MORPHOLOGICAL CHARACTERISTICS, GROWTH AND YIELD OF ELITE GRAIN AND LEAF AMARANTH IN NORTHERN TANZANIA

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Morphological Characteristics, Growth and Yield of Elite Grain and Leaf Amaranth in Northern Tanzania

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DECLARATION

I, Omary Ijumaa Mbwambo, do hereby declare that this dissertation is my own original work and has not been submitted for a degree in any other university. All sources of materials used in this dissertation have been fully acknowledged.

Signature:  Date:……

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This dissertation has been submitted for examination with our approval as University supervisors.

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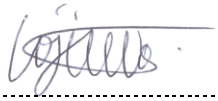
2. Signature:  Date:.....

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DEDICATION

I would like to dedicate this work to my lovely wife Mwazani Mohamedi Fakhi for her consistent encouragement and moral support. My wife Mwazani significantly contributed to successful completion of my graduate work. I also wish to express my appreciation to my children Yusra, Rahma and Nabeel for their patience and tolerance when I was not always with them because of this study. Finally I wish to extend my gratitude to my parents, Mr. and Mrs. Ijumaa Omary for having laid down the foundation of my studies.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

LIST OF APPENDICES

LIST OF ABBREVIATION

%	Percentages
^{0}C	Degree Celsius
ANOVA	Analysis of variance
AVRDC	Asian vegetable research center
cm	Centimeter
DAP	Diammonium phosphate
DAS	Days after sowing
EC	Emulsifiable concentrate
g	Grams
GRSU	Genetic resource and seed unit (of AVRDC)
Ha	Hectare
HORTI-Tengeru	Horticulture Research and Training Institute (Tengeru)
IFPRI	International Food and Policy Research Institute
IU	International units
Kg	Kilogram
M.c	Moisture content
RCA	Regional center for Africa (of AVRDC), Arusha
RCBD	Randomize complete block design
RH	Relative humidity
RSA	Republic of South Africa

RUFORUM	The Regional Universities Forum for Capacity Building in Agriculture
SSA	Sub-Saharan Africa
t	Tonnes
USA	United State of America
USDA	United State Department of Agriculture

ABSTRACT

Amaranth is considered one of the most commonly produced and consumed indigenous vegetables on the African continent. In Tanzania amaranth constitutes about 6% of total hectares of vegetable planted annually. The genus consists of nearly 60 species, several of which are cultivated as leaf vegetables, grains or ornamental plant. Most of cultivated varieties of amaranth are relatively low in terms of leaf and grain yield, mainly due to lack of improved varieties. This study was conducted to: a) To evaluate amaranth lines for both leaf and grain production potential. b) To identify at least two lines with high potential for grain yield and one line with both leaf and grain yield potential. c) To generate yield information needed for breeding and improvement of amaranths and d) To conduct participatory research as a demand-driven strategy to meet farmers' needs. An experiment was thus carried out at the World vegetable center (AVRDC) in Arusha, Tanzania in two seasons; from February to May and May to September 2012. Fourteen lines (RVI00007, RVI00130, RVI00089, RVI00138, RVI00090, RVI00116, RVI00002, RVI00001, RVI00117, RVI00022, INCA, RVI00086, RVI00121 and RVI00021) were used in a randomized complete block design. Data were collected on leaf yield, seed yield, morphological characteristics and participatory selection. Results indicated that over the seasons, leaf yield differed significantly ($p \leq 0.01$) among the lines. Line RVI00117 had higher leaf yield of 21 t/ha, while line RVI00089 had the lowest yield of 12 t/ha over the two seasons respectively. Grain yield obtained after leaf harvesting revealed a significant difference ($p \leq 0.001$) among lines. Line RVI00021 had the highest seed yield of 1929

kg/ha, while line RVI00121 had seed yield (2920 kg/ha) over the seasons in plots where leaf was not harvested.

Thirty-three agro-morphological traits for plant characteristics observed in both seasons indicate similarities in the traits such as germination rate, growth habit and sex type, absence of spines in leaf axils, seed coat type and presence of axillary inflorescence. However, variability was observed in the rest of the traits. Cluster dendrogram analysis grouped the lines into three main clusters according to their similarities. In this study line RVI00121 appeared to be preferred most by farmers following participatory selection whereas out of five criteria agreed by farmers, the line was selected in top three in the four criteria. This study found that line RVI00007 was the best for dual purpose (leaf and grain), while line RVI00121 and RVI00001 was the best for grain production. However, further investigation was recommended to determine how timing and harvesting frequency affects the grain yield. Similarly, the performance of lines when leaf harvested indefinitely without consideration of seed yield needs investigation. Probably repeating the experiment in different agro-ecological zones would also be necessary to reach a broad conclusion.

Key words: Amaranth, leaf yield, seed yield, morphological characteristics, participatory selection, cluster dendrogram

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background Information

Amaranth is cultivated as a minor food crop in Central and South America, Mexico and parts of Asia and Africa. In many tropical countries it is extensively grown as a green leaf vegetable. Amaranth is one of the oldest food crops in the world. Evidence of its cultivation dates back to as far as 6700 BC (Itúrbide and Gispert, 1994; RSA, 2010). Amaranth is considered one of the most commonly produced and consumed indigenous vegetables on the African continent (Grubben and Denton, 2004). Of the 72,000+ ha of vegetables planted annually in Tanzania, amaranth constitutes about 6% (NBS, 2004). A study by Keller (2004) indicates that amaranth is an important traditional leafy vegetable in northeast Tanzania, and is listed as one of its "upper five" vegetables.

The genus Amaranth consists of nearly 60 species, several of which are cultivated as leafy vegetables, grains, or ornamental plants, while others are considered as weeds (Maboko, 1999; RSA, 2010). Amaranth is one of the few plants whose leaves are eaten as a vegetable while the seeds are used in the same way as cereals. There is no distinct separation between the vegetable and grain types. Leaves of young plants grown for grain are eaten as both human and animal food, in South America, Africa, Asia and Eastern Europe (Kaul *et al.,* 1996; Muyonga *et al.,* 2008). Species grown for vegetables are represented mainly by *A.*

tricolor, A. dubius, A. lividus, A. creuntus, A. palmeri and *A. hybridus.* Three principal species considered for grain include, *A. hypochondriacus*, *A. cruentus* and *A. caudatus.* (Teutonico and Knorr, 1985; Muyonga *et al*., 2008; Mlakar *et al*., 2010). Amaranth leaf can be used as greens in salads, boiled or fried in oil and mixed with meat or fish. This can be used as side dish in soups or as an ingredient in sauce and baby food (Mlakar *et al*., 2010). The grain of amaranth can also be used in numerous recipes ranging from popped amaranth snack, porridge, stiff porridge, chapatti (flat bread), bread, creamy soup, pancakes, cakes, scones, pizza, etc.

Amaranth, a C_4 plant, is one of a few dicots in which the first product of photosynthesis is a four carbon compound. The combination of anatomical features in amaranth and C_4 metabolism, results in increased efficiency to use CO_2 under a wide range of both temperature and moisture stress environments. This contributes to the plant's wide geographic adaptability to diverse environmental conditions (Kaul *et al.,* 1996; Stallknecht and Schulz-Schaeffer, 1993).

Amaranth both leaves and grains are rich in vitamins A, (2917 IU) and vitamin C (43.5 mg), iron (2.32 mg), calcium (215 mg), potassium (135-611 mg), phosphorus (50-148 mg), protein (2.46-3.8 g), and lysine (0.13-0.34 g). Amaranth is an annual crop that grows rapidly and is harvested within 3–4 weeks after sowing for leaves while grain can be harvested at 60-90 days. The crop is also known for being tolerant to common vegetable disease and pest incidences and less labour-demanding (AVRDC, 2004; Maundu *et al.,* 2009). Despite its

positive agronomic and nutritional characteristics, majority of cultivated lines of amaranth in Africa including Tanzania offer low yields relative to its potential (Moinester, 2007).

Through collection and selection programmes, a number of strains have been introduced and acclimatized in various parts of the World and Africa, but evaluation studies of foliage and grain yield and its contributing quantitative and qualitative traits are scarce (Shukla *et al.,* 2006).

The yield aspects are particularly important as many farmers wish to optimize yields and profits for their efforts. Therefore improvement of traditional crops such as amaranths through research and development could produce an easy and cost-effective way of eliminating malnutrition and promoting the people's health as well as attaining food security (Onyango, 2010).

1.2 Problem statement

Low crop productivity is a general problem facing most farming systems in sub-Saharan Africa (SSA). Low leaf yields of less than 1.2 tons per hectare (Mabulu and Chalamila, 2005) are normally realized against the potential of 32-40 tons per hectare in amaranth (Oluoch *et al*., 2009; RSA, 2010). Grain yield are very highly variable. Good grain yields, in relative terms would be considered to be 1000 kg/ha (Myers, 1994; Myers, 1996; RSA, 2010) but yields up to 6000kg/ha under conventional agricultural practices have been reported (Svirskis, 2003; Gajdosova *et al.,* 2003). However, information on accessions or lines with both potential of leaf and grain yield (dual purpose) has not been exhaustively

evaluated and documented. This information gap presents a problem to researchers in advocating the right amaranths lines for promotion and adoption to farmers with regards to dual purpose lines. The question arising is whether the genetic diversity of vegetable Amaranthus collection held at AVRDC-RCA can have these potential.

1.3 Objectives

1.3.1 Overall objective

The objective of this study was to identify superior lines of amaranth for adoption in terms of high grain yield and dual purpose (grain and leaf) among existing diverse species.

1.3.2 Specific objectives

i. To evaluate amaranth lines for both leaf and grain production potential
ii. To identify at least two lines with high potential for grain yield and one line with both leaf and grain yield potential.
iii. To generate yield information needed for breeding and improvement of amaranths.
iv. To conduct participatory research as a demand-driven strategy to meet farmers' needs.

1.4 Hypotheses

- ✓ There are differences in performance of various lines in terms of grain yield and both grain and leaf in amaranth.
- ✓ Grain yield is inversely proportional to leaf yield.

- ✓ Participatory research leads to valid and practical conclusion.

1.5 Justification

In sub-Saharan Africa, roughly 70 percent of the population depends on agriculture as a primary source of employment (IFPRI, 2001).

In this region, about 20-25% of the population is under-nourished due to poor energy and protein intake. In addition 40% of women in childbearing age are anaemic, while a similar proportion of children under-five lack enough nutrients for normal physical development (IFPRI, 2001). In Tanzania anemia is considered to be a public health problem with more than 40% of children aged 7-11 suffering from iron deficiency induced anaemia (Hall *et al.,* 2001). Approximately 35% of Tanzania's children grow up with lowered immunity, leading to frequent ill health and poor growth, due to vitamin A deficiency. For this reason low productivity in agriculture, particularly vegetables cannot be disconnected from the nation's poverty and malnutrition crisis.

Nutritionally, amaranth contains lysine, an essential amino acids lacking in diets based on cereals and tubers. Compounds in amaranth enhance human growth and development, improve health, and strengthen immune responses to combat diseases. If used by pregnant women, the folic acid in amaranth reduces the risk of neural defects in their newborns (AVRDC, 2011) and therefore amaranths have a strong potential contribution to meeting the daily dietary needs.

Most of existing cultivated types of amaranth in Africa are generally much smaller, up to 50 cm, strongly branched and prostrate with many flowers and small leaves which creates difficulties during harvest e.g. *A. blitum, A. graecizans* (Maundu and Grubben, 2004). These characteristics contribute to the problem of low yield which farmers experience in production. Research indicates that the vast majority of yield growth in African agriculture to date has been due to improved seed varieties, as opposed to technological improvements in cultivation practices or other inputs (Evenson, 2004). Recently AVRDC scientists selected two vegetable amaranths 'Madiira 1' and 'Madiira 2' which were released by national institution, Horticulture Research and Training Institute (HORT)-Tengeru in 2011. These two varieties grow tall and have potential yield of up to 40 t/ha in a continous harvest of 4-6 times (AVRDC, 2011). However there is no much study on identifying new varieties with both potentials i.e. leaf and grain. Therefore this study was conducted to identify new lines with potential in dual purpose (leaf and grain) as well as grain yield.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Origin and distribution of Amaranth

Amaranth is the collective name for the domesticated species of the genus Amaranthus (family Amaranthaceae). It is one of the oldest food crops in the world with evidence of cultivation dating back to over 6700 years in Puebla, Mexico (Itúrbide and Gispert, 1994; Onyango, 2010). Its Centers of diversity are Central and South America, tropical and South Africa, and Australia (Kadereit *et al.*, 2003). Amaranth is cultivated as a minor food crop in Central and South America, Mexico and parts of Asia and Africa and is extensively grown as a green leaf vegetable in many tropical countries (Maboko, 1999). At present *Amaranthus cruentus* is a widespread traditional vegetable in all countries of tropical Africa. It is the main leafy vegetable in Benin, Togo, and Sierra Leone, and very important in many lowland areas e.g. Southern Nigeria, Democratic Republic of Congo, Kenya and Tanzania (Grubben, 2004b).

2.2 Uses and Nutritive value of Amaranths

Amaranthus spp. is utilized for food in diverse geographical areas. Vegetable types (also leaves of grain one) are usually picked fresh, used as greens in salads or blanched, steamed, boiled, fried in oil, and mixed with either meat, fish, cucurbit seeds, groundnut or palm oil. Cooked greens can be used as a side dish, in soups or as an ingredient in sauce and baby

food etc. (Grubben, 2004b; Mlakar *et al.,* 2010). Amaranth grain, mostly rolled or popped can be used in muesli and in granola bars. Grain can also be germinated for sprouts, malted for beer production. Amaranth like maize and buckwheat can be popped through intense, short and dry heat without addition of fat. Ground grain can be used as flour ingredient in different mixtures for pancakes, bread, muffins, dumplings, crackers, cookies, pudding etc. (Early 1990; Bejosano and Corke 1998; Mlakar *et al*., 2010).

On the other hand different amaranth species have been used for medicinal purposes in Africa. *A. graecizans* is used in East and West Africa to manufacture a local salt, where by the plants are dried and burned to ashes and used as a substitute for common salt. In Uganda the leaves are chewed and the liquid swallowed to treat tonsillitis. In Senegal, the leaves are used as an anthelmintic (Maundu and Grubben, 2004).

In Nigeria *A. blitum* is used as medicine against lung disorder (Grubben, 2004a). Use of *A. cruentus* as medicine is reported in different parts of Africa. In Senegal the roots are boiled with honey as a laxative for infants. In Ghana the water of macerated plants is used as a wash to treat pains in the limbs. In Ethiopia it is used as a tapeworm-expeller. Sudan, the ash from the stems is used as a wound dressing and in Gabon heated leaves were used on tumours (Grubben, 2004b).

Vegetable amaranths are recommended as a good food with medicinal properties for young children, lactating mothers and for patients with constipation, fever, haemorrhage, anaemia and kidney complaints. In general medicinal uses of amaranth in Africa are many and diverse.

The consumption of vegetable amaranth helps balance vitamin and mineral intake (Shukla *et al.,* 2005). Per 100g portion, seed of grain amaranth is composed of water 75.16g, energy 102 kcal , protein 3.80g, total lipid (fat) 1.58, carbohydrate 18.69g, fiber 2.1g, calcium 47mg, iron 2.1mg, magnesium 65mg, phosphorus 148mg, potassium 134mg, sodium 6mg, zinc 0.86mg, thiamin 0.015mg, riboflavin 0.022mg, niacin 0.235mg, vitamin B-6 0.113mg and vitamin E (alpha-tocopheral) 0.19mg. Proteins have high digestibility (approx. 90%) and are rich with lysine, 0.34 g Lys/g N (which usually appears in grains as limiting amino acid). Amaranth seed is also a rich source of tryptophan and amino acids containing sulphur. These usually do not appear often enough in grains (Mlakar *et al.,* 2010; USDA, 2010).

Amaranth leaf is highly nutritious vegetable both in raw and cooked form. Its nutritional value is much higher than cabbage and Chinese cabbage (Ebert *et al.,* 2011). Each 100g portion of raw amaranth leaves contains; water 91.69g, energy 23 kcal, protein 4.8g, total lipids (fat) 0.7g, carbohydrates 2.02g, calcium 246mg, iron 3.0mg, magnesium 55mg, phosphorus 50mg, potassium 611mg, sodium 20mg, zinc 0.9mg, vitamin C 43.3mg, thiamin

0.027mg, riboflavin 0.158mg, niacin 0.658mg, vitamin A 2917 IU and vitamin K 1140 µg (Lyimo *et al.,* 2003; USDA, 2010).

2.3.0 Agronomy of Amaranths

2.3.1 Climate and soil requirement

Amaranth grows well in both hot humid and hot dry climates. The plant prefers temperatures between 25 and 30°C. Amaranth is photoperiod-sensitive and most species will flower when day lengths are shorter than 12 hours. Amaranth grows best in loam or silty-loam soil with good water-holding capacity, but it can grow on a wide range of soil types and soil moisture levels. Some species are tolerant to drought for example *A. blitum, A. spinosus*. Amaranth can tolerate a soil pH from 4.5 to 8.0 (Palada and Chang, 2003; Ebert *et al.*, 2011).

2.3.2 Pest and diseases

Insects are serious problem in amaranth. Caterpillars (*Hymenia recurvalis, Spodoptera litura, Heliothis armigera*) and sometimes grasshoppers are the most harmful pests. The larvae of the stem borer *Lixus truncatulus* may cause much damage due to growth retardation. Many other insects such as aphids, leaf miners, stinkbugs, mole crickets as well as mites attack amaranth but generally cause only minor damage (Grubben, 2004a). In well drained soil, amaranth does not suffer disease problems of economic importance. However, some amaranth lines are susceptible to soil-borne organisms associated with damping-off and stalk-rot caused by *Pythium, Fusarium and Bacterium* (Grubben, 2004b). Damping-off

caused by *Pythium* and *Rhizoctonia* may be serious in seedbeds. Good drainage and light dense-sowing will help to reduce this problem. Wet rot or stem rot caused by *Choanephora curcubitarum* is a major fungal disease on *A. cruentus*, while *A. tricolor* and *A. dubius* are much less susceptible (Ebert *et al.*, 2011). Some amaranth species are reported to host some virus and fungi pathogens. For example, *A. graecizans* act as host plant of *Verticillium* fungi and *A. blitum* is a natural host for turnip mosaic virus and tobacco leaf curl virus (Grubben, 2004a; Maundu and Grubben, 2004). *Alternaria* leaf spot has been reported in *A. cruentus* in Tanzania while it is hardy or not susceptible to nematode damage (Grubben, 2004b).

2.3.3 Breeding of amaranths

In amaranth breeding the following factors are taken into account, high productivity of leaf, large flower head, seed colour, stem height, low seed shattering, satisfactory nutritive and utilization properties (Weber, 1990; Svirskis, 2003). Breeding of amaranths is limited to selection of landraces in many places of the World. For example in Benin and Nigeria, selection of landraces resulted in a popular and productive cultivar known as 'Fotete' in Benin (Grubben, 2004b). In Peru selection in landraces has led to the release of the *A. caudatus* cultivar "Noel Vietmeyer", "Oscar Blanco" and "Alan Garcia". In Tanzania two new varieties (Madiira 1 and Madiira 2) of vegetable amaranth has been selected by AVRDC scientists and released by HORT-Tengeru. Furthermore genetic studies have identified marker loci for traits such as pigmentation patterns, inflorescence morphology and seed characters in *A. caudatu*s and other grain amaranth (Agong, 2006), where *A. graecizans*

might be used as genitor of resistance gene (Maundu and Grubben, 2004). However there is no breeding work reported on *A. blitum* and *A. hypochondriacus* as leafy vegetable, while in A. *hypochondriacus* all efforts are directed towards development of good seed cultivar (Jansen, 2004). Amaranth breeding is constrained by the fact that various forms of amaranth readily cross, though hybrids of more distant species are often sterile. Various types of amaranth are still insufficiently investigated, and the developed varieties are imperfect (Meyers, 1996).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Study area

To address the above objectives two separate field experiments were conducted at AVRDC-RCA, research station (Madiira Farm) in Arusha, Tanzania. The first trial was from February to May and then repeated from 29th May to September 2012. The area is located at 1290 m above sea level and latitude 4.8°S and longitude 37°E. The soil at the experimental area is clay loam with a pH range of 6.0 - 6.7. Average temperature for the season one experiment was 25.1^{o}C with a mean daily maximum temperature of 28.5^{o}C and means daily minimum temperature of 20.5^{o}C; while the average temperature for season two was 24.3^{o}C with 26.1^{o}C and 21^{o}C mean daily maximum and minimum temperature respectively. Rainfall distribution is bimodal with the long rain occurring from February to June and short rains from September to December. Total rainfall recorded during season one experiment (February to May) was 322.1 mm while season two (June to September) recorded 32.7 mm. Average relative humidity recorded during first and second season was 86.3% and 80.8% respectively (fig.1).

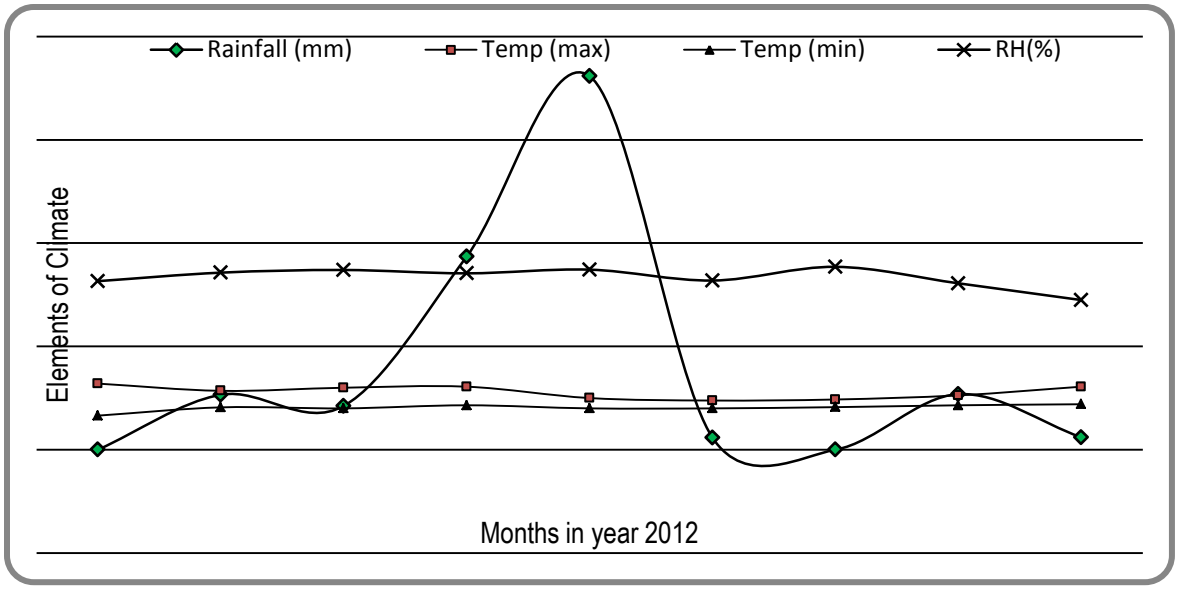

Figure 1: Maximum (max.) and minimum (min.) temperature (Temp), monthly rainfall (mm) and mean monthly relative humidity (RH) at AVRDC-RCA, Arusha: Source: Tengeru Met. Station.

3.2 General agronomic practices

Land was ploughed and harrowed by tractor while preparation of ridges was done manually by hand hoe. Seeds were sown directly by drilling after mixing with sand in 1:4 ratios on 7th February and 29th May for 1st season and 2nd season respectively. Thinning was carried out twice at 14 and 22 days after sowing (DAS) at a spacing of 60cm between rows and 25cm between plants. A plot size of 0.6m x 6m was used which contained two rows of amaranth line. A total of 48 plants per plot were maintained in each plot. 200kg/ha DAP (18:46:0) was used as a basal application at sowing and 120kg/ha urea (46:0:0) were applied as side-dressing in two split applications of 60kg/ha each two and six weeks after sowing. Insecticides such as Selecron® (a.i. profenofos 720 g/l EC) and Actellic® (a.i. pirimiphos-

methyl) were used to control aphids, white flies, cutworm and caterpillars, while Folicur (a.i. Tebuconazole 430 g/l) and Ridomil (a.i. Metalaxyl-M) to control dumping off especially for 1st season experiment. Each chemical being applied as needed following observation symptoms of the respective pathogens/pests. Weed control was done by hand-hoeing at 2-week intervals immediately after germination, but the frequency reduced as the plants grew, forming a canopy. Furrow irrigation was used twice a week to supplement rainfall whenever needed.

3.3 Experimental design and treatments

In this experiment a total of fourteen treatments were investigated. These treatments were laid out in randomized complete block design (RCBD) with three replications and a total of 42 experimental plots. Fourteen treatments denoting lines of amaranth were randomly assigned to plots within each replicate where seeds were sown. Materials used were obtained from AVRDC-RCA, Gene-bank. The lines codes/ name and origins are indicated in Table 1.

Table 1: Treatments, codes and origins of amaranth lines used in experiments at AVRDC-RCA Arusha, Tanzania: February- September 2012.

Treatments	Line Name/Code	Line former name	Origin
T1	RVI00007	AH-TL	Tanzania
T2	RVI00130	HTT	Kenya
T3	RVI00089	MELANGE	Madagascar
T4	RVI00138	BRESIL	Madagascar
T5	RVI00090	PARIS (A)	Madagascar
T6	RVI00116	DB 2006306	USA
T7	RVI00002	IP-5	Zambia
T8	RVI00001	AM-25	Uganda
T9	RVI00117	SIMON FARM	Sudan
T10	RVI00022	TZSMN 102	Tanzania
T11	INCA	INCA	-
T12	RVI00086	RED INFLORESCENCE	Sudan
T13	RVI00121	AH-NL	Tanzania
T14	RVI00021	TZSMN 82	Tanzania

3.4 Data collection

3.4.1 Yield and yield related parameters

3.4.1.1 Fresh leaf yield (g/plant and t/ha)

Leaf data were recorded as weight of fresh leaves (kg) per plot; number of leaves harvested per plot and number of plants harvested were counted at each harvest. A scale balance was used to determine the fresh leaf weight. Fresh leaf yield from four harvests were added to get total leaf yield per plot or treatment. Leaf yield g/plant and t/ha were calculated as shown in formulas below.

$$\text{Leaf Yield g plant}^{-1} = \frac{\text{Total leaf yield kg per plot}}{\text{Number of plants per plot}} \text{ X } 1000$$

$$\text{Leaf Yield t ha}^{-1} = \frac{\text{Leaf Yield g plant}^{-1} \text{ x Area of 1 ha}}{\text{Plant spacing (m}^2\text{) x } 1000000}$$

3.4.1.2 Seed yield (g/plant and t/ha)

Seeds were harvested once when inflorescence change colour to yellow. Plants were cut, threshed and seed cleaned. The seed were put in net bags and dried on seed drier for two weeks. Before weighing seed moisture content (m.c) was determined and mean m.c was found to be 6.5%. A total seed yield (Kg) per plot was measured using analytical balance. Seed yield gram per plant and kg/ha were calculated as follows:

$$\text{Seed Yield g plant}^{-1} = \frac{\text{Total seed yield kg per plot}}{\text{Number of plants per plot}} \text{ X } 1000$$

$$\text{Seed Yield kg ha}^{-1} = \frac{\text{Seed Yield g plant}^{-1} \text{ x Area of 1 ha}}{\text{Plant spacing (m}^2\text{) x 1000}}$$

3.4.1.3 1000 Seed weight (g)

A sample of thousand seeds from each treatment and replication was counted and weighed using analytical balance.

3.4.1.4 Leaf length and width (cm)

Leaf length and width was measured in centimeter using ruler during vegetative growth on 6^{th} or 8^{th} leaf. Total of twenty leaf samples were randomly picked and measured from each treatments and replications.

3.4.2 Growth parameters

3.4.2.1 Days to 50% flowering

Days to 50% flowering were recorded from each treatment. This refers to 50% or half of the number of plants attaining inflorescence in a plot or treatment (AVRDC-GRSU, 2008).

3.4.2.2 Plant height (cm)

Plant height at flowering stage was recorded using bamboo stick calibrated in centimeters, whereby the height from the ground level of plant to the apex of inflorescence was measured from ten plants sampled randomly in each treatment (AVRDC-GRSU, 2008).

3.4.2.3 Number of leaves harvested per plant

Number of leaves in each harvest were counted and then added to get total number of leaves harvested per plot. Number of leaf per plant was calculated from number of leaves per plot and number of plant harvested.

$$\text{Number of leaves plant}^{-1} = \frac{\text{Total number of leaves harvested per plot}}{\text{Number of plants harvested per plot}}$$

3.4.2.4 Average number of branches per plant

Number of brunches per plant for ten plants selected randomly in the plot was counted at seed maturity and then average was determined.

3.4.2.5 Morphological characteristic data

Morphological features were assessed according to AVRDC-GRSU (2008) descriptors. These include germination rate, growth habit (either erect or prostrate), branching index, stem and leaf pigmentation, inflorescence and seed characteristics. All of these morphological features were observed and assessed at a specific plant growth stage i.e. during seedling, vegetative, flowering and seed stage (Appendix 1).

3.4.3 Farmer's participatory selection

Two groups of farmers participated in selection. The first group comprised of 33 amaranth farmers and second group comprised 21 amaranth farmers. Characters or criteria preferred

by farmers were (resistance to insects pest and diseases, colour of leaves, ability to give many sprouts after harvest, late flowering, fast growing and good taste) were used to determine the best amaranth line(s). All the characters were determined through visual observation in the field except for taste which was tasted by farmers after being boiled without addition of any ingredients. Farmers made their selections by dropping between zero and five seeds (0 = extremely poor and 5= excellent) in a container placed in front of each treatment. After each criterion seeds were collected and kept in a paper bags and labeled to indicate treatment and criteria. Later seeds were counted from each treatment in each criterion and recorded.

3.5 Data Analysis

Data collected from leaves, seeds and all yield related data was subjected to Analysis of variance (ANOVA) using CoStat version 6.204 (CoHort Software, 2003). Treatment with different means was compared using LSD at 5%, 1% and 0.1%.

Mixed linear model was used: $y_{ij} = \mu + \alpha_i + \beta_j + \varepsilon_{ij}$

Where: y_{ij}; measureable variable of i^{th} treatment in j^{th} replication, μ; overall mean, α_i; effect due to treatment , β_j; effect due to replication and ε_{ij}; residual effect.

Morphological characterization data were organized into a matrix and subjected to cluster analyses using the R statistical software version 2.13.0. Variables were segregated into four mathematical type: - discrete factors (e.g. leaf colour seed colour etc.); integers factors (e.g. number of days to 50% flowering); ranked-ordered factors (e.g. leaf pubescence none, low

to conspicuous) or numerical (e.g. measurement whose average was calculated such as leaf length, plant height) and clustered using the DAISY (dissimilarity matrix calculation) function. The clustering method was determined by wards. This produced dendrogram which represented the relationships among the lines under investigations in terms of approximate distances based on morphological traits.

CHAPTER FOUR

4.0 RESULTS

Results of this study are presented in tables, figures and plates. The results principally show treatment effects, relationships among lines in terms of approximate distances based on morphological traits and association of variables in yield performance.

4.1 Yield and yield related parameters

4.1.1 Fresh leaf yield

Table 2 shows the analysis of variance (ANOVA) for fresh leaf yield. The ANOVA revealed significant differences in amaranths lines at ($p \leq 0.01$) and ($p \leq 0.05$) for season one and two respectively. The interaction effects between lines were also significant ($p \leq 0.01$) in fresh leaf yield. The highest fresh leaf yield in season one was obtained in line RVI00117 (493 g/plant; 33 t/ha), followed by lines RVI00001 and RVI00021 which gave yields of 314 g/plant; 21 t/ha and 309 g/plant; 21 t/ha respectively. The lowest yield was observed in line RVI00121 with 212 g/plant; and/or 14 t/ha (Table 2).

Season two result indicate that the highest mean leaf yield was obtained in lines RVI00002 (210 g/plant; 14 t/ha) and RVI00001 (205 g/plant; 14 t/ha), while the lowest yield was observed in line RVI00090 (94 g/plant; 6 t/ha).

However, yield over the two seasons indicate that the line RVI000117 was the highest with the yield of 311 g/plant (21 t/ha) while the lowest yield over two season was recorded in line RVI00089 with 176 g/plant; 12 t/ha (Table 2).

Table 2: Mean fresh leaf yield and pooled fresh leaf yield of amaranth lines evaluated in two seasons (February-May and May-September 2012) at AVRDC-RCA Arusha, Tanzania

Lines name/code	**Season 1**		**Season 2**		**Pooled data over seasons**	
	Leaf yield (g plant^{-1})	Leaf yield (t ha^{-1})	Leaf yield (g plant^{-1})	Leaf yield (t ha^{-1})	Leaf yield (g plant^{-1})	Leaf yield (t ha^{-1})
RVI00007	299.83	19.99	178.27	11.88	239.05	15.94
RVI00130	253.37	16.89	120.79	8.05	187.08	12.47
RVI00089	251.71	16.78	100.9	6.73	176.31	11.75
RVI00138	272.20	18.15	97.69	6.51	184.95	12.33
RVI00090	273.14	18.21	93.75	6.25	183.44	12.23
RVI00116	273.32	18.22	124.75	8.32	199.03	13.27
RVI00002	314.27	20.95	210.32	14.02	262.29	17.49
RVI00001	266.32	17.75	205.06	13.67	235.69	15.71
RVI00117	492.3	32.82	130.09	8.67	311.2	20.75
RVI00022	248.18	16.55	168.17	11.21	208.18	13.88
INCA	273.53	18.24	132.41	8.83	202.97	13.53
RVI00086	305.26	20.35	128.13	8.54	216.69	14.45
RVI00121	211.09	14.07	165.99	11.07	188.54	12.57
RVI00021	308.92	20.59	131.55	8.77	220.23	14.68
F-test	**	**	*	*	**	**
Lsd $_{(0.05)}$	95.56	6.37	68.45	4.56	61.88	4.13
Seasons						
1					288.82	19.25
2					141.99	9.47
F-test					***	***
S * L					**	**
Lsd$_{(0.05)}$					23.39	4.13
CV (%)	19.71	19.71	28.72	28.72	24.82	24.82

Values with common letter in a column are not significantly different (ns). Mean separation by LSD at P=0.05

4.1.2 Seed yield

Analysis of variance result indicate that there is significant differences at ($p \leq 0.01$) and ($p \leq 0.001$) in seed yield among lines for season one and two respectively (Table 3).

The highest mean seed yield was observed in line RVI00021 (33.94 g/plant; 2262.99 kg/ha) followed by RVI00022 (33.56 g/plant; 2237.02 kg/ha) for first season, whereas the second season result indicated that line RVI00022 (25.59 g/plant; 1705.68 kg/ha) was the highest in terms of seed yield. On the other hand in both seasons, the lowest yield was recorded in line RVI00002 with 8.74 g/plant; 582.94 kg/ha and 4.74 g/plant; 315.79 kg/ha for first and second season respectively (Table 3).

Mean seed yield results in un-harvested leaf revealed that there was significant ($p \leq 0.01$) and highly significant ($p \leq 0.001$) differences among lines for first and second season, respectively. In both seasons line RVI00121 gave the highest mean seed yield of 54.46 g/plant; 3630.6 kg/ha and 33.17 g/plant; 2211.27 kg/ha in first and second season respectively, while the lowest mean seed yield were observed in lines RVI00007 (13.39 g/plant; 892.4 kg/ha) and RVI00002 (11.9 g/plant; 793.75 kg/ha) in first and second season, respectively (Table 4).

Table 3: Mean seed yield as affected by leaf harvesting in amaranth lines evaluated in two seasons (February-May and May-September 2012) at AVRDC-RCA Arusha, Tanzania

	Season 1		Season 2		Pooled data over season	
Lines name/code	Seed yield (g plant^{-1})	Seed yield (kg ha^{-1})	Seed yield (g plant^{-1})	Seed yield (kg ha^{-1})	Seed yield (g plant^{-1})	Seed yield (kg ha^{-1})
RVI00007	29.12	1941.06	18.61	1240.95	23.87	1591
RVI00130	25.81	1720.41	22.48	1498.62	24.14	1609.52
RVI00089	15.73	1048.89	16.35	1089.86	16.04	1069.4
RVI00138	20.75	1383.43	9.62	641.64	15.19	1012.53
RVI00090	16.11	1074.28	14.09	939.71	15.1	1006.99
RVI00116	9.11	607.53	5.06	337.57	7.09	472.55
RVI00002	8.74	582.94	4.74	315.79	6.74	449.36
RVI00001	21.79	1452.57	25.4	1693.35	23.59	1572.96
RVI00117	23.65	1576.86	8.13	541.8	15.89	1059.33
RVI00022	33.56	2237.02	25.59	1705.68	29.57	1971.35
INCA	27.99	1866.08	18.72	1248.19	23.36	1557.1
RVI00086	10.31	687.26	10.91	727.18	10.61	707.22
RVI00121	14.77	984.93	14.82	988.19	14.79	986.56
RVI00021	33.94	2262.99	23.93	1595.04	28.94	1929.02
F-test	**	**	***	***	***	***
Lsd $_{(0.05)}$	13.53	901.73	6.81	454	7.44	496.18
Seasons						
1					20.81	1387.59
2					15.6	1040.26
F-test					***	***
S * L					ns	Ns
Lsd$_{(0.05)}$					2.81	187.54
CV (%)	38.72	38.72	26	26	35.31	35.31

Values with common letter in a column are not significantly different (ns). Mean separation by LSD at P=0.05

Table 4: Mean seed yield on plots where leaves were not harvested on amaranth lines evaluated in two seasons (February-May and May-September 2012) at AVRDC-RCA Arusha, Tanzania

	Season 1		Season 2		Pooled data over season	
Lines name/code	Seed yield (g plant^{-1})	Seed yield (kg ha^{-1})	Seed yield (g plant^{-1})	Seed yield (kg ha^{-1})	Seed yield (g plant^{-1})	Seed yield (kg ha^{-1})
RVI00007	13.39	892.47	22.75	1516.85	18.07	1204.66
RVI00130	22.51	1500.84	27.28	1818.98	24.89	1659.91
RVI00089	19.96	1330.35	20.29	1352.96	20.12	1341.66
RVI00138	17.03	1135.39	17.9	1193.54	17.47	1164.47
RVI00090	24.59	1639.95	20.99	1399.3	22.79	1519.63
RVI00116	22.72	1514.54	12.41	827.03	17.56	1170.78
RVI00002	20.65	1376.91	11.91	793.75	16.28	1085.33
RVI00001	27.47	1831.18	32.19	2145.69	29.83	1988.43
RVI00117	33.05	2203.62	18.03	1202.29	25.54	1702.96
RVI00022	27.26	1817.13	31.58	2105.07	29.42	1961.1
INCA	29.29	1952.49	24.29	1619.97	26.79	1786.23
RVI00086	30.15	2009.05	18.07	1204.85	24.1	1606.95
RVI00121	54.46	3630.6	33.17	2211.27	43.81	2920.93
RVI00021	27.94	1862.59	22.83	1521.87	25.38	1692.23
F-test	**	**	***	***	***	***
Lsd $_{(0.05)}$	16.14	1076.08	9.65	643.37	9.36	623.69
Seasons						
1					26.46	1764.08
2					22.41	1493.82
F-test					*	*
S * L					ns	ns
Lsd$_{(0.05)}$					3.54	235.73
CV (%)	36.35	36.35	25.66	25.66	33.08	33.08

Values with common letter in a column are not significantly different (ns). Mean separation by LSD at P=0.05

4.1.3 Leaf length and width

Significant differences ($p \leq 0.05$) were observed in leaf length among lines in season one. Leaf width was highly significant ($p \leq 0.001$) in season one among lines (Table 5). Line RVI00086 had the longest leaf (22 cm). The shortest leaf length was recorded from line INCA (17.8 cm). Widest leaf was recorded from line RVI00138 (12 cm) and line RVI00089 was recorded with thin leaf (7.5 cm).

Season two result indicated a significant ($p \leq 0.01$) and highly significant ($p \leq 0.001$) differences concerning leaf length and width accordingly. The longest leaf was recorded from lines RVI00001 (19.15 cm) followed by RVI00086 (19.03 cm), while line RVI00002 (15.99 cm) was the shortest. Furthermore result shows that line RVI00007 had higher mean leaf width (11.09 cm), while the lowest mean leaf width was recorded in line RVI00089 (7.2 cm).

On the other hand, over season result indicated a significant ($p \leq 0.01$) and highly significant ($p \leq 0.001$) differences on leaf length and width respectively with no interaction effect over seasons. However, line RVI00086 had the highest mean leaf length (20.55 cm), while the lowest mean leaf length was recorded in line RVI00116 (16.29 cm). The highest mean leaf width was recorded in line RVI00138 (11.19 cm) and the lowest mean leaf width of 7.32 cm was recorded in line RVI00089 (Table 5).

Table 5: Mean leaf length and width of amaranth evaluated in two seasons (February-May and May-September 2012) at AVRDC-RCA Arusha, Tanzania

	Season 1		Season 2		Pooled data over seasons	
Lines name/code	Leaf length (cm)	Leaf width (cm)	Leaf length (cm)	Leaf width (cm)	Leaf length (cm)	Leaf width (cm)
RVI00007	18.07	9.17	18.12	11.09	18.09	10.13
RVI00130	18.02	8.44	17.51	9.67	17.77	9.06
RVI00089	17.95	7.48	16.57	7.16	17.26	7.32
RVI00138	21.98	11.85	17.97	10.53	19.98	11.19
RVI00090	21.06	11.17	17.67	10.14	19.36	10.67
RVI00116	19.13	9.92	13.45	8.77	16.29	9.35
RVI00002	18.8	8.99	15.99	8.04	17.39	8.52
RVI00001	18.36	8.28	19.15	9.58	18.75	8.93
RVI00117	20.02	9.19	17.97	10.09	18.99	9.64
RVI00022	18.78	9.39	18.44	9.88	18.61	9.63
INCA	17.83	8.057	16.85	8.98	17.34	8.52
RVI00086	22.06	9.80	19.03	10.63	20.55	10.22
RVI00121	19.18	9.98	17.14	9.99	18.16	9.98
RVI00021	18.87	9.45	17.92	10.40	18.39	9.93
F-test	*	***	**	***	**	***
Lsd $_{(0.05)}$	2.89	1.55	2.33	1.48	1.88	1.09
Seasons						
1					19.29	9.37
2					17.41	9.64
F-test					***	ns
S * L					ns	ns
Lsd $_{(0.05)}$					0.71	0.42
CV (%)	8.92	9.87	7.98	9.17	8.84	9.99

Values with common letter in a column are not significantly different (ns). Mean separation by LSD at P=0.05

4.1.4 Terminal inflorescence stalk length and 1000 seed weight

Highly significance differences ($p \leq 0.001$) among amaranths lines were observed in inflorescence stalk length in both seasons (Table 6). Longest inflorescence stalk were recorded from lines RVI00001 (31.47 cm) and RVI00130 (27.93 cm) in first season. Lines RVI00130 (31.47 cm) and RVI00022 (30.4 cm) had the longest in second season. The shortest length was recorded in line RVI00002 (12.77cm and 10 cm) in first and second season respectively.

Result also shows that there is high significant differences at ($p \leq 0.01$) and ($p \leq 0.05$) among lines in terms of thousands seed weight in grams for season one and two respectively (Table 6). Lines RVI00007, RVI00089 and RVI00138 observed to have highest mean average weight of thousands seed (0.9 g) in both seasons, while the lowest mean average weight of 0.57 g was observed in line RVI00116.

Table 6: Mean values of terminal inflorescence stalk length of amaranth lines evaluated in two seasons (February-May and May-September 2012) at AVRDC-RCA Arusha, Tanzania

	Season 1		Season 2	
Lines name/code	Terminal inflorescence stalk length (cm)	1000 Seed wt (g)	Terminal inflorescence stalk length (cm)	1000 Seed wt (g)
RVI00007	24.33	0.9	17.93	0.93
RVI00130	27.93	0.8	30.47	0.83
RVI00089	23.26	0.9	22.33	0.87
RVI00138	24.26	0.87	14.8	0.87
RVI00090	20.85	0.83	13.07	0.83
RVI00116	15.96	0.57	11.6	0.57
RVI00002	12.77	0.6	10	0.6
RVI00001	31.47	0.73	28.8	0.8
RVI00117	22.13	0.63	17.2	0.67
RVI00022	18.73	0.67	30.4	0.7
INCA	22.97	0.73	26.27	0.73
RVI00086	22.36	0.67	16.4	0.8
RVI00121	20.21	0.8	19.93	0.77
RVI00021	24.35	0.77	29.93	0.83
F-test	***	**	***	*
Lsd $_{(0.05)}$	6.55	0.17	3.73	0.19
CV (%)	17.54	13.3	10.75	14.31

Values with common letter in a column are not significantly different (ns). Mean separation by LSD at P=0.05

4.2 Growth parameters

4.2.1 Plant height

Highly significant differences were observed among lines in two seasons respectively (Table 7). The interaction effects were also significant $p \leq 0.001$ (Table 7). Tallest plant height was

recorded in lines RVI00002 (211.13 cm) and RVI00090 (210 cm) for season one while for season two, the tallest plant height was attained from lines RVI00130 (85.23 cm) followed by RVI00001 (83. 97 cm) (Table 7).

The shortest plant height in season one and two was observed from line RVI00022 (126.45 cm) and RVI00116 (50.47 cm) respectively (Table 7).

Furthermore the result indicated that the highest mean plant height across seasons was attained from line RVI00002 (147.07 cm) while the line RVI00116 (96.63 cm) was the shortest (Table 7).

4.2.2 Days to 50% flowering

Number of days to fifty percent flowering showed significant differences in amaranths lines at ($p \leq 0.01$) and ($p \leq 0.001$) for season one and two respectively. The interaction effect between lines and seasons were also significant (Table 7). Earliest flowering was observed from lines RVI00007 and RVI00001 (37 days) for season one. Line RVI00130 (42 days) was recorded the earliest for season two. The late flowering in season one was recorded in lines RVI00090 and RVI00116 (47.67 days). In season two, late flowering was observed from RVI00002 (76 days).

Across the season result indicated that line RVI00001 was the earliest to attain 50% flowering (40 days), whereas the longest days of 61 was observed from line RVI00002 (Table 7).

Table 7: Mean Plant height and Days to 50% flowering of amaranth lines evaluated for two seasons from February-May and May-September 2012 AVRDC-RCA, Arusha Tanzania

	Season 1		Season 2		Pooled data over seasons	
Lines name/code	Plant height (cm)	Days to 50% flowering	Plant height (cm)	Days to 50% flowering	Plant height (cm)	Days to 50% flowering
RVI00007	182.93	37.33	76.8	48	129.87	42.67
RVI00130	150.2	40.67	85.23	42	117.72	41.33
RVI00089	171.3	42	74.83	51.67	123.08	46.83
RVI00138	191.07	43.33	69.57	59.67	130.32	51.5
RVI00090	210	47.67	73.53	61.67	141.77	54.67
RVI00116	142.8	47.67	50.47	57.67	96.63	52.67
RVI00002	211.13	46	83	76	147.07	61
RVI00001	140	37	83.97	43	111.98	40
RVI00117	151.93	42	56.93	59.67	104.43	50.83
RVI00022	126.45	40.67	77.73	45	102.1	42.83
INCA	160	37.67	79.8	44	119.9	40.83
RVI00086	148.67	45.67	64.97	59.67	106.82	52.67
RVI00121	181	35.67	76.83	48	128.93	41.83
RVI00021	140.2	41	70.7	43	105.45	42
F-test	***	*	***	***	***	***
Lsd $_{(0.05)}$	26.45	6.96	12.5	4.3	15.35	3.94
Seasons						
1					164.84	41.74
2					73.17	52.79
F-test					***	***
S * L					***	***
Lsd $_{(0.05)}$					5.8	1.49
CV (%)	9.56	9.94	10.18	4.85	11.14	7.2

Values with common letter in a column are not significantly different (ns). Mean separation by LSD at P=0.05

4.2.3 Average leaf harvested per plant

Leaves numbers significantly differed at ($p \leq 0.01$) and ($p \leq 0.001$) for season one and two respectively. Result also revealed interaction effects between lines and seasons were significant (Table 8).

Line RVI00117 had the highest mean leaf number harvested per plant (128) for season one. Line RVI00002 (154) was observed the highest at season two and across the season (123). The lowest mean leaf number harvested per plant in both seasons and across was observed in line RVI00090 (46, 30 and 38) respectively (Table 8).

4.2.4 Number of branches per plant

Number of branches per plant showed highly significant difference ($p \leq 0.001$) in season one, significant ($p \leq 0.05$) in season two and highly significant ($p \leq 0.001$) across seasons with interaction effects. Result also indicated that line RVI00002 had many number of branches per plant for season one, two and across (29, 16 and 23) respectively. On the other hand few number of branches per plant was observed in lines RVI00022 (13), RVI00021 (10) and RVI00022 (14) for season one, two and across seasons respectively (Table 8).

Table 8: Mean average of leaf number harvested and number of branches per plant in amaranth lines evaluated in two seasons from February-May and May-September 2012, AVRDC-RCA Arusha, Tanzania

	Season 1		Season 2		Pooled data over seasons	
Lines name/code	Leaf harvested plant $^{-1}$	Branch number plant $^{-1}$	Leaf harvested plant $^{-1}$	Branch number plant $^{-1}$	Leaf harvested plant $^{-1}$	Branch number plant $^{-1}$
RVI00007	86.62	20.93	89.13	11.4	87.88	16.17
RVI00130	82.81	17.27	69.32	11.4	76.07	14.33
RVI00089	74.21	25.07	67.79	10.73	70.99	17.9
RVI00138	48.84	22.4	47.05	11.13	47.94	16.77
RVI00090	46.09	20.9	30.25	11.13	38.17	16.02
RVI00116	81.43	23.8	50.21	11.6	65.82	17.7
RVI00002	91.28	29.2	154.22	16.2	122.75	22.7
RVI00001	90.89	16	117.56	11.73	104.23	13.87
RVI00117	127.94	20.27	77.65	11.07	102.81	15.67
RVI00022	67.99	13.4	95.512	11.6	81.75	12.5
INCA	90.7	16.8	89.54	12	90.12	14.4
RVI00086	83.62	22.2	76.54	11.8	80.08	17
RVI00121	56.42	15.87	80.33	11.6	68.38	13.73
RVI00021	94.09	17.33	67.97	9.67	81.03	13.5
F-test	**	***	***	*	***	***
Lsd $_{(0.05)}$	33.94	5.43	30.42	2.59	24.43	2.98
Seasons						
1					80.21	20.1
2					79.51	11.65
F-test					ns	***
S * L					**	**
Lsd $_{(0.05)}$					9.231	1.13
CV (%)	25.21	16.11	22.79	13.29	26.43	16.24

Values with common letter in a column are not significantly different (ns). Mean separation by LSD at P=0.05

4.3 Correlation analysis

The correlation analysis results of selected parameters are shown in Table 9. Results indicates that leaf yield per plant had strong positive significant correlation (r = 0.76) with number of leaf, while there is no significant correlation with the rest of parameters. Seed yield per plant indicates strong positive significant with terminal inflorescence stalk length (r = 0.75) and negative correlation with Days to 50% flowering and Branch number per plant (r = -0.85; -0.76) respectively. Results also indicate that there is weak negative non significant correlation between seed and leaf yield (r = -0.02).

Table 9: Person's rank correlation coefficients of selected parameters showing relationships among yield parameters at AVRDC-RCA, Arusha Tanzania 2012

Yield parameters[1]	PH	LY	D50F	LN	NB	SY	TIS
LY	-0.14^{ns}						
D50F	0.35^{ns}	0.22^{ns}					
LN	-0.09^{ns}	0.76**	-0.03^{ns}				
NB	0.48^{ns}	0.21^{ns}	0.84***	0.23 ^{ns}			
SY	-0.24 ^{ns}	-0.02^{ns}	-0.85***	0.13 ^{ns}	-0.76**		
TIS	-0.18 ^{ns}	-0.11^{ns}	-0.67**	-0.07 ^{ns}	-0.57*	0.75**	
TIL	-0.13^{ns}	0.03^{ns}	-0.35 ^{ns}	-0.13 ^{ns}	-0.41^{ns}	0.51^{ns}	0.77**

Non significant difference (ns) was considered when P>0.05, * when P≤0.05, ** when P≤0.01 and *** when P≤0.001.

[1]**Abbreviations represent;** PH=Plant height, LY=Leaf yield g/plant, D50F=Days to 50% flowering, BN=Number of branch per plant, SY=Seed yield g per plant, TIS=Terminal inflorescence stalk length (cm), TIL=Terminal inflorescence lateral length (cm)

4.4 Agro-morphological characteristics

Results of the cluster analyses of morphological characteristics data are illustrated in figures 2 and Table 10 & 11. Thirty-three agro-morphological traits for plant characteristics observed during both seasons indicate similarities in the following traits; germination rate in all lines are slow in germination that takes 2-7 days, with erect growth habit. Prominent sex type in all lines is monoecious. Absence of spines in leaf axils and prominence of leaf vein i.e. rugose is similar in all lines. Presence of axillary inflorescence and opaque seed coat also is similar to all lines. Variability observed in the rest of the traits as indicated in Table 11.

Cluster dendrogram analysis grouped the amaranths lines evaluated into three main clusters according to their similarities (Fig. 2). The differentiation was based on two main criteria, one was group branching of the dendrogram and secondly the magnitude of the similarity identified by the horizontal line making the branches (Fig. 2)

Considering group branching, there were two main groups that are cluster I and II, and cluster III (Fig. 2). For using second criteria on magnitude of the similarities, cluster I is closer to cluster II than cluster III, where by line RVI00138 and RVI00090 members in cluster I were more similar to each other. These lines characterized by tall plant with mean average of 136 cm (Table 10), with purple or pink pigmentation on stem, petiole and drooping of terminal inflorescence lax to dense spike and generally pink in colour with low seed shattering of less than10% (Plate 1).

Cluster II consisted of five lines which was characterized by low seed shattering (<10%), erect terminal inflorescence, with dense panicle and yellow in colour (Plate 3). Also this cluster was characterized by average plant height of 115.6 cm (Table 10).

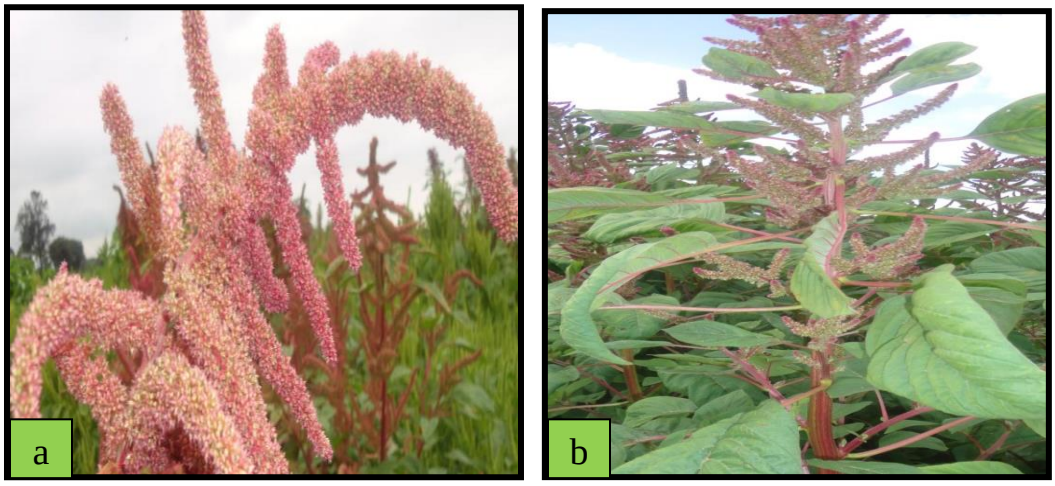

Plate 1: Morphological characteristics of cluster I. Plate 1a indicates inflorescence colour and 1b indicates stem, leaves and petiole colour characteristics

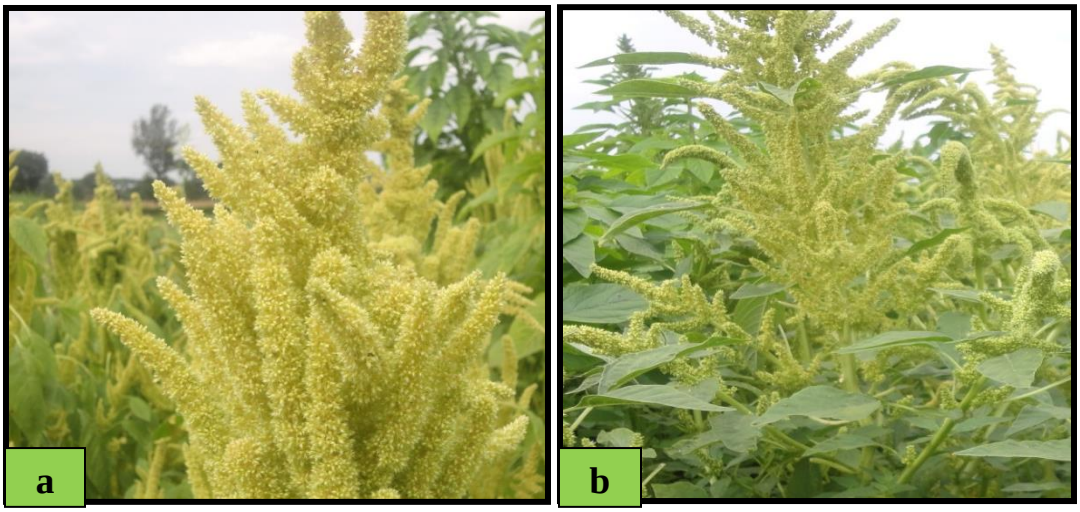

Plate 2: Showing inflorescence colour for majority of amaranth lines in cluster II (Plate 2a) and cluster III (Plate 2b)

Cluster III consisted of seven lines, most of which were characterized by early flowering (41 days), with average plant height of 116.6 cm.

All lines in this cluster exhibited an intermediate seed shattering characteristic, which means 10-50% of seed shattering before harvest. Seed colour in this cluster was characterized to be brown.

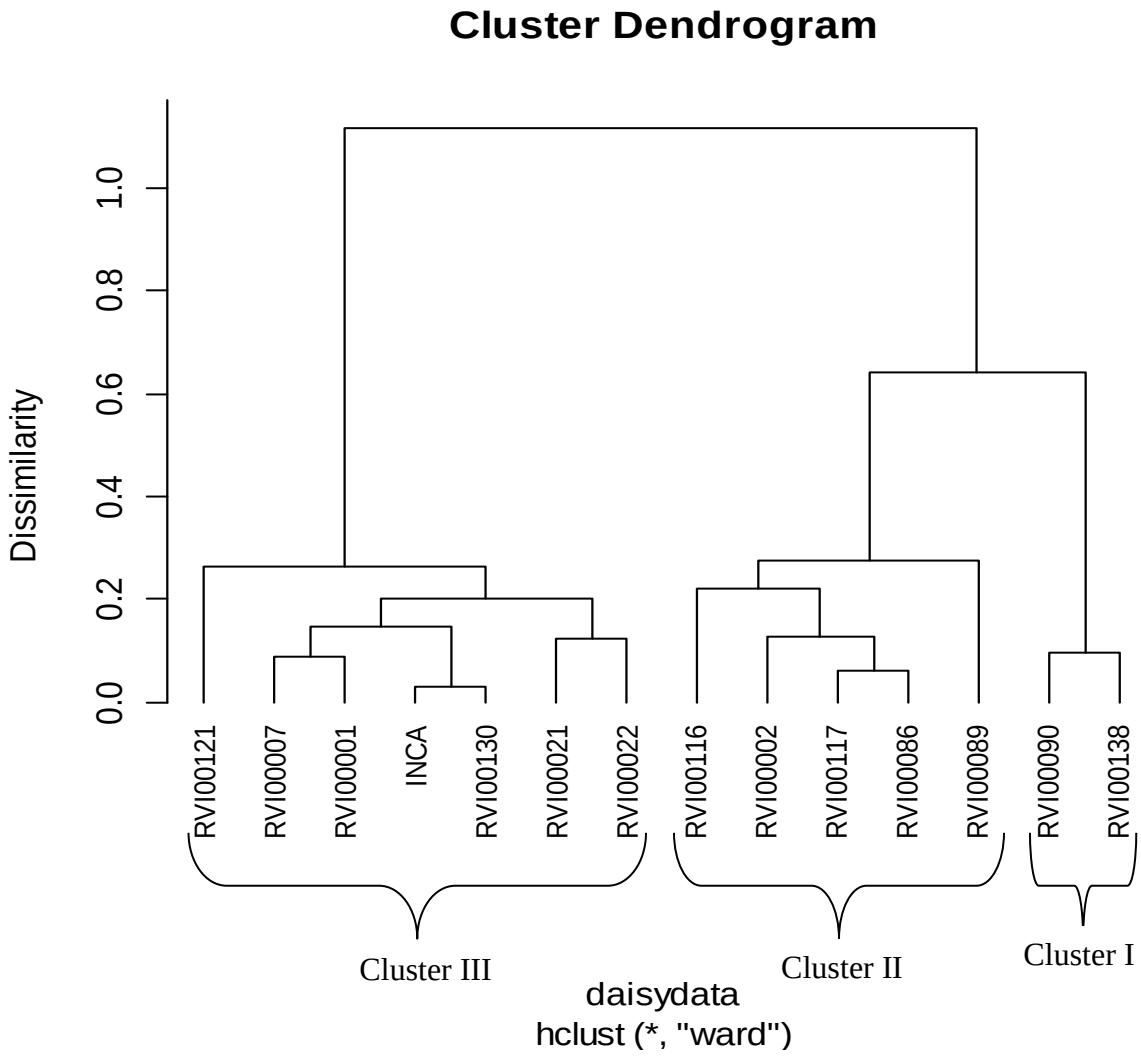

Figure 2: Cluster dendrogram illustrating morphological characteristics in 14 amaranths lines.

Table 10: Descriptive analysis of quantitative morphological characteristics of amaranth lines evaluated at AVRDC-RCA, Arusha Tanzania 2012

	Cluster1				Cluster2				Cluster3			
Characters**	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD
D50F	51.5	54.7	53.1	2.24	46.8	61	52.8	5.17	40	42.8	41.6	1
LL	19.4	19.9	19.7	0.43	16.3	20.6	18.1	1.68	17.3	18.8	18.2	0.59
LW	10.7	11.2	10.9	0.38	7.32	10.2	9	1.13	8.52	10.1	9.5	0.62
LAI	31.4	36.4	33.9	3.54	21	32.4	26.7	4.8	24	43.9	34.7	8.19
PH	130	142	136	8.1	96.6	147	116	20	102	130	117	10.8
SW	0.73	0.87	0.8	0.09	0.6	0.93	0.69	0.14	0.8	0.93	0.86	0.04
TIL	12.3	14.6	13.4	1.59	6.32	15.3	11.1	4.22	8.99	14.3	12.2	1.92
TIS	24.4	27.9	26	2.53	12.8	31.5	20.9	7.17	18.7	24.3	22.1	2.17

** Abbreviations represent; D50F=Days to 50% flowering, LL= Leaf length (cm), LW= Leaf width (cm), LAI= Length of axillary inflorescence (cm), PH= Plant height (cm), SW= 1000 Seed weight (g), TIL= Terminal inflorescence lateral length (cm) and TIS= Terminal inflorescence stalk length (cm)

Table 11: Frequency distribution (%) of discrete morphological descriptors in 14 amaranth lines evaluated at AVRDC-RCA, Arusha Tanzania 2012

Descriptor	Description	No. of accessions	Frequency (%)
Germination rate	Slow (2-7 days)	14	100.0
Growth habit	Erect	14	100.0
Branching index	Few branches (all near the base of stem)	1	7.1
	Branches all along the stem	13	92.9
	None	4	28.6
Stem pubescence	Low	3	21.4
	Conspicuous	7	50.0
Stem pigmentation	Green	6	42.9
	Purple or pink	2	14.3
	Mixture	6	42.9
Spines in leaf axils	Absent	14	100.0
Leaf pubescence	None	13	92.9
	Low	1	7.1
Leaf pigmentation	Margin and vein pigmented	2	14.3
	Normal green	12	85.7
Leaf shape	Rhombic	14	100.0
Leaf margin	Entire	14	100.0
Prominence of leaf veins	Rugose	14	100.0
Petiole pigmentation	Green	2	14.3
	Purple	2	14.3
	White	10	71.4
Terminal inflorescence shape	Spike	2	14.3
	Panicle with short branches	11	78.6
	Panicle with long branches	1	7.1
Terminal inflorescence attitude	Erect	12	85.7
	Drooping	2	14.3
Presence of axillary inflorescence	Present	14	100.0
Sex type	Monoecious	14	100.0
Inflorescence density index	Lax	2	14.3
	Intermediate	3	21.4
	Dense	9	64.3
Inflorescence color	Yellow	11	78.6
	Pink	3	21.4
Seed shattering	Low <10%	7	50.0
	Intermediate 10-50%	7	50.0
Seed color	Pale yellow	8	57.1
	Brown	6	42.9

Seed coat type	Opaque	14	100.0
Seed shape	Round	13	92.9
	Ellipsoid or round	1	7.1

4.5 Farmers' participatory selection

A total of fifty four farmers with gender distribution of 87:13% female and male ratio participated in selection. Using fast growing as selection criteria farmers participatory research indicated that lines RVI00121, RVI00022 and RVI00001 are most preferred with 145, 120 and 117 score point respectively. RVI00121 (189 score) and RVI00090 (142 score) recorded high preference for resistant to disease and insect. Ability to sprout after harvesting is important criteria especially when farmer select variety for continuous harvesting. In this category lines RVI00022 (141), RVI00121 (132) and RVI00021 (129) recorded high preference score point. Line RVI00002 (168 score), RVI00138 (159 score) and RVI00117 (131 score) recorded high preference for late flowering, while in criteria for leaf colour indicate that line RVI00121 (137), RVI00116 (135) and RVI00022 (110) are most preferred due to their dark green colour. On the other hand sensory evaluation (taste) showed that line RVI00121 (260), RVI00130 (144) and RVI00138 (116) were preferred for good taste (Table 12).

Table 12: Score point distribution of farmers' preference in amaranth lines and rank (superscript) for criteria selected during 2012

Amaranth lines	Fast Growing	Resistant to disease and insect	Ability to Sprout	Late Flowering	Dark Green in colour	Taste
RVI00007	97	69	105	76	96	72
RVI00130	70	66	128	120	101	144^{2}
RVI00089	82	111	83	125	67	68
RVI00138	105	90	95	159^{2}	79	116^{3}
RVI00090	104	142^{2}	79	113	51	58
RVI00116	69	93	122	106	135^{2}	93
RVI00002	79	95	103	168^{1}	104	86
RVI00001	117^{3}	83	105	40	86	62
RVI00117	69	124	98	131^{3}	76	57
RVI00022	120^{2}	125^{3}	141^{1}	75	110^{3}	71
INCA	69	118	82	61	73	84
RVI00086	70	98	84	119	72	77
RVI00121	145^{1}	189^{1}	132^{2}	58	137^{1}	260^{1}
RVI00021	69	79	129^{3}	56	106	39

CHAPTER FIVE

5.0 DISCUSSION

5.1 Leaf and seed yield

Widely variable and significant differences in leaf and seed yield were observed between amaranths lines evaluated. There were differences within season and across season among the lines evaluated. In season one line RVI00117 recorded the highest leaf yield value while in season two lines RVI00002 and RVI00001 were highest. However, over season results shows that line RVI00117 was the highest in terms of leaf yield. On the other hand highest seed yield was recorded in lines RVI00021 and RVI00022 for first season, while RVI00022 was the highest in second season.

The variations in leaf and seed yield in these two seasons might be due to the influence of the growing environments. The first season was characterized by warm and wet conditions, while the second season was cool and dry. The weather conditions influenced the genetic potential of the lines evaluated in the study. Season one recorded average temperature of 25.1^0c and 322mm of rainfall, whilst season two resulted with average temperature of 24^0c and 32.7mm rainfall, respectively. Therefore, the warm and wet conditions seems to be optimum for amaranth production since it affects other traits like plant height and number of branches which might affect directly or indirectly leaf and seed yield.

It has been reported that fresh leaf yield of Amaranthus may vary from 10 to 70 t ha^{-1}, while seed yield range from 1 to 6 t ha^{-1} (Svirskis, 2003). Gupta *et al.* (1994) achieved grain yield of 300 kg ha^{-1} under unfavorable conditions and 700 kg ha^{-1} under optimized cultivation date

in Kenya. Leaf yield values reported in this study were generally lower but comparable, to those reported earlier for amaranths species *A. cruentus*, *A. hypochondriacus* and *A. dubius* (Oluoch *et al.,* 2009) as varying between 17.8 t/ha and 32 t/ha in different harvesting techniques. The higher values reported in the earlier study may be explained by the fact that harvesting technique used was continuous harvesting with topping while a continuous harvesting without topping was used in the current study. Topping allows more side shoots and delayed flowering which enhances more leaf yield. These genotypic differences with regard to leaf and seed yields support the hypothesis that there are clear differences among genotypes in their potential to be used as dual purpose or grain amaranths.

In general, seed yield reported in this study was within the yield ranges reported earlier (Svirskis, 2003). The variations among seed yield in amaranth lines with leaf harvested and those without leaf harvested, confirms the opinion that in many cases the leaf yield is inversely proportional to seed yield (Svirskis, 2003). Also Saidi *et al.* (2007) reported the highest seed loss in cowpea when leaf harvesting frequency was as per appearance. Removing leaves interferes with the photosynthetic process of the plant and, finally, affects the prevailing source to sink assimilation. However, there are some cases in this study which indicate that higher seed yield was obtained with leaf harvested than without leaf harvested. This may be explained by the fact that harvested part usually has few branches and inflorescence are not dense and heavy due to removal of leaves while un-harvested part has many branches and inflorescences that are dense and heavy. Therefore during rain

inflorescence become heavier and hence break and lodge which result into most of seeds being lost before harvesting.

5.2 Plant height and days to 50% flowering

Result in this study revealed that seasons significantly affect plant height and days to 50% flowering. Plant height ranged from 126.45 cm to 211.13 cm and 50.47 cm to 85.23 cm for first and second season respectively. On the other hand the same trend was observed in days to fifty percent flowering whereas more days were observed in second season (76 days). These variations can be explained by the fact that differences in genotypic as well as weather condition between two seasons affect the growth of plant. In first season the weather condition was warm and wet while the second season was cool and dry. Vegetable amaranth has been reported to achieve optimum growth when air temperatures are above 25^0c (Whitehead *et al.,* 2002). The result of this study also confirm the finding of Kauffmann and Weber (1990) who reported that some traits of amaranths are affected by environmental influence such as plant height, days to maturity, plant architecture and dry-down.

5.3 Number of leaves harvested and branches per plant

Differences observed in number of leaves harvested and branch number per plant might have been due to genetic variation that existed among lines and/ or due to favorable influence of growing environment. In general higher value of leaves harvested per plant was observed in season two compared to season one. This might be explained due to the fact that different genotypes respond differently to weather conditions. The line RVI00002 took longer time to

flower in season two as to compared to other lines, and therefore extended the vegetative phase which resulted into higher number of leaves harvested. This observation is in line with findings by Okokoh and Bisong (2011) which observed a sharp decline of leaf productivity in *A. cruentus* after on-set of flowering.

5.4 Agro-morphological characteristics

Amaranths have increasingly gained importance as a nutritious leafy vegetables and grain crop both for home garden and commercial production. There is wide genetic diversity but, preservation and characterization studies have been limited. Preservation and characterization of amaranth germplasm are necessary for maintaining genetic diversity, identifying genotype, and studying local genetic material that will facilitate its utilization in crop improvement programs. In the process of genetic improvement, genetic diversity among germplasm plays a major role, since it opens the way to determine the most divergent parents based on the contribution of different qualitative and quantitative traits, for further utilization in any hybridization program.

The present study evaluated 14 amaranth lines using 32 morphological characters. Cluster analysis using Ward's method generated a dendrogram that showed two major groups which subdivide into three clusters. The dendrogram showed that the genotypes that were derivatives of genetically similar type, clustered together. Furthermore, the study demonstrates a high level of genetic similarity between cluster I and II. These two clusters involved the diverse germplasm of different geographical origin ranging from Madagascar to

America and also they resemble more of *A. cruentus.* Cluster three which comprises of seven lines, are dominated by *A. hypochondriacus* due to presence of two lines identified earlier as *A. hypochondriacus* RVI00007 and RVI00121, (Ojiewo *et al.,* 2010). In this study, lines from different regions were placed with each other in cluster II and III with exception of cluster I where two lines (RVI00090 and RVI00138) are from same region. These confirmed that there is no association between the lines and their geographical origin. This result concurred with earlier study by Erum *et al.* (2012) who compared different species of amaranth collected in different agro-ecological zones of Pakistan, and found no association between cultivars and their origin. Lowest dissimilarity observed between INCA and RVI00130 may be due to narrow selection zone. 10-100% similarity among varieties of *A. hypochondriacus* was reported by Mandal and Das (2002). In addition, (Popa, *et al.,* 2010) reported relationship between *A. hypochondriacus* and *A. cruentus,* the genetic distance between them being 18-20%.

Finally, cluster analysis has proved to be an effective method in grouping germplasm with common morphological traits. The dendrogram indicated genetic diversity of germplasm within and between cluster groups. It showed variations in quantitative characters such as plant height, branching, inflorescence length and leaf size that led to the identification of small, intermediate and large plant types among clusters. High variability of qualitative characters was also evident such as stem, leaf and petiole pigmentation, leaf shape, leaf margin, inflorescence color, terminal inflorescence shape and density, and seed color. From the results, lines of a particular cluster having desirable traits can be evaluated using farmers

participatory approach to select for lines that are best adapted to a specific agro-ecological condition. Furthermore, line(s) having desirable traits can be hybridized with other promising lines to produce the desired hybrid after fixing following recurrent selections. Thus, the present characterization information enhances the utilization of the amaranth germplasm in breeding programs, and in ensuring efficient management of germplasm collection.

5.5 Farmers' participatory selection

Farmer's selection of amaranth lines has the potential to improve the relevance of on-station researcher-design trials to identify preferred character. In this study farmers identified fast growing, resistant to insect pest, ability to sprout, leaf colour and taste as important characteristics for good vegetable amaranth. Line RVI00121 was preferred by the farmers for multiple characters (fast growing, resistant to diseases and pest, ability to sprout, leaf colour and taste). Fast growth in amaranth could be a desirable character when the need arises for varieties with a short growth cycle to meet early market demands. Conversely, fast growing varieties could have short vegetative phase which may result into low leaf productivity, because more energy will directed to seed production. This result concurred with study by Adeniji *et al.* (2010) which found that most of farmers preferred early maturing varieties of cabbage in order to meet market demand. On the other hand consumer health and environmental issues become a major concern due to the chemicals used by vegetable growers in order to protect against insect pest. Therefore by having varieties

which are resistant to diseases and pest will avoid this concern. Farmers also prefer lines with dark green leaves; this probably might be due to their previous experience with other leafy vegetables such as spinach and sweet potato leaves. This is in line with Muthoni *et al.* (2010) which found that majority of farmers preferred genotypes with dark green leaves during participatory characterization and evaluation of amaranth, African nightshade and spider plant in central Kenya.

CHAPTER SIX

6.0 CONCLUSIONS, RECOMMENDATIONS AND SUGGESTIONS FOR FUTURE RESEARCH

6.1 Conclusions

In general, there were genotypic differences exist in amaranth lines evaluated for leaf and grain yield potential. These differences in performance of agronomic traits portray the potential success in future improvement work of amaranth for different purposes.

It is concluded from this study that lines RVI00121 and RVI00001 are best for grain production while line RVI00007 is the best for dual purpose (leaf and grain).

This investigation also indicated that lines which present cluster I and II constitute an important traits such as brown colour of the seed, dense panicle, low to medium seed shattering and early flowering. Therefore one of the line(s) from these clusters can be used as genitor/ donor parents to improve other lines or varieties in the breeding programs of of this crop.

On the other hand participatory selection reveals that preference for resistance to insects pest and diseases, leaves colour, late flowering, ability to give many sprouts after harvest, fast growing and good taste are important traits that should be constitute breeding objectives to rapidly develop new varieties. Promising line which was selected by farmers after meeting most of these criteria was RVI00121. Participation of farmers in assessment has the potential to improve the relevance of on-station researcher designed trial to identify

preferred character and also ensure higher chance of adoption of varieties or technology introduced.

6.2 Recommendations

Based on findings in this study, lines RVI00121 and RVI00001 appear to perform best in this location especially in grain production and hence can be recommended to farmers. While for dual purpose (grain and leaf) line RVI00007 can be recommended. However, it is also considered that different genotypes or the aims of maximizing nutritive value or any other factor may modify this recommendation.

6.3 Suggestions for future research

The study generated data which could be useful to fulfill the set objectives. However, future research is needed to:

- ✓ Determine how timing and harvesting frequency affect the grain yield.
- ✓ Study the effects of leaf harvesting indefinitely without consideration of seed yield.
- ✓ Carry out nutritional analysis to find out nutrient contents of these lines.
- ✓ Undertake experiments in different agro-ecological zones so as to have broad recommendations.
- ✓ Conduct studies to determine response of these lines to different level and type of fertilizers (organic and in-organic).

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APPENDICES

Appendix 1: Descriptor list for Amaranthus (Adapted from AVRDC-GRSU, 2008)

AVRDC-GRSU CHARACTERIZATION RECORD SHEET

Crop:	***Amaranthus* spp.**
Plot No. :	Accession No. :
Sowing Date:	Name:
Transplanting Date:	Species:
Location:	Origin:

SEEDLING DATA

Am110 Germination period (no. of days from sowing to first germination)

Am120 Germination rate
1 = Rapid (< 2 days) 2 = Slow (2-7 days)
3 = Very slow (> 7 days) 4 = Irregular

VEGETATIVE DATA

Am210 Growth habit
1 = Erect 2 = Prostrate

Am220 Plant height (cm) (at flowering stage)

Am230 Branching index (score if erect growth habit)
1 = No branches
2 = Few branches (all near the base of the stem)
3 = Many branches (all near the base of the stem)
4 = Branches all along the stem

Am240 Mean length of basal lateral branches (cm)

Am250 Mean length of top lateral branches (cm)

Am260 Stem pubescence
0 = None 3 = Low 7 = Conspicuous

Am270 Stem pigmentation
1 = Green 2 = Purple or pink 3 = White X = Mixture

Am280 Spines in leaf axils
1 = Absent 2 = Present X = Mixture

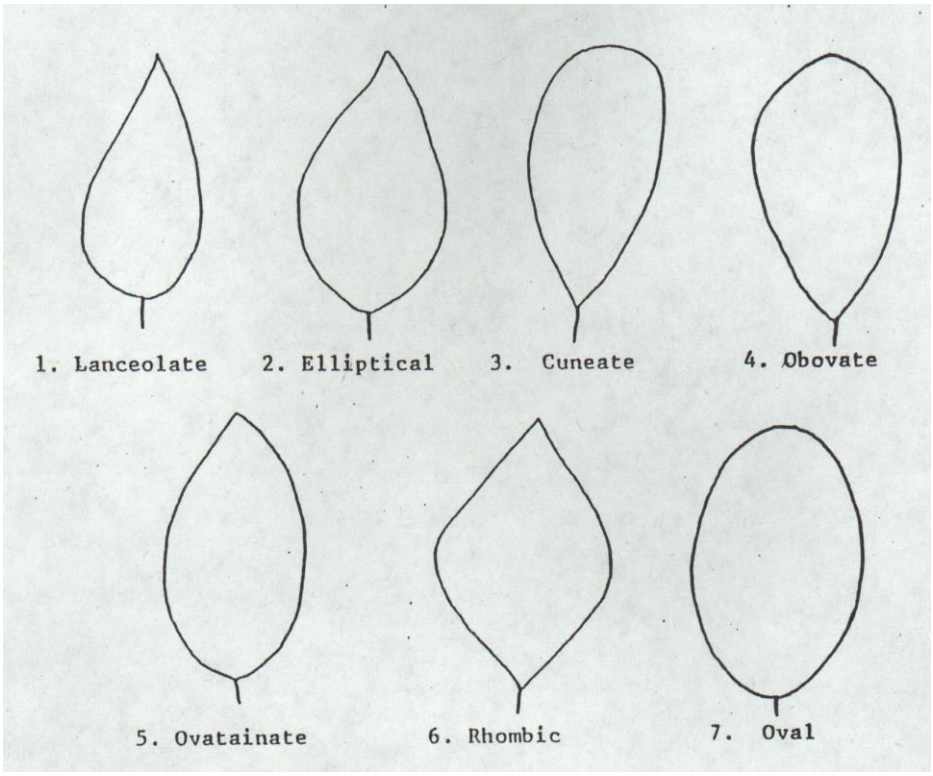
Am290 Leaf length (cm) (on 6^{th} or 8^{th} leaf)

Am300 Leaf width (cm) (on 6^{th} or 8^{th} leaf)

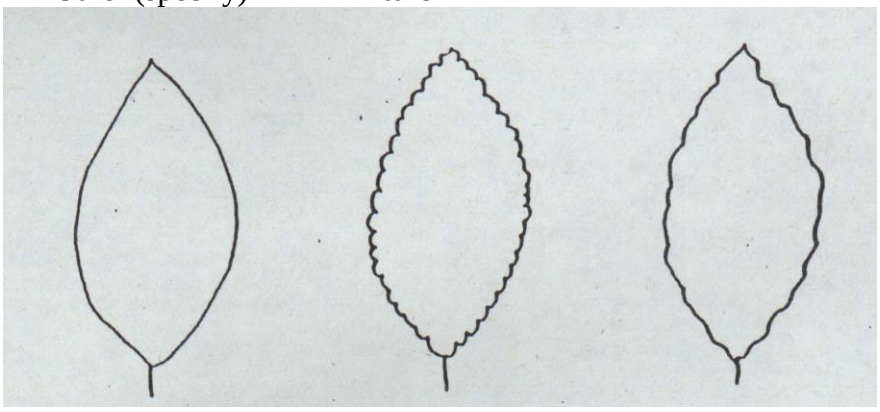
Am310 Leaf pubescence
0 = None 3 = Low 7 = Conspicuous

Am320 Leaf pigmentation
1 = Entire lamina purple or pink
2 = Basal area pigmented
3 = Central spot
4 = Two stripes (V-shaped)
5 = One stripe (V-shaped)
6 = Margin and vein pigmented
7 = One pale green or chlorotic stripe on normal green
8 = Normal green 9 = Dark green
10 = Other (specify) X = Mixture

Am330 Leaf shape
1 = Lanceolate 2 = Elliptical 3 = Cuneate
4 = Obovate 5 = Ovatainate 6 = Rhombic
7 = Oval 8 = Other (specify) X = Mixture



Am340 Leaf margin
1 = Entire 2 = Crenate 3 = Undulate
4 = Other (specify) X = Mixture



1. Entire 2. Crenate 3. Undulate

Am350 Prominence of leaf veins
1 = Smooth 2 = Rugose (veins prominent)

Am360 Petiole pigmentation

1 = Green 2 = Dark green 3 = Purple
4 = Dark purple 5 = White X = Mixture

INFLORESCENCE DATA

Am400 Days to flowering (from sowing to 50% with inflorescence)

Am410 Terminal inflorescence stalk length (cm)

Am420 Terminal inflorescence laterals length (cm)

Am430 Terminal inflorescence shape
1 = Spike (dense) 2 = Panicle with short branches
3 = Panicle with long branches 4 = Club-shaped at tips
5 = Other (specify) X = Mixture

Am440 Terminal inflorescence attitude
1 = Erect 2 = Drooping

Am450 Presence of axillary inflorescence
1 = Absent 2 = Present

Am460 Length of axillary inflorescence (cm)

Am470 Sex type
1 = Monoecious 2 = Dioecious 3 = Polygamous

Am480 Inflorescence density index
3 = Lax 5 = Intermediate 7 = Dense

Am490 Inflorescence color
1 = Yellow 2 = Green 3 = Pink 4 = Red
5 = Other (specify) X = Mixture

SEED DATA

Am500 Seed shattering
1 = Low (<10%) 2 = Intermediate (10-50%) 3 = High (>50%)

Am510 Seed color
1 = Pale yellow 2 = Pink 3 = Red 4 = Brown 5 = Black

Am520 Seed coat type
1 = Translucent 2 = Opaque

Am530 Seed shape
1 = Round 2 = Ellipsoid or ovoid

Am540 1000 seeds weight (gm)