ($r=0.839$, $r^2=0.7038$) and leaf yield (Table 12). This implies that the greater the value of each of these traits, the higher the leaf yield. This accounts for the highest leaf yield recorded for accession AH since it was the best in most of the growth and morphological characteristics than all the other accessions. Accession AH can thus be considered as the best source of traits for vegetable production. Phenotypic variables whose existence and development are determined by both genes and gene x environment interactions are direct contributors to leaf yield (Shukia *et al*., 2006). Shukia *et al*., (2006) reported a positive contribution of several morphological traits like plant height, number of branches on the main stem, leaf area among others to the foliage yield in vegetable amaranths (*A. tricolor* L.). Selection based on the morphological characteristics could thus lead to increase in the leaf yield of the vegetable amaranth genotypes. Sarker *et al*. (2014) observed that increase in leaf area leads to a corresponding increase in leaf yield. Shukla *et al*. (2005) reported that foliage yield can be increased substantially either through direct or indirect selection based on the leaf size.

5.2.2 Seed yield

There were significant differences ($P<0.05$) in seed yield per plant among the accessions in both season 1 and 2 (Table 13). An insignificant difference ($P>0.05$) was however noted between accessions EG, GBK and SIM due to their similar genetical background. Result across the seasons revealed seed yield per plant of between 8.05g to 76.35g (Table 13). Erum *et al.* (2012) reported similar results for seed yield per plant at the range of 5g/plant to 129g/plant. The result also concurs with findings of Mbwabo *et al*. (2013) who reported seed yield per plant of between 13.39-54.46g/plant. However Shukia *et al.* (2010) findings on seed yield per plant from the different strains of *Amaranthus tricolor* was very low (0.34g-1.57g). This difference can be explained in terms of the diversity of the genotypes and the different geographical zones from which they were collected. The variation in seed yield per plant can therefore be largely attributed to the difference in the genetic make-up of the different accessions since seasonal variation did not have significant effect ($P>0.05$) on seed yield. Accession AH ranked the highest in terms of seed yield per plant, it can thus serve as the best source of this trait for selection.

5.3 Seed quality

Table 14 shows that there were significant differences ($P<0.05$) in mean germination percentages among the accessions in both season 1 and 2. Combined season 1 and 2 results indicate that accession AH had the highest mean germination percentage of 91.67% while GBK had the lowest at 66.33% (Table 14). This is in tandem with Erum *et al.*, (2012) findings on germination percentage in Pakistani amaranths which reported a germination percentage of 36.67 to 93.33. The relatively low germination percentage exhibited by some of the accessions may be due to lack of domestication processes and very little breeding efforts on the crop. Accession AH could be the

best progenitor for selection for quality seeds since it had the highest germination %. Seasonal variation did not have a significant effect on the differences observed in the germination % among the accessions and as such the variation noted may have been inherently genotypic. Higher germination percentages were however generally observed for most of the accessions in season 2 compared to season 1. This could have been due to the high moisture content of seeds at the time of germination tests in the first season (Table 15). Baker and Duarte, (1998) argued that higher moisture content in seeds led to reduced viability. Seed moisture content was significantly different ($P<0.05$) between accessions AH and EG and between each of one of them and accessions GBK, LV and SIM in season 2 (Table 15). The overall result indicated insignificant variation ($P>0.05$) among accessions AH, EG and GBK and between accessions SIM and LV. The insignificant variation in seed moisture content among the accessions may be an indication that they belong to the same maturity group. The mean moisture content range was 11.3 % to 15.51 % from the combined data of the two seasons (Table 15). This is slightly higher than the observation made in a similar study which recorded moisture content of between 5% and 13% for different amaranth accessions (Erum *et al.*, 2012). The difference may have been due to variation in the environmental conditions between the two regions of study at the time of harvesting. There was a significant difference in seed moisture content between the two seasons. In the first season, seed moisture content range was 16.67 % to 22.47 % while in the second season the range was 5.49 % to 8.84 %. Variation noted in seed moisture content may have thus been due to environmental influence.

CHAPTER SIX

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

6.1 SUMMARY

All the five amaranth accessions were found to have an upright growth stature and black seed color except *Amaranthus hybridus ssp cruentus* (AH) which produced brown seeds. *Amaranthus hybridus ssp cruentus* (AH) was significantly the tallest and therefore had the highest number of branches and internodes on the main stem in the two seasons. Accession AH also had the highest number of leaves, the highest leaf blade ratio and the largest total leaf area per plant. It could thus be considered as the best in terms of fresh leaf production for market. Accession AH could serve as the best progenitor for vegetable production traits since correlation studies revealed a significantly positive association between plant height ($r=0.706$, $r^2=0.4988$), number of branches on the main stem ($r=0.567$, $r^2=0.3220$), leaf blade ratio ($r=0.551$, $r^2=0.3040$), number of leaves per plant ($r=0.567$, $r^2=0.3218$) total leaf area per plant ($r=0.839$, $r^2=0.7038$) and leaf yield. Accession AH ranked the highest in seed yield per plant and could thus be the best source of this trait for selection. A dendogram constructed based on the growth and morphological traits showed *Amaranthus dubius* species (Accessions EG, GBK and SIM) placed in the same cluster. This is an indication that they have close genetic ties and therefore the different collections of the source of their germplasms did not have significant effect on their growth and morphological traits. Accessions LV (*Amaranthus lividus ssp lividus*) and AH were found in completely different clusters. This shows that they probably have little genetic association hence the dissimilarity in most of their phenotypic traits. Accession LV took the shortest time to attain 50 % flowering and therefore 50 % maturity. Accession AH was the best performer in seed germination tests and therefore could be the best source of trait for quality seeds.

6.2 CONCLUSIONS

Amaranthus hybridus ssp cruentus (AH) was the best in plant architectural traits and leaf character traits and thus can be a good source of these traits in a breeding programme since they are direct contributors to leaf yield.

Amaranthus lividus ssp lividus (LV) took the shortest time to mature hence the best for selection for earliness.

The most outstanding accession in both seed and leaf yield was *Amaranthus hybridus ssp cruentus*. It is thus the most suitable accession for selection for either seed or vegetable production. It can also be grown as a dual purpose accession.

Amaranthus dubius accessions (EG, GBK and SIM) showed insignificant variation in most of their growth and morphological characteristics, an indication that they have similar genetic background.

Accession AH produces the best quality seeds since it exhibited the highest germination percentage.

6.3 RECOMMENDATIONS

6.3.1 Recommendations from the present study

Amaranthus hybridus ssp cruentus (AH) exhibited desirable plant architectural traits and leaf character traits hence the best progenitor for these traits.

Accession AH is the best to be grown by farmers in western Kenya for both seed and vegetable production. This is because it performed exemplarily well in terms of seed and leaf yields.

Accession LV emerged the fastest maturing variety. It is therefore the best for selection for earliness in a breeding programme.

6.3.2 Recommendations for further research

A further study needs to be done on variation at the molecular level to validate the diversity among these amaranth accessions as well as the degree of heritability of their traits for a possible hybridization in order to improve their foliage yield potential.

There may also be a need to expand this study to include larger numbers of accession. This will lead to identification and selection of more varieties for genetic improvement of the crop.

Accession AH being the highest leaf and seed yielding variety needs to be tried out in other regions to verify the consistency of its performance in varied climatic regions.

REFERENCES

Achigan-Dako G.E, Houdegbe A.C, Gle`le` M. and Nono-Womdim R., (2014). *Analyse du syste`me de production et de distribution des semences de maı¨s (Zea mays L) au Sud-Be´nin*: Biotechnology Agronomy Society and Environment **18**:44–55.

Afolayan S.O., Babalola O. and Igbeka J.C, (2004). *Effect of tillage on soil physical properties, growth and yield of amaranth*: African crop science journal **12**(2):141-151.

Agnew A. D. Q (2013). *Upland Kenya wild flowers and ferns*: Nature Kenya **3:**82-84

Akaneme F.I and Ani G.O, (2013). *Morphological Assessment of Genetic Variabilty among Accessions of Amaranthus hybridus*: World Applied Sciences Journal **28**:568-577, 2013 ISSN 1818-4952.

Akindahunsi A.A and Salawu S.O, (2005). *Phytochemical screening of nutrient and antinutrient composition of selected tropical green leafy vegetables*: African Journal of Biotechnology **4**:497-500.

Anjali K., Joshi A., Maloo S.R and Sharma R., (2013) *Assessment of morphological diversity in Amaranthus species*: African Journal of Agricultural Research **8**:2307 - 2311.

Arik A.F., Arumingtyas E.L. and Mastuti R. (2013). *Morphological and genetic variation of Amaranthus spinosus L.: an adaptation evidence of climate differences and gene interaction*: International Journal of Biosciences 3(11): 205-212 ISSN: 2220-6655

Armillas, P. (1971). *Gardens on swamps*: Science **174**:653-661.

Awe O.A and Osunlola O.S (2013). *Influence of induced growth patterns on green yield components of Amaranthus cruentus*: Indian Journal of Science and Technology **6**:5522-5526.

Barker, L.A and Duarte, P.R (1998). *Retrogradation of amaranth starch at different storage temperatures and the effects of salt and sugars*: Cereal chemistry **75**(3):308-314.

Brenner D.M, Baltensperger D.D, Kulakow P.A, Lehmann J.W, Myers R.L, Slabbert M.M and Sleugh B.B, (2000). *Genetic resources and breeding of Amaranthus*. In: Janick Journal (ed) Plant breeding reviews, **19:**227–285.

Chattopadhyay A., Das S., Pandia R., Seth T. and Dutta S (2013). *Estimation of genetic parameters, inter-relationships and genetic divergence of vegetable amaranths:* International journal of plant breeding **60**: 156-179

Chweya J.A and Eyzaguire P.B, (1999). *The biodiversity of traditional leafy vegetables*: International plant genetic resource institute (IPGRI). 191 pp

Costea M., Waines G. and Sanders A., (2001). *Structure of the pericarp in some Amaranthus (Amaranthaceae) species and its taxonomic significance*. Aliso **20**:51–60.

DAFFSA, (2010). *Amaranthus production guidelines*: Department of forestry and fisheries directorate of plant production, Pretoria.

Das S, (2012). *Systematics and taxonomic delimitation of vegetable, grain and weed amaranths*: *a morphological and biochemical approach*: Genetic Resources and Crop Evolution **59**:289–303.

Ebert A.W., Wu T. and Wang S. (2011). *Vegetable amaranth (Amaranthus L.). International cooperators guide*: AVRDC-The world vegetable centre **11**:754

Enoch G., Achigan-Dako., Olga E.D., Sogbohossou and Maundu P., (2014). *Current knowledge on Amaranthus species: Research avenues for improved nutritional value and yields in leafy amaranths in sub-saharan Africa*: Euphytica 10681-014-1081-9.

El-sharkawy M.A., Loomis R.S. and Williams W.A (1968). *Photosynthetic and repiratory exchanges of carbondioxide by leaves of grain amaranth:* Applied ecology journal **15**: 243-251

Erum S., Naeemullah M., Masood S., Qayyum A. and Rabbani A., (2012). *Genetic divergence in Amaranthus collected from Pakistan*: Animal and plant sciences journal **22**:653-658, 2012 ISSN 1018-7081.

Espitia-Rangel E., (1994) *Breeding of grain amaranth*: In Paredes- Lo´pez O (ed) Amaranth: biology, chemistry, and technology. CRC Press, Boca Raton, pp 23–38.

FAO/IPGRI, (1994). *Genebank Standards*: Rome. ISBN 92-9043-236-5.

Franssen A.S, Skinner D.Z, Al-Khatib K., Horak M.J and Kulakow P.A, (2001). *Interspecific hybridization and gene flow of ALS resistance in Amaranthus species*. Weed Science **49**:598–606.

Gerrano A.S, Jansen W.S, Van Rensburg and Adebola P.O, (2010). *Agro-morphological variability of Amaranthus genotypes in South Africa*: International Symposium on the taxonomy of cultivated plants. ISHS Acta Horticulturae 1035.

Gomez K.A and Gomez A.A, (1984). *Statistical procedures in Agricultural Research. Experimental Agriculture*. New York, chichester: Wiley (1984), 2nd edition paperback. 680pp

Grant W.F, (1959). *Cytogenetics studies in Amaranthus III chromosome numbers and phytogenetics aspects*. Canadian journal of genetical cytology **1**:313

Grubben G.J.H and Denton, (2004). *Plant genetic resources of Tropical Africa 2*. Vegetable. Wageningen, Netherlands: PROTA foundation.

Grubben G.J.H, (1994). *Amaranthus L.* In: Siemonsma JS, PiluekK (eds) Prosea: *plant resources of South-East Asia 8. Vegetables*. Prosea Foundation, Bogor, pp 82–86.

Grubben G.J.H, (2004) *Amaranthus dubius* Mart. ex Thell. (Internet) record from protabase.

Grubben G.J.H (1980). *Cultivation method and growth analysis of vegetable amaranth, with special reference to south Benin*: Proc. 2nd amaranth conf. Kuztown, pp

Hasan M., Akther C.A and Raihan M.S, (2013). *Genetic Variability, Correlation and Path Analysis in Stem Amaranth (Amaranthus tricolor L.) Genotypes*. Department of Genetics and Plant Breeding, Bangabandhu Sheikh Mujibur Rahman Agricultural University, Gazipur 1706, Bangladesh.

Hauptli H. and Jain S.B, (1983). *Genetic structure of landrace populations of the new world grain amaranths*: Euphytica **33**:875–884.

Keller G.B, (2004). *African nightshade, eggplant, spiderflower Production and consumption of traditional vegetables in Tanzania from the farmers' point of view*: Master thesis. Institut für Pflanzenbau in den Tropen und Subtropen. Georg-August Universität Göttingen, Fakultät für Agrarwissenschaften. www.underutilized-species.org.

Khanam U.K.S and Oba S, (2014). *Phenotypic Plasticity of Vegetable Amaranth, Amaranthus tricolor L. under a Natural Climate*: Plant Production Science **17**:2, 166-172, DOI: 10.1626/pps.17.166

Kioko E.N, Kagali R.N, Osiemo Z., Muya S. and Wachera C. (2013). *Insect abundance and diversity on cultivated Amaranthus species in Meru-county-Kenya*: American International Journal of Contemporary Research **3**:7

Koshoo T.N and Pal M., (1972). *Cytogenetic patterns in Amaranthus*: Chromosome Today **3**:252.

Lanta, V., P. Havranek, and V. Ondrej (2003). *Morphometry analysis and seed germination of Amaranthus cruentus, A.retroflexus and their hybrid (A. x turicensis)*: Plant Soil Environ. 49: 364-369.

Lavernee S.G., Teresita Borromeo., Constacio De Guzman (2016). *Diversity in the morphology of Amaranth (Amaranthus sp.) germplasm Collection in the Philippines*: Asian Journal of Agriculture and Food Sciences ISSN: 2321 – 1571

Law-Ogbomo K.E and Ajayi S.O, (2009). *Growth and yield performance in Amaranthus cruentus influenced by planting density and poultry manure application*: Notulae Botanicae Horti Agrobotanici cluj-Napoda **37**:195-199

Masanobu O., Amzad H., Nakamura I., Akamine H., Tamaki M. and Bhowmik P.C (2016). *Effects of soil types and fertilizers on growth, yield, and quality of edible Amaranthus tricolor lines in Okinawa, Japan*: Plant production science journal **19**:1

Mbwambo O., Abukutsa M.O, Dinssa R.F and Ojiewo C., (2015). *Performances of elite amaranth genotypes in grain and leaf yields in northern Tanzania*: Journal of Horticulture and Forestry **7**:16-23.

Mlakar, S.G., Turinek, M., Jakop, M., Bavec, M. and Bavec, F. (2009). *Nutrition value and use of grain amaranth: potential future application in bread making*: Agricultura **6**: 43-53.

Mohammed D. T, (2016). *Yield of Vegetable amaranth (Amaranthus Cruentus L.) as Influenced by row spacing and nitrogen fertilizer in Mubi, Northern Guinea Savannah Zone of Nigeria*: International Journal of Innovative Agriculture & Biology **4(1)**:40-48.

Mosyakin S.L and Robertson K.R, (2003). *Amaranthus. In: Flora of North America. North Mexico*: Oxford University press. New York. USA.

Mumias District Development Plan (2012). Pgs 3-6.

Murua M (2002). *Polymer seed coating effects on feasibility of early planting in corn, planting date and corn productivity*: M.Sc.Thesis submitted to Purdue University.

Mwase W.F, Kachiguma N., Manduwa D. and Maliro M. (2014). *Agro-morphological diversity of Amaranthus species in central Malawi*: International Journal of Agriscience **4**:235-241.

Myers R.L, (1996). *Amaranth. New crops opportunity*: Progress in new crops. ASHS press, Alexandria, VA, pp.207-220.

National research council (2006). *Lost crops of Africa: Vegetables*: Volume II ISBN: 0-309-66582-5

O'Brien G. K and Price M.L, (2008). *Amaranth grain and vegetable types*. www.echonet.org.

Odigie-Tony A.E, Adekoya K.O, Makinde S.C.O, Oboh B.O, Ogunkanmi L.A and Fowora M.A, (2012). *Assessment of Genetic Interspecies Relationships among Five Selected Amaranthus Species Using Phenotypic and RAPD Markers*. International Journal of Botany **8**:145-152.

Olowaeke A.A and Ojo J.A, (2014). *Effect of fertilizer types on the growth and yield of Amaranthus caudatus in Ilorin Southern Guinea, Savanna zone of Nigeria*, Advances in Agriculture (2014), Article ID 947062 http://dx.doi.org/10.1155/2014/947062.

Orech F.O, Akenga T., Ochora J., Friis H. and Aagaard-Hansen J., (2005). *Potential toxicity of some traditional leafy vegetables consumed in Nyang'oma division, Western Kenya*: African journal of food Agriculture and nutritional development **5**:1-14.

Pal M., (1972). *Evolution and improvement of cultivated amaranths. III. Amaranthus spinosus-dubius complex*: Genetica **43**:106–118.

Palomino G. and Rubi R., (1991). *Diferencias cromoso'micas entre algunas especies y tipos del genero Amaranthus distribuidos en Mexico*: Actas Primer Congreso internacional del Amaranto: 24

Polhill R.M, (1985). *Amaranthaceae*: *Flora of the tropical East Africa*: A.A Balkema publishers, Rotterdam, Netherlands. 136pp.

Putnam D.H, (1990). *Agronomic practices for amaranth*: Proceedings of 4th national amaranth symposium. Rodale press, Emmans, PA, pp. 151-162.

Ramesh K.S, Mohamed G.Y and Govindarasu R., (2013). *Studies on genetic parameters in grain amaranthus (amaranthus hypochondriacus* l*.) as influenced by plant densities*: Journal of Plant Breeding. Genetics.**1**:34-42.

Reema S. (2015). *Assessment of morphological diversity of selected Amaranthus species*: Journal of Global Biosciences 4:3044-3048, 2015 ISSN 2320-1355.

Rita A., Shigeki Y., Yasuko Y. and Ryo O., (2013). *Amaranthus genetic resources in Indonesia: morphological and protein content assessment in comparison with the world wide amaranths*: Genetic Resources and Crop Evolution **60**:2115-2128.

Sarker U., Islam M.T., Rabbani M.G. and Oba S, (2014). *Genotypic variability for nutrient, antioxidant, yield and yield contributing traits in vegetable amaranth:* J Food Agric Environ **12 (3/4)**: 168-174.

Sauer J.D, (1967). *The grain amaranths and their relatives: a revised taxonomic and geographic survey*: Annals of the Missouri Botanical Garden **54**:103–137.

Schippers R.R, (2000). *African indigenous vegetables. An overview of the cultivated species*: Natural Resources Institute/ACP-EU Technical Centre for Agricultural and Rural Cooperation, Chatham, United Kingdom. 214pp

Shukia S., Bhargava A., Chatterjee A., Pandey A.C and Mishra B.K, (2010). *Diversity in phenotypic and nutritional traits in vegetable amaranth*. (*Amaranthus tricolor*), *a nutritionally underutilized crop:* Journal science food Agriculture **90**:139-144.

Shukla S., Bhargava A., Chatterjee A. and Singh S.P, (2006). *Genotypic variability in vegetable amaranth (Amaranthus tricolor L.) for foliage yield and its contributing traits over successive cuttings and years*: Euphytica **151**:103–110.

Shukla S., Bhargava A., Chatterjee A., Srivastava A. and Singh S.P (2005). *Estimates of genetic variability in vegetable amaranth (A. tricolor) over different cuttings*: Horticult Sci **32**(3): 60-67.

Simmonds R., (2014). *Characterization of genetic diversity in Amaranthus species*: Faculty of science research talk. University of Nottingham Malaysia Campus, school of Biosciences.

Singh B.P and Whitehead W.F, (1993). *Population density and soil pH effects on vegetable amaranth production*: In J. Janick and J.E. Simon (eds.), New Crops. Wiley, New York. Pg. 562-564.

Stallknecht G.F. and Schulz-Schaeffer, J.R, (1993). *Amaranth rediscovered*. In: J. Janick and J.E. Simon (Eds.), New crops. Wiley, New York. Pg 211-218.

Suzanne A., (2002). *Seed to Seed: Seed Saving and Growing Techniques for Vegetable Gardeners*, 2nd Edition Paperback.

Svirskis A., (2003). *Investigation of amaranth cultivation and utilization in Lithuana*. Agronomy Research **1:**253-264.

Varalakshmi B., (2011) *Characterization and preliminary evaluation of vegetable amaranth* (*Amaranthus species) germplasm*: Bioversity International – FAO, Rome.

Waithaka K. and Chweya J.D, (1991). FAO *Plant Production and Protection*, pp 107.

Wambugu P.W. and Muthama Z.K (2009).*The state of plant genetic resources for food and agriculture in Kenya*: KARI, National Gene bank of Kenya. Pg 22-23

Weber, (1987). *Amaranth production guide. Ecological Agriculture Projects*: Rodale Research center press, Inc.

Whitehead W.F, Carter J. and Singh B.P, (2002). *Effect of planting date on vegetable amaranth leaf yield, plant height and gas exchange*: Agricultural Research Station, Fort Valley State University, Fort Valley, GA 3030-4313. Horticultural Science **37**:773-777.

Xu F. and Sun M., (2001). *Comparative analysis of phylogenetic relationships of grain amaranths and their wild relatives* (*Amaranthus; Amaranthaceae*) *using internal transcribed spacer, amplified fragment length polymorphism, and double-primer fluorescent intersimple sequence repeat markers*: Molecular Phylogenetics and Evolution **21**:372–387.

APPENDICES

APPENDIX I: ANOVA for the different morphological variables among the amaranth accessions in season 1

TRAIT	SOURCE	DF	SS	MS	F	P
PH	Accession	4	4845.930667	1211.482667	2.57	0.1190
	Rep	2	739.161333	369.580667	0.78	0.4884
NBMS	Accession	4	88.05733333	22.01433333	4.54	0.0330
	Rep	2	31.04400000	15.52200000	3.20	0.0330
NIMS	Accession	4	88.05733333	22.01433333	4.54	0.0330
	Rep	2	31.04400000	15.52200000	3.20	0.0952
BRATIO	Accession	4	0.41690067	0.10422517	32.13	<.0001
	Rep	2	0.01818120	0.00909060	2.80	0.1196
LNUMBER	Accession	4	77.60000000	19.40000000	4.26	0.0387
	Rep	2	28.93333333	14.46666667	3.18	0.0964
TLAREA	Accession	4	2267028.182	566757.045	4.08	0.0431
	Rep	2	368007.866	184003.933	1.33	0.3183
DFLOWER	Accession	4	1059.600000	264.900000	Infty	<.0001
	Rep	2	10.000000	5.000000	Infty	<.0001
DMATURITY	Accession	4	2324.266667	581.066667	8716.00	<.0001
	Rep	2	0.133333	0.066667	1.00	0.4096
LYIELD	Accession	4	5045.776067	1261.444017	12.98	0.0014
	Rep	2	480.325613	240.162807	2.47	0.1460
SYIELD	Accession	4	11842.49733	2960.62433	175.80	<.0001
	Rep	2	64.57600	32.28800	1.92	0.2088
GERM	Accession	4	2190.266667	547.566667	2.31	0.1461
	Rep	2	916.133333	458.066667	1.93	0.2070
MC	Accession	4	86.24562667	21.56140667	2.24	0.1536
	Rep	2	11.66321333	5.83160667	0.61	0.5683

APPENDIX II: ANOVA for the different morphological variables among the amaranth accessions in season 2

TRAIT	SOURCE	DF	SS	MS	F	P
PH	Accession	4	5187.637333	1296.909333	12.93	12.93
	Rep	2	56.803000	28.401500	0.28	0.7607
NBMS	Accession	4	485.0160000	121.2540000	23.65	0.0002
	Rep	2	7.8773333	3.9386667	0.77	0.4952
NIMS	Accession	4	485.0160000	121.2540000	23.65	0.0002
	Rep	2	7.8773333	3.9386667	0.77	0.4952
BRATIO	Accession	4	0.38025533	0.09506383	16.53	0.0006
	Rep	2	0.00145773	0.00072887	0.13	0.8827
LNUMBER	Accession	4	485.9973333	121.4993333	22.77	0.0002
	Rep	2	5.2173333	2.6086667	0.49	0.6305
TLAREA	Accession	4	17401253.78	4350313.44	15.50	0.0008
	Rep	2	489067.29	244533.65	0.87	0.4547
DFLOWER	Accession	4	1192.266667	298.066667	1117.75	<.0001
	Rep	2	6.533333	3.266667	12.25	0.0037
DMATURITY	Accession	4	376.6666667	94.1666667	122.83	<.0001
	Rep	2	5.2000000	2.6000000	3.39	0.0858
LYIELD	Accession	4	23445.20882	5861.30221	16.28	0.0007
	Rep	2	710.01777	355.00889	0.99	0.4142
SYIELD	Accession	4	8645.428760	2161.357190	116.27	<.0001
	Rep	2	44.549760	22.274880	1.20	0.3506
GERM	Accession	4	1259.066667	314.766667	2.29	0.1476
	Rep	2	86.933333	43.466667	0.32	0.7372
MC	Accession	4	23.84677333	5.96169333	17.19	0.0005
	Rep	2	2.45369333	1.22684667	3.54	0.0793

APPENDIX III: ANOVA for different morphological variables among the amaranth accessions for season 1 and 2 combined

TRAIT	SOURCE	DF	SS	MS	F	P
PH	Accession	4	9167.128000	2291.782000	8.24	0.0006
	Season	1	78.408333	78.408333	0.28	0.6020
	Seas x Acc	4	866.440000	216.610000	0.78	0.5536
	Rep	2	357.918167	178.959083	0.64	0.5373
NBMS	Accession	4	439.1846667	109.7961667	23.47	<.0001
	Season	1	788.4813333	788.4813333	168.55	<.0001
	Seas x Acc	4	133.8886667	33.4721667	7.16	0.0012
	Rep	2	34.5166667	17.2583333	3.69	0.0454
NIMS	Accession	4	439.1846667	109.7961667	23.47	<.0001
	Season	1	788.4813333	788.4813333	168.55	<.0001
	Seas x Acc	4	133.8886667	33.4721667	7.16	0.0012
	Rep	2	34.5166667	17.2583333	3.69	0.0454
BRATIO	Accession	4	0.77961900	0.19490475	40.36	<.0001
	Season	1	0.05985333	0.05985333	12.39	0.0024
	Seas x Acc	4	0.01753700	0.00438425	0.91	0.4803
	Rep	2	0.00467487	0.00233743	0.48	0.6241
LNUMBER	Accession	4	426.9186667	106.7296667	22.79	<.0001
	Season	1	783.3630000	783.3630000	167.26	<.0001
	Seas x Acc	4	136.6786667	34.1696667	7.30	0.0011
	Rep	2	28.9286667	14.4643333	3.09	0.0703
TLAREA	Accession	4	16001121.96	4000280.49	17.52	<.0001
	Season	1	4283005.32	4283005.32	18.75	0.0004
	Seas x acc	4	3667160.00	916790.00	4.01	0.0169
	Rep	2	102782.92	51391.46	0.23	0.8007

APPENDIX III (Contd)

TRAIT	SOURCE	DF	SS	MS	F	P
DFLOWER	Accession	4	2148.533333	537.133333	721.52	<.0001
	Season	1	53.333333	53.333333	71.64	<.0001
	Seas x Acc	4	103.333333	25.833333	34.70	<.0001
	Rep	2	5.266667	2.633333	3.54	0.0506
DMATURITY	Accession	4	2116.133333	529.033333	1090.37	<.0001
	Season	1	1254.533333	1254.533333	2585.68	<.0001
	Seas x Acc	4	584.800000	146.200000	301.33	<.0001
	Rep	2	3.266667	1.633333	3.37	0.0573
LYIELD	Accession	4	23493.93900	5873.48475	26.07	<.0001
	Season	1	3256.29176	3256.29176	14.46	0.0013
	Seas x Acc	4	4997.04589	1249.26147	5.55	0.0043
	Rep	2	793.70594	396.85297	1.76	0.2001
SYIELD	Accession	4	20357.43651	5089.35913	310.36	<.0001
	Season	1	941.80827	941.80827	57.43	<.0001
	Seas x Acc	4	130.48958	32.62239	1.99	0.1394
	Rep	2	97.39808	48.69904	2.97	0.0768
MC	Accession	4	79.900180	19.975045	3.97	0.0176
	Season	1	1258.027763	1258.027763	250.04	<.0001
	Seas x Acc	4	30.192220	7.548055	1.50	0.2440
	Rep	2	3.194480	1.597240	0.32	0.7320
GERM	Accession	4	2128.800000	532.200000	2.96	0.0482
	Season	1	634.800000	634.800000	3.53	0.0764
	Seas x Acc	4	1320.533333	330.133333	1.84	0.1655
	Rep	2	766.466667	383.233333	2.13	0.1474

APPENDIX IV: Result of multiple linear regression model of leaf yield per plant

	Coefficient	Standard error	t – value	P- value
Intercept	-39.2509	13.6893	-2.8670	0.0048
PH	0.2585	0.1282	2.0170	0.0456
BR	28.3034	10.4914	2.6980	0.0078
TLAP	0.0224	0.0021	10.8950	< 2e-16
Residual se =23.13, $R^2 = 0.7378$, R^2_{adj} =0.7324, F-stat: 136.9 on 3 and 146 DF, P< 2.2e-16				