IDENTIFICATION AND CHARACTERIZATION OF SORGHUM (*Sorghum bicolor* (L.) Moench) LANDRACES AND IMPROVEMENT OF ON-FARM SEED PRODUCTION IN EASTERN KENYA

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DECLARATION

Declaration by the candidate

I Catherine W. Muui declare that this thesis is my original work and has not been presented for a degree in any other University or any other award.

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I dedicate this research work to my parents Mr and Mrs Muui, Grace Chelel, Joseph Ndana and Charity Gathoni.

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LIST OF ABBREVIATIONS AND ACRONYMS

ABI	Applied Biosystems
AEZ	Agro Ecological Zone
ALRMP	Arid Lands Resource Management Project
AOSA	Association of Official Seed Analysts
ASARECA	Association for Strengthening Agricultural Research in Eastern and Central Africa
bp	Base pair(s)
CO_2	Carbon dioxide
CTAB	Cetyl Trimethyl Ammonium Bromide
CV	Coefficient of Variance
DNA	Deoxyribonucleic acid
dNTP	2’-deoxynucleoside 5’-triphosphate
ECA	Eastern and Central Africa
EDTA	Ethylenediaminetetraacetic acid
F_1	Type of hybrid variety: denotes first filial generation
FAO	Food and Agriculture Organisation of the United Nations.
FAOSTAT	FAO statistical database
FST	Fixation index of sub-population relative to the total population/total fixation index
G	Number of seedlings germinated
G_P	Germination percentage
GR	Growth rate
Ha	Hectare(s)
IBPGR	International Board of plant genetic resources
ICRISAT	International Crops Research Institute for Semi-Arid Tropics
ISTA	International Seed Testing Association
KARI	Kenya Agricultural Research Institute
KEPHIS	Kenya Plant Health Inspectorate Services
KFSSG	Kenya Food Security Steering Group
LIZ	Internal size standard for sequences up to 500 bp

LM	Lower Midland
LSD	Least Significant Differences
MTG	mean germination time
N	known population
n	sample size; and
N/A	Not applicable
N_g	final number of normal emerged seeds
ng	Nanogram(s)
n_o	unknown population
N_p	total number of seed
PBB	Participatory plant breeding
PCoA	Principle coordinate analysis
PCR	Polymerase chain reaction
PDA	Potato Dextrose Agar
PIC	Polymorphic information content
PM	physiological maturity
ppm	parts per million
PVS	Participatory variety selection
RCBD	Randomized Completely Block Design
RH	relative humidity
RNase	Ribonuclease
rpm	Revolutions per minute
s	Second(s)
SAS	Statistical Analysis Systems software
SAT	semi-arid tropics
SE	Standard error
ssp	Subspecies
SSR	Simple sequence repeat
t	Tonnes
Taq	*Thermus aquaticus*
TE	Tris/EDTA buffer
Tris-HCl	Tris (hydroxymethyl) aminomethane hydrochloride

UM	Upper Midland
USA	United States of America
USAID	United States Agency for International Development

ABSTRACT

Sorghum (*Sorghum bicolor* (L.) Moench) is an under-utilized crop that is tolerant to drought, flooding, saline-alkaline, infertile soils and high temperature. Farmers maintain landraces through preference selection and obtain seed from different sources. Local germplasm provides greater genetic variability and may provide useful traits to broaden the genetic base. Decline in use may erode the genetic base, preventing use of distinctive traits in crop adaptation and improvement which may result in their disappearance. There is also lack of information on on-farm seed production strategies leading to lack of quality seeds, information on use and improved cultural management. The objectives of this research were to identify and determine the key sorghum landraces grown in lower eastern Kenya, establish their diversity, quality levels for seed used by farmers, come up with pre and post harvest handling methods that could be used by farmers to improve on-farm seed quality. A baseline survey was conducted and landraces collected in various agro-ecological zones of lower eastern Kenya. Morphological and molecular characterization, varietal assessment in different ecozones and seed quality tests were done. Two varieties were used to test the effect of location of seed on different panicle sections, storage containers, and seed drying at different times of the day for different duration on seed quality. Results showed that farmers maintain a diversity of landraces unique in adaptation, food quality, grain yield, quality of harvested products and biotic stress resistance. They obtain seed for planting from informal systems of which 36% recorded low viability and 38% low vigor with 85% of seed samples contaminated with either *Fusarium sp.*, *Penicillium sp.*, *Rhizorpus sp*., *Aspergillus niger* and *Aspergillus flavurs*. The landraces recorded low heterozygosity indicating high level of stability in the population. Landraces clustering based on geographical locations was distinct with some overlaps across the locations. Variations were observed for leaf and mid rib colour, panicle compactness, awns and seed colour. A wide range of quantitative characters was observed between the accessions. The lower third part of the panicle recorded the highest seed viability and vigor indicating deterioration had not occurred compared to other panicle parts. The highest seed viability and vigor was realized in seed stored in the gourds and the seed stored for four weeks. Significant differences (P=0.05) were observed in leaf area, leaf, shoot and root length, and in dry matter accumulation among the seeds sampled after one month, two months and three months after storage. The seed viability and vigor decreased with increase in time the seed was sun dried but had no negative effect on seed dried in the seed drier. Farmers maintain a diversity of landraces, and since the region has a high agricultural potential, productivity for better food security could be improved by use of locally available germplasm adapted to this particular environment. Sorghum production may be effectively increased by use of improved production technologies and teaching farmers the importance of the crop to increase the production area. Seeds used by farmers to plant their crop are of poor quality in relation to germination, vigor and pathogen infestations.

CHAPTER ONE

INTRODUCTION

1.1 Background

Sorghum (*Sorghum bicolor* (L.) Moench) is one of the most important cereal crops in the semi-arid tropics (SAT). Sorghum is a globally cultivated cereal, unique due to its tolerance to drought, water logging, saline - alkaline, infertile soil and high temperatures (Taylor, 2003). In Kenya, sorghum is grown principally in the drought-prone marginal agricultural areas of Eastern, Nyanza and Coast Provinces. Consumption of sorghum is similarly localized to these growing areas. The crop is a C_4 photosynthetic plant which increases efficiency of carbon dioxide fixation in plants. Such plants are well adapted to regions of lower latitude that have higher temperatures and are prone to drought (Edwards *et al.,* 2004).

Sorghum crop performs well in areas between 500 metres and 1700 metres above sea level, with seasonal rainfall of 300mm and above. As an indigenous Kenyan crop, sorghum could provide food security and become a suitable alternative in many places where maize crop fails **(**Ministry of Agriculture, 2003; Jaetzold *et al.,* 2006). Sorghum is therefore an important subsistence cereal crop in semi-arid areas for its diverse germplasm (Menz *et al.,* 2004), adaptation to drought (Doggett, 1988) and its close relationship in use to maize (Kellogg, 2001; Swigonova *et al.,* 2004).

In most countries in the world, sorghum is used primarily as animal feed and industrial raw material, but in Africa it is used as human food, where it is a staple food for millions of people (Agrama and Tunistra, 2003). Grain is mostly for food purpose (55%), consumed in the form of flat bread and porridge; stover is an important source of dry season maintenance rations for livestock, also an important feed grain (33%) in U.S.A. Sorghum grain has high levels of iron (>70 ppm) and zinc (> 50 ppm), hence may be used to reduce micronutrient malnutrition and hidden hunger (CABI, 2005). In most families in lower eastern part of Kenya, sorghum landraces are used for making fermented and un-fermented porridge. Sorghum grains are milled for use in making *ugali* (thick porridge) to supplement maize which is a staple food. In some cases, the grains are mixed with other grains such as green grams, cowpeas and amaranthus and then boiled to make traditional dishes. However, the crop has been neglected due to the perception as food for the poor (Engle and Altoveros, 2000).

Plant genetic resources play an important role in generating new crop varieties with the high yield potential and resistance to biotic and abiotic stresses (Sajid *et al.,* 2008). Sorghum landraces has a wide genetic diversity rich in traits useful in crop improvement (Rosenow and Dalhberg, 2000; Mutegi *et al.,* 2010). Most indigenous food crops like sorghum are threatened by rapid adoption of highly improved crop varieties many of which are introductions and poorly adapted. Together with genetic resources, indigenous knowledge associated with the cultivation, utilisation and conservation is also endangered. Unless something is done to conserve and re-popularise their use, this natural resource may be lost forever. Gene introgression occur mainly through cross pollination of plants from same variety, different varieties and wild relatives (Hall *et al.,* 2000; Johnson *et al.,* 2004; Muui *et al.,* 2007).

Germplasm characterization allows the morphological and genetic identification and classification. Morphological characterization enables building a catalogue of descriptors essential to collection management or to direct use in agriculture (Ferreira, 2005). However, the use of morphological descriptors could be limited where the environment affects specific morphotypes (Sergio, 2005). Molecular characterization reflects more truly the genetic variability since they are direct products of genes and are not influenced or affected by the environment (Mohammadi and Prasanna, 2003).

Sorghum small scale farmers obtain seed from different sources which include farm saved, local markets, borrowed from neighbours and relatives and or from commercial outlets (Schippers, 2000; Simiyu *et al.*, 2003). The quality of seed saved on-farm, from local markets, borrowed from neighbours and relatives is not known. Maintaining crop production in terms of yield and product quality which give the farmer maximum return requires good seed which carries the genetic, physiological, and physical quality aspects. Good seed requires constant care to prevent loss of quality and to ensure high yield for farmers (Ahmed *et al.*, 2009).

The objectives of this study were to identify the key sorghum landraces grown in eastern Kenya, establish their morphological and genetic composition, determine the quality of seed used by farmers, constraints in production and enable production of quality on farm seeds.

1.2 Statement of the problem

Sorghum is one of the under-utilized crop species that could play an important role in the food security, income generation and food culture of the rural poor in Kenya. The crop is mainly grown by the small scale farmers in the arid and semi-arid areas that are prone to drought in Kenya. The farmers grow and maintain the crop using the traditional practices and cultural preferences resulting to low and poor yields (Mutegi *et al.*, 2010).

There is demand for sorghum mainly in brewing industry to replace barley, yet the amount produced by farmers is too low to satisfy the market demand. On average, sorghum yields are as low as 0.85 t ha^{-1} in Africa (Gerda and Christopher, 2007). In Kenya, farmers' sorghum grain yield productivity is about 0.5 t ha^{-1} while the research potential yield is more than 4 t ha^{-1} (Ashiono *et al.*, 1994; Ogecha, 1995). Diverse management practices and complex socio-cultural factors usually contribute to this variation (Wanyama *et al.*, 1996).

Sorghum has been neglected and regarded to be of low potential yet untapped natural resource (Engle and Altoveros, 2000). The crop has one of the largest germplasm collections in the world, comprising more than 42,000 accessions (Dahlberg *et al.*, 2002; Huang, 2004) which could be utilized in crop improvement. However, in many sorghum growing areas of Africa, many sorghum accessions have been lost or are under serious risk of genetic erosion, and hence, genetic diversity within primary gene pools has been decreasing (Mohammadi and Prasanna, 2003).

There are sorghum landraces still grown by farmers in lower eastern Kenya which are not known and their genetic diversity has not been established. This natural genetic diversity is subjected to threats from natural selection, destruction of habitats and modern agricultural practices (Reddy *et al.*, 2008). Cross pollination occurs in sorghum plants and there is likelihood of gene exchange from wild relatives and hybrids to the local varieties (McGuire, 2004; Ejeta and Grenier, 2005). Farmers plant different varieties obtained from different sources resulting to a mixed population. Morphological and molecular characterization of the germplasm from farmers could help identify the different genotypes in the region which could be useful in furnishing the genetic base of the crop. The acceptability of any variety depends on quality of the end product and the response to abiotic and biotic stresses (Sthapit *et al.*, 1999). Specific sorghum utilization imposes a positive selection pressure towards the desired trait by farmers (Tusekwa *et al.*, 2000; Manzelli *et al*., 2007).

Most small scale farmers who plant landraces in sub Saharan Africa use on-farm produced and saved seed whose quality is usually poor (Government of Kenya, 2006). This could result in poor crop establishment leading to low crop productivity. The informal seed system includes the practices of retaining seed on-farm from previous harvests to plant the following season and farmer-to-farmer seed exchange net works (Ochieng *et al.,* 2011).

Seed quality is of basic importance for a good seedling establishment and crop development. Maintaining crop production in terms of yield and product quality which give the farmer maximum return requires good seed which carries the genetic, physiological, and physical quality aspects (Muasya *et al.,* 2008). Good seed requires constant care to prevent loss of quality and to ensure high yield for farmers.

Understanding socio-economics, farming and/or cropping systems, cultural practices, pre and post-harvest handling, constraints, landraces grown, the morpho - and - genetic diversity, preffered traits, source of seed and grain utilization could be of importance in improving sorghum production in this region. The purpose of this research was to identify the key sorghum landraces grown in eastern Kenya, establish their morphological and genetic composition, select varieties with quality traits and enhance production of quality on farm seeds. The study also evaluated the quality of seed used for planting by farmers and constraints encountered in production.

1.3 Significance and Justification

Sorghum is an important staple food for millions of people; as animal feed and an industrial raw material (Agrama and Tuinstra, 2003; Mamoudou *et al.,* 2006). The crop is closely related to maize in utilization (Kellogg, 2000; Swigonova *et al.,* 2004), therefore could be an alternative food crop in arid areas prone to drought. The grain is used in making porridge and *ugali* (Ministry of Agriculture, 2010). Since the grain has high levels of iron (>70 ppm) and zinc (> 50 ppm) it may be used to reduce micronutrient malnutrition and hidden hunger. Industrially, the grain is used to manufacture wax, starch, syrup, alcohol, dextrose agar, edible oils and gluten feed (Rainford, 2005; Mamoudou *et al*., 2006). Increasing the yields can help meet the high demand for sorghum in brewing industry to replace barley and for use in making other products. As a result, the crop could be a good source of income to the subsistence farmers' majority who rely on farming as an occupation. As an indigenous Kenyan crop, sorghum could provide food security and become a suitable alternative in lower eastern Kenya where maize crop failure is common **(**Ministry of Agriculture, 2003; Jaetzold *et al.,* 2006).

Sorghum is highly tolerant to drought and able to withstand periods of water-logging (Takuji and Baltazar, 2009; Smith, 2010). The crop is characterized by an extensive root system, waxy bloom on leaves that reduces water loss, ability to stop growth in periods of drought and resume it when the stress is relieved, and C_4 photosynthesis (Balole and Legwaila, 2005; Paterson, 2008).

Eastern Province is a major sorghum growing zone in Kenya where there exist different landraces (Meeske *et al*., 1993; Jaetzold *et al.,* 2006). The sorghum landraces continue to be maintained by cultural preferences and traditional practices by the farmers (Mutegi *et al.,* 2010). Sorghum originated in Africa; therefore the landraces have been rich sources of traits resistant to new pathogens, insect pests, high temperature and drought. The landraces are also rich in traits to improve the quality of food, fodder, animal feed and industrial products (Rosenow and Dalhberg, 2000).

The quality of a variety to be used as food largely determines its acceptability by the farmers while adaptation to biotic stresses determines the survival in the field and in storage (Sthapit *et al.,* 1999). Farmers prefer sorghum varieties that are high yielding, good in quality of both grain and fodder, and resistance to biotic and abiotic stresses (Kenga *et al.*, 2004; Mgonja *et al.,* 2005; Medraoui *et al.,* 2007). The color of the grain of landraces is related to a particular grain use where grain color selection varies from one region to another (Wortmann *et al*., 2006). Specific sorghum utilization imposes a positive selection pressure towards the desired trait by farmers (Tusekwa *et al.,* 2000; Manzelli *et al.*, 2007).

A wide range of sorghum landraces are cultivated under diverse agro-climatic conditions in Africa (Tesso *et al.*, 2008; Mutegi *et al.*, 2010). About 5% cross pollination between plants occur in sorghum resulting to hybridization between crop-wild relatives (ICRISAT, 2002; McGuire, 2004). The genetic composition of the traditional varieties grown by farmers could be a mixture of genes from different pools. Molecular and morphological characterization of sorghum landraces could provide information on their genetic makeup. The information could be used in germplasm conservation of unique traits for breeding programmes.

Most small scale farmers use on-farm saved seeds from previous seasons, from market and/or borrow from neighbours and relatives for planting (Schippers, 2000; Simiyu *et al.,* 2003). Maintaining crop production in terms of yield and product quality which give the farmer maximum return requires good seed which carries the genetic, physiological, and physical quality aspects.

1.4 Objectives

1.4.1 General Objective

To identify, characterize and improve on farm seed quality of sorghum landraces through improved production technologies in lower eastern Kenya.

1.4.2 Specific Objectives

1. Identify the sorghum landraces grown by farmers in lower eastern Kenya based on preferred traits, grain utilization and factors affecting productivity
2. Establish the quality of sorghum seeds obtained by farmers from different sources in lower eastern Kenya
3. Characterize sorghum landraces grown by farmers in lower eastern Kenya using morphological characters and by molecular markers
4. Identify sorghum landraces collected from farmers with quality traits
5. Enhance quality of on-farm saved sorghum seeds through improved pre- and post-harvest handling techniques

1.5 Research questions

1. Why do farmers maintain sorghum landraces in lower eastern Kenya?
2. Are sorghum seeds obtained by farmers from different sources of high quality?
3. Are the sorghum landraces in lower eastern Kenya similar in morphological and molecular characteristics?
4. How is the performance of the landraces grown by farmers in lower eastern Kenya?
5. What measures can be taken to improve quality of sorghum seeds produced on farm in lower eastern Kenya?

CHAPTER TWO

LITERATURE REVIEW

2.1 Sorghum production

Sorghum (*Sorghum bicolor* (L.) Moench) is an important food crop and is ranked the fifth most important cereal crop worldwide in terms of consumption after wheat, rice, maize and oats (Agrama and Tuinstra, 2003; EMBRAPA, 2005). It is an important native cereal in Africa (FAO, 1995; FAO and ICRISAT, 1996; Murty and Renard, 2001). Globally, the production of sorghum expanded from 40 million tonnes during early 1960s to 66 million tonnes in early 1980s. By early 1990s, it had fallen to about 58 million tonnes. Total world production of sorghum in the year 2002 was estimated at about 54 million tonnes (FAO, 2004) and total annual production of about 70 million metric tonnes of grains from 50 million hectares of land (National Academic Science, 1996). Acreage under sorghum declined marginally from about 45.6 million ha in early 1960s to 44.4 million ha in the mid-1990s (FAO, 2004). In 2003, about 46 million ha of sorghum was harvested globally, of which 26 million was in Africa. Annual production of sorghum is estimated at about 60 million tonnes, with Africa contributing 21 million tonnes (FAO, 2004). In Eastern and Central Africa (ECA), sorghum is grown on approximately 10 million ha (ASARECA, 2004; Rohrbach, 2004).

Africa produces about 21 million tonnes of sorghum per annum (ICRISAT, 1994; FAO, 2003). Sorghum accounts for only 5% of cereal production in Kenya (FAO, 2004; Taylor, 2004). In Kenya the crop is predominantly and traditionally grown in Eastern, Coast, Western, and Nyanza provinces (Kilambya and Witwer, 2013). Sorghum production has been the most volatile in recent years, reaching its lowest point in 2008 (Fig. 2.1). The production level increased between 2008 and 2010; growth was driven by increases in area harvested, which was largely due to the promotion of sorghum as a drought resistant crop in the Arid and Semi-Arid Lands (ASALs) as well as attractive prices from increased consumption (MoA-ERA, 2011).

The average yield from 1990 to 2011 remained low at 0.8 tonnes per hectare. Average annual sorghum production in Kenya during this period was about 109,414 tonnes, while the average annual growth in production was about 10 percent (Kilambya and Witwer, 2013). Generally sorghum productivity is influenced by rainfall (Taylor, 2003). As an indigenous Kenyan crop, sorghum provides food security and is becoming a suitable alternative in many places where maize crop fails (Mwadalu and Mwangi, 2013).

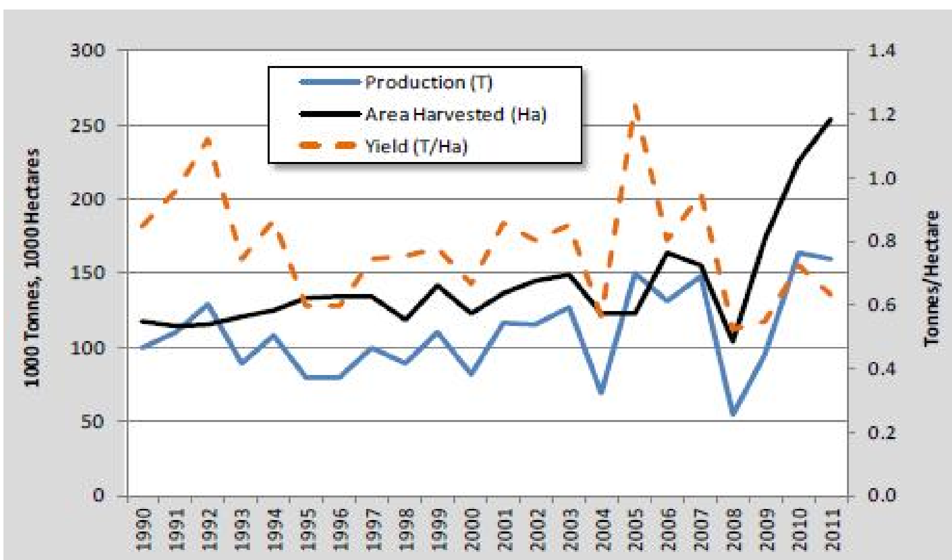

Figure 2.1: Sorghum Production, Area Harvested and Yield in Kenya, 1990-2011

Source: MoA-ERA, 2011

2.2 Importance of Sorghum

Sorghum grain is a major food in much of Africa, South Asia, and Central America, and an important animal feed and industrial raw material in the United States of America, Australia and South America (National Academic Science, 1996). Sorghum is the dietary staple of more than 500 million people in more than 30 countries (National Academic Science, 1996). In many parts of the world, grain is mostly for food purpose (55 %), in making flat breads and porridges (thick or thin) (ICRISAT, 2009). Traditionally, the grain is used in brewing, baking and in various traditional foods (Grains Council, 2010).

Sorghum grain is rich in antioxidants and is gluten-free, an alternative for people with wheat allergy (Grains Council, 2010). Also, sorghum grain has high levels of iron (>70 ppm) and zinc (> 50 ppm), hence can be used to reduce micronutrient malnutrition globally. Sorghum is also a principal source of energy, protein, vitamins and minerals to the poorest people of the semi-arid tropics (National Academic Science, 1996; CABI, 2005). The nutrient composition of sorghum is relatively high compared to other cereals and can be supplemented for use in areas where other cereals are not grown or fail (Table 2.1).

Table 1.1: Nutrient composition of sorghum and other cereals

Cereal type	Protein (g)	Fat (g)	Crude fibre (g)	Carbohydrate (g)	Energy (kcal)	Calcium (mg)	Iron (mg)
Rice (brown)	7.9	2.7	1.0	76.0	363	33	1.8
Wheat	11.6	2.0	2.0	71.0	348	30	3.5
Maize	9.2	4.6	2.8	73.0	358	26	2.7
Sorghum	**10.4**	**3.1**	**2.0**	**70.7**	**329**	**25**	**5.4**
Pearl Millet	11.8	4.8	2.3	67.0	363	42	11.0
Finger Millet	7.7	1.5	3.6	72.6	336	35	3.9

Source: FAO, 1995

In addition to these uses of the grain, sorghum crop residues and green plants also provide sources of animal feed, building materials, and fuel, particularly in the semi -arid tropics (SAT). The leaves provide fodder for farm animals and the stalks are used in fencing, roofing, weaving baskets and mats and also as fuel wood (Rainford, 2005). Sweet sorghum has been introduced as a feedstock and for ethanol production (ICRISAT, 2009).

2.3 Agro ecological requirements for sorghum

The potential of sorghum for improvement of dry land production has been recognized in many parts of the world. Sorghum is becoming a more important crop in the dry tropical and sub-tropical regions owing to its high yields and drought resistance potential, and could replace maize in those areas (Meeske *et al*., 1993). This could be important in a situation such as in Kenya where human resettlement is rapidly expanding into marginal areas prone to frequent with crop failures (Anindo and Topps, 1993).

The regions of sorghum cultivation are characterized by poor soils, high population pressure, erratic rainfall, and high temperatures (Webber, 1996). Sorghum is more adapted to drought-prone areas, particularly the hot, semi-arid tropical environments with 400 to 600 mm rainfall that is too dry for most cereals. Rainfall of 500 to 800 mm evenly distributed over the cropping season is normally adequate for cultivars maturing in 3 – 4 months (Balole and Legwaila, 2005). The crop is grown from sea level to up to 2300 m altitude. The optimum temperature is 25 – 31 ºC, but temperatures as low as 21 ºC will not dramatically affect growth and yield (Balole and Legwaila, 2005).

Sorghum is mainly grown on low potential, shallow soils with clay content between 10-30%, which are not suitable for the production of maize (Balole and Legwaila, 2005). Sorghum is more tolerant to alkaline salts than other grain crops and can therefore be successfully cultivated on soils with a pH (KCl) between 5.5 and 8.5 (CABI, 2005). Further, sorghum tolerate short periods of water logging compared to maize.

2.4 Distribution and adaptation

Sorghum originated in Africa, having been cultivated in Egypt in antiquity, and the largest producer of sorghum in the modern era is still Africa, although the crop has spread to southern Asia and America as well (Kimber, 2000; Smith, 2010). The crop has been reported to have originated from Ethiopia and Eritrea area (Gbebru *et al.,* 2002; Zidenga, 2004). Since sorghum originated in Africa, it is uniquely adapted to Africa’s climate, being both drought resistant and able to withstand periods of water-logging (Smith, 2010).

Sorghum is primarily a plant of hot, semi-arid tropical environments that are too dry for maize. It is particularly adapted to drought due to a number of morphological and physiological characteristics, including an extensive root system, waxy bloom on leaves that reduces water loss, ability to stop growth in periods of drought and resume it when the stress is relieved, and a C_4 photosynthetic (Balole and Legwaila, 2005; Paterson, 2008). As a result, sorghum crop can survive the harsh climatic conditions of the arid environments (Ritter *et al.*, 2007).

Sorghum is an annual monocot angiosperm in the grass species cultivated mainly in warmer climates worldwide and it is in the family Poaceae and sub family Panicoideae (ICRISAT, 2009). These grass species carry out C_4 photosynthesis, an important adaptation that increases the efficiency of CO_2 fixation in plants. C_4 species contribute disproportionately to global productivity and agriculture, in that they compose only 3% of angiosperm species (Edwards *et al.*, 2004). The C_4 grasses are particularly well adapted to regions of lower latitude that have higher average temperatures and are prone to drought (Edwards *et al.*, 2004).

2.5 Production constraints in Sorghum crop

Sorghum production faces several constraints including a lack of quality seeds, birds, insect pests and diseases, incomplete understanding of farming systems, poor soil fertility and financial limitations of farmers in purchasing agricultural inputs (Atokple, 1993; Kudadjie *et al.*, 2007). In eastern and southern Africa, it is primarily a crop of resource-poor, small-scale farmers and is typically produced under adverse conditions. The major challenges in these areas are low moisture, low input use and poor seed for planting (Jaetzold *et al*., 2006). In East and Central Africa, sorghum is grown without any significant use of external inputs, such as fertilizers, improved seed, agro-chemicals and farm implements (ASARECA, 2004).

Farmer seed management has been a neglected area in the past (Wright and Tyler, 1994). The major focus has been on farmer seed management practices, and seed quality on crops such as maize and cowpea (Dankyi and Dakurah, 1993; Wright *et al.*, 1995). Use of poor quality seed is one of the constraints to sorghum production identified in Bomet, Kenya where 98% of the farmers rely on the informal seed supply sources (Ochieng *et al.*, 2011). The informal seed system includes practices such as retaining seed on-farm from previous harvests to plant the following season and farmer-to-farmer seed exchange net works contributing to the largest proportion of informal seed (Ochieng *et al*., 2011**)**.

Poor on-farm seed management in relation to nutrient application and choice of variety to plant is another identified constraint to sorghum seed production (Ochieng *et al*., 2011). Many small scale farmers in Sub-Saharan Africa do not apply fertilizers to their farms (Jama *et al*., 1998; Ochieng *et al*., 2011). This is attributed to the fact that sorghum is often grown under marginal rainfall conditions and fertilizer prices are unfavourably high in relation to sorghum grain price. This practice of using little or no fertilizer affects both seed quality and yield of the crop negatively (Swinkels *et al.*, 1997).

Lack of marketing incentives has been reported by farmers as a major constraint of sorghum production in Bomet, Kenya (Ochieng *et al.,* 2011) due to low production as most farmers opt for maize (Ministry of Agriculture, 2004). This is due to the good prices of maize prevailing in the market as compared to sorghums. The crops' low demand could also be attributed to the fact that its versatility as a food and feed crop is still unknown to many.

Sorghum grain is very susceptible to damage by storage pests, such as rice weevil, flour beetle and the grain moth (Teetes and Pendleton, 2001; Kudadjie *et al*., 2004). Each year, about 20% of the sorghum that otherwise would be available for food and feed is lost due to diseases (Fakir, 1999). Anthracnose is a major seed, soil and trash borne fungal disease causing yield losses of up to 67% (Gwary *et al*., 2003; Gwary *et al*., 2006). Other diseases include seed and seedling rot, covered kernel smut, head smut, loose kernel smut, long smut, downey mildew and rust (Youdeowei, 2002; Buntin, 2005; CABI, 2005). Important pests include shoot fly, stem borers, army worms, midge, aphids, head bugs, cutworms and chaffer grubs (Youdeowei, 2002; Buntin, 2005; CABI, 2005; van den berg *et al.,* 2005).

2.6 Growth and development

The sorghum landraces are towering plants over two meters tall, while improved varieties are dwarf varieties, specially designed for easy harvesting. In Africa, traditional tall sorghum is still grown for human consumption, and the stalks are put to a variety of uses (Smith, 2010). Floral initiation in cultivated sorghum starts 30 to 40 days after germination. The flowers of sorghum open during the night or early morning with those at the top of the panicle opening first resulting to variations in maturity. Anthesis proceeds in a sequential downward manner, with florets in a horizontal plane opening during the same period (ICRISAT, 1997; Balole and Legwaila, 2005). About six to ten days before flowering, the boot forms a bulge in the sheath of the flag leaf. Sorghum usually flowers in 55 to 70 days in warm climates, depending on the genotype (House, 1985). Two days after the emergence of the inflorescence from the boot, the flowers begin to open. The flowering starts in the sessile spikelets at the tip of the inflorescence and progresses toward the bottom over a period of four to five days. It takes six to nine days for the whole panicle to complete flowering with maximum flowering occuring on the third or fourth day (House, 1985; ICRISAT, 1997). However, flowering can extend over a period of six to fifteen days within a panicle depending on panicle size, air temperature and the genotype (Rosenthal and Gerik, 1989; Balole and Legwaila, 2005).

2.7 Likelihood of gene flow and its consequences in sorghum production

Sorghum is predominantly self-pollinating (Doggett, 1988; Ollitrault, 1997), with an outcrossing rate variation up to 40% (Barnaud *et al.*, 2008; 2009). For cultivated sorghum, out-crossing is about 5−10% in compact panicles compared to 10−30% in loose panicles (Dogget, 1988; Deu *et al.*, 1994; McGuire, 2005). As a result, cross pollination between plants occur (McGuire, 2004; Ejeta and Grenier, 2005).

Sorghum plant is a diploid (2n=2x=20) with a relatively small genome containing 818 Mega base pairs (Mbp) of DNA distributed among ten chromosomes (Price *et al.*, 2005). Cultivated sorghum and wild relatives have been classified under species *Sorghum bicolor.* The cultivars of sorghum are encompassed within ssp. *Bicolor* namely; bicolor, kafir, caudatum, durra, guinea and 10 intermediates. The closest wild relatives of cultivated sorghum found in Africa are encompassed within the ssp. *Verticilliflorum* namely; arundinaceum, verticilliflorum, aethiopicum and virgatum (Mutegi, 2009).

Gene introgression in sorghum crop-wild relatives' complex takes place from one population to another through pollen drift (ICRISAT, 2002; Johnston *et al.,* 2004). Crop-specific alleles have been reported in progeny of Johnson grass (*S. halepense* (L.) Pers.) planted 100 meters from cultivated sorghum crop and F1 hybrids having similar fitness to their wild parent (Morrell *et al.*, 2005). Repeated introduction of genes from one population to another increases their frequency in the recipient varieties (Haygood *et al.*, 2003**)**. Newly introduced genes become fixed and may persist in crop populations if their effects have benefits to the crop, or if they have agronomic traits desired by farmers (Gepts, 2002; Reagon and Snow, 2006). Gene flow is an ongoing process affecting the genetic diversity of crop populations and may be a source of new genetic combinations in traditional farming systems (Elias *et al.,* 2001; Pressoir and Berthaud, 2004).

Crop-wild sorghum diversity has been reported in many of the sorghum growing regions of Africa (De Wet, 1978; Ejeta and Grenier, 2005). This long-term coexistence in a given habitat may signal the need to assess the genetic composition of the landraces grown by farmers (Eber *et al.,* 1994; Jenczewski *et al.,* 2003). Most small scale farmers who plant sorghum landraces crop varieties obtain seed from different sources (Schippers, 2000; Simiyu *et al.*, 2003). As a result, there is gene exchange over time resulting to new genotypes.

2.8 Germplasm diversity

Seed flows are an important aspect of farmers' diversity management and are the processes by which farmers obtain the physical unit of seed for a given variety (Bellon and Smale, 1998). Seed exchange and movement in sorghum is important for understanding the diversity in a given location because they form the basis for incorporating new varieties and obtaining material that has been lost but is still regarded as desirable (Bellon *et al*., 1997).

Sorghum diversity in growth cycle, plant architecture, and suitability of grains and stover for use by humans and animals determine the value placed on individual varieties and the extent of cultivation (Kudadjie *et al*., 2004). Many farmers prefer a variety whose yield is stable over years and those that mature early (Nkongolo *et al.,* 2008; Ochieng *et al.,* 2011). Farmers manage mixtures of landraces in their farms which are valuable sources of desirable genes for modern plant breeding programmes (Kudadjie *et al.*, 2004).

Sorghum landraces are gradually being neglected though an important traditional food crop in lower eastern Kenya among others. The crop has been neglected due to their perception as poor man's crop (Engle and Altoveros, 2000). This might eventually lead to genetic prosion. Sorghum diversity enhances food security, helps small scale farmers to maximize production in variable environments and provides farmers with a range of products for multiple uses (Bishaw, 2004; Sajid *et al.*, 2008).

The informal sorghum seed system has received little attention even though there has been much research focus on farmer seed management practices for crops such as maize and cowpea (Wright *et al*., 1995; Lyon and Afikorah- Danquah, 1998). Genetic diversity or knowledge on patterns of diversity of genetic resources is of great importance (Warburton *et al.*, 2002) and is a key component in crop improvement and plant breeding. There is a wide variability within sorghum landraces cultivated under diverse climatic conditions in the semi-arid Africa including Kenya (Folkertsma *et al.,* 2005; Mutegi *et al.,* 2010). Therefore there is need to assess the diversity and the management practices in the farmers fields.

2.9 Germplasm characterization

Characterization of germplasm is important for the sustainable conservation and increased use of crop genetic resources (Sergio and Gianni, 2005). It involves distinctly identifying characteristics which are heritable leading to classification that will facilitate enhanced utilization of germplasm (Upadhyaya, 2008).

The objective of characterizing sorghum landraces is to describe accessions, establish their characteristics, identify duplicates, identify accessions with desired agronomic traits, select entries for more precise evaluation, develop interrelationships between or among traits and between geographic groups of cultivars; and estimate the extent of variation in the collection (Upadhyaya, 2008). The resulting data allows the identification and classification of accessions, building a catalog of descriptors with embedded biological information that is essential to collection management or to direct use in agriculture (Sergio and Gianni, 2005).

Morphological and molecular characterization is recommended in sorghum accessions collected from different regions to ensure a more complete and informative characterization (Atokple, 2003). Results of molecular studies are considered complementary to agronomic and morphological characterization (Karp *et al*., 1997). DNA-based techniques have been used in genetic diversity studies in sorghum and other crops (Ayana *et al.*, 2000; Agrama and Tuinstra, 2003). Phenotypic and genetic diversity are important in genetic conservation, evaluation and utilization of genetic resources, and the study of breeding germplasm for determining uniqueness and genetic constitution (Franco *et al.*, 2001; Ramakrishnan *et al.*, 2004; Sergio and Gianni, 2005).

2.9.1 Morphological characterization

Morphological markers are phenotypic characters such as flower color, seed color and shape, growth habits, pigmentation, texture, maturity, yield, and pest and disease resistance (Franco *et al.*, 2001; Schulman, 2006). Plant selections are done on basis of morphological characteristics that are readily discrimible and that are co-inherited with the desired trait.

Although these methods remain effective, morphological comparisons are influenced by the environment, management practices (Sergio and Gianni, 2005); are limited in number and influenced by developmental stage of the plant (Morell *et al.,* 1995; Winter and Kahl, 1995). However, despite these limitations, morphological markers have been extremely useful to plant breeders (Eagles *et al.,* 2001).

Morphological traits displayed by sorghum landraces determine selection and preference by the farmers. Majority of the farmers keep sorghum landraces that are early maturing, high yielding, tolerant to drought, pests and diseases, and with grain color producing appealing products (Rana *et al.,* 2000; Bantilan *et al.,* 2004; Muui *et al.*, 2013). The morphological markers are highly influenced by the environmental conditions, therefore there is a need to supplement or compliment their clustering with molecular marker data (Semagn *et al.,* 2006).

2.9.2 Molecular / genetic characterization

Molecular characterization provides reliable information for assessing the amount of genetic and structure of diversity; rates of genetic divergence among populations and the distribution of diversity in populations found in different locations (Perera *et al*., 2000; Shim and Jørgensen, 2000; Maestri *et al*., 2002; Ferguson *et al.,* 2004; Figliuolo and Perrino, 2004). Molecular characterization indicates any contaminants such as material mixtures, introgressed genes from other accessions and presence of duplicates (McGregor, 2002). Molecular data provide the baseline for monitoring natural changes in the genetic structure of the accession or those occurring as a result of human selection (Chwedorzewska *et al.,* 2002). Genetic characterization plays a role in identifying useful genes in germplasm to maximize conservation of genes that will be able to meet the challenges of current and future agriculture (De Vicentel *et al.*, 2005).

The use of molecular markers to assess relatedness in and between cultivated and wild sorghum have been successfully used (Uptmoor *et al.*, 2003; Anas and Yoshida, 2004; Menz *et al.,* 2004; Ritter *et al.,* 2007). DNA markers are unlimited in number and are not affected by environmental factors and/or the developmental stage of the plant (Winter and Kahl, 1995). The choice of molecular markers to use is determined by the cost effectiveness, simplicity, high throughput, number of samples, degree of relatedness between samples, research objectives and knowledge on the target genotype (Ji *et al*., 2004).

Simple Sequence Repeats (SSRs) are relatively cheap and highly discriminative (Missiaggia and Grattapaglia, 2006) and therefore useful tools for characterisation of sorghum genotypes (Ghebru *et al.*, 2002). SSR markers are highly polymorphic, reproducible, powerful, stable and less complex (Budak *et al.,* 2004b; Han *et al.,* 2008; Zhao *et al.,* 2009). Small quantities of genomic DNA are required for the analysis, are suitable for automation and high-throughput platforms; and have been found to be very efficient and reveal more diversity in sorghum landraces (Agrama and Tuinstra, 2003; Gutierrez *et al.,* 2005; Kudadjie, 2006).

Farmers grow a mixture of several landraces per field (Barnaud *et al.*, 2007). Over time, outcrossing occurs in sorghum though variable among different landraces (Barnaud *et al*., 2008). Also selection exerted by farmers is a key parameter for determining the fate of new genetic combinations from the outcrossing events and thus in the patterns of genetic differentiation among landraces. Landraces perform well under sub-optimal conditions as they are well adapted to local stresses and possesses farmers' preferable traits (Bantilan *et al*., 2004; Setimela *et al*., 2004). It is, therefore, necessary to study the genetic relationships of these landraces and identify traits to be incorporated in the released varieties. Estimation of genetic diversity to identify groups with similar genotypes is important for conserving, evaluating and utilising genetic resources, for studying the diversity of different germplasm as possible sources of genes that can improve the performance of cultivars, and for determining the uniqueness and distinctness of the phenotypic and genetic constitution of genotypes (Subudhi *et al.*, 2002).

2.10 Seed quality

Seed quality encompasses genetic (trueness-to-type), physiological (viability and vigor), sanitary (seed and resulting seedling health) and physical (physical purity and extent of damage) quality (Larinde, 1997). Seed deterioration which is loss of viability and vigor commences at physiological maturity and continues during seed harvesting, processing and storage. It is highly governed by the genetic constitution, environmental factors during seed development and storage conditions (McDonald, 1999; Muasya *et al.*, 2008).

Seed deterioration results in reduced overall germination percentage, poor germination uniformity and poor plant growth. Such seeds are susceptible to environmental and biological stresses resulting to a large number of abnormal seedlings and poor plant development (Kalpana and Rao, 1995).

As seeds deteriorate, their energy synthesis mechanisms are impaired, respiration and biosynthesis activities affected, chromosomal aberration and DNA degradation occurs. Also there are changes in RNA and protein synthesis, enzymatic activities, food reserve and membrane alterations (Walters, 1998; McDonald, 1999). Seed is usually at its highest potential when it attains physiological maturity, i.e. maximum dry weight (Bewly and Black, 1994; Muasya *et al.,* 2008). At this stage, the seed is at its maximum vigor which denotes the best time for sowing (Muasya *et al.*, 2008). Also, several seed borne pathogens and insects especially if moisture content increases during storage cause deterioration reducing germination and vigor (Saravanan *et al*., 2001; Chitio *et al*., 2004; Abdulsalaam and Shenge, 2011).

Seed germination potential and vigor can be improved through proper crop production and harvesting, seed conditioning, processing and storage (Musa, 1999; Khan *et al.,* 2003). Farmers consider availability of quality seed to be vital especially in low input agriculture (Almekinders and Louwaars, 1999; Kudadjie, 2006). In the informal or local seed system the farmers manage variety selection, seed production and storage under local conditions (Almekinders *et al.*, 1994).

Germination and seedling growth rate tests have been developed to measure seed viability and vigor (Hampton and TeKrony, 1995; Bonner, 1998).

Germination test is an analytical procedure to evaluate seed germination under optimum conditions to predict their potential in the field; while seedling growth rate gives an indication of the seedling vigor (Copeland and McDonald, 1995). It has been reported that seedling growth and vigor decrease with the decrease in germination percentage in several crop species (Kant and Tomar, 1995).

2.10.1 Effect of seed position on the panicle on seed quality

In sorghum, flowering starts in the sessile spikelets at the tip of the inflorescence and progresses toward the bottom over a period of up to fifteen days (House, 1985; ICRISAT, 1997). Flowering period within a panicle depends on panicle size, air temperature and genotype (ICRISAT, 1997). Flowering in sorghum begins from the upper part of the panicle downwards resulting to variations in maturity. Anthesis proceeds in a sequential downward manner, with florets in a horizontal plane opening during the same period (ICRISAT, 1997; Balole and Legwaila, 2005). The flowering duration (FD), time required for tip to basal anthesis within a grain sorghum panicle and flowering period (FP), time required for tip to basal anthesis within a field are major components of flowering process and are important in determining the exposure period to seed damage (Balole and Legwaila, 2005). As soon as seed mature on the mother plant, they begin to deteriorate depending on the environmental conditions at that particular period. Each crop and plant species undergoes characteristic changes leading to seed ripening, which must be known to establish the best time to harvest (Muasya, 2001). A seed reaches physiological maturity (PM) when it has attained maximum dry weight

(Tekrony and Egli, 1997; K'Opondo, 2011). At that stage it can be removed from the plant without impairing the seed's germination. The rate at which deterioration takes place depends on the environmental conditions inside and around the seeds. Seed deterioration eventually leads to loss of viability or death when the seed is not able to germinate (Thomsen and Stubsgaard, 1998).

2.10.2 Effects of type of containers used in storage and duration on seed quality

Small scale sorghum farmers store seeds in small quantities in traditional containers with a major objective of retaining a high proportion of viable seeds for planting in subsequent seasons. The farmers generally produce and store their own seed under often stressful conditions (Kudadjie, 2006). The quality therefore may be lower and/or more variable than the quality of seed produced in formal seed systems.

Seeds undergo deterioration during storage regardless of storage environment or storage materials (Mettananda *et al.*, 2001; Adetumbi *et al.*, 2009). The rate of deterioration depends largely on storage temperature, moisture and storage duration (Ellis and Roberts, 1980). Most seeds are hygroscopic, and tendency of absorbing environmental moisture during storage is high (Copeland and McDonald, 1995). Seeds that have initially attained a safe moisture level during drying may absorb environmental moisture and loose quality during storage (Nguyen and Blum, 2004). As moisture content of the seeds is one of the most important factors determining seed longevity during storage (Qaisrani, 2000), conditions which maintain seeds moisture content close to that of the newly harvested seed provide better storage.

Reduction in germination and seedling vigor of seeds during storage has been reported in sorghum (Chitio *et al*., 2004). Containers offering insulation from external climatic factors and seed infection maintain seed viability and vigor (Eltayeb and Sana, 2010). High relative humidity in storage and oxygen depletion leads to embryo death and hence loss of viability and vigor (Qaisrani, 2000; Desai, 2004; Eltayeb and Sana, 2010).

2.10.3 Effects of drying on seed quality

Drying is a vital operation in the chain of seed handling, since the moisture content of seeds is the most important factor determining whether and to what extent they will be liable to deterioration during subsequent storage (Desai *et al.*, 1997). Seed drying is intended to inhibit germination temporarily, reduce the seed moisture content to safe limits to maintain its viability and vigor during storage, which may otherwise deteriorate quickly due to mould growth, heating and enhanced microbial activity (Hanson, 1985). Natural or artificial drying methods may be used, depending on characteristics of each species, the amount of harvested seeds, and on weather conditions prevailing after seeds were harvested (Berti *et al.*, 2005).

The maximum drying temperature that seeds will tolerate depends on species, the initial moisture before drying commences and the rate of drying (Thomsen and Stubsgaard, 1998). Farmers spread small quantities of seed in a thin layer on smooth earthen floor or on straw mat utilizing the sun and natural wind for drying. When seeds are dried under the sun, the sun normally raises the temperature, lowering the relative humidity in the air around the seed which results to loss of moisture from the seed (Desai *et al.,* 1997).

Prolonged exposure of seed to direct sunlight may cause overheating of the seed, especially if the seed is still having high moisture content. The high temperature and ultraviolet radiation through direct sunlight, together with high moisture content may accelerate respiration and impose stress to the seed, thereby bringing about ageing, thus adversely affecting the germinability, and may even kill the seed (Desai *et al.,* 1997; Thomsen and Stubsgaard, 1998). Under drying or slow-drying result in seed deterioration due to fungi and bacteria, which in extreme cases lead to total viability loss (Desai *et al.*, 1997). The effectiveness of sun drying depends on weather conditions which vary from day to day and during the day (Thomsen and Stubsgaard, 1998; Franke *et al.,* 2008).

When drying the seed, drying speed is higher in upper layer, due to the fact that seeds are directly exposed for a longer period to the airflow, causing a larger reduction in seeds moisture content. In the other layers, the seeds final moisture content is higher, requiring longer drying periods (Franke *et al.*, 2008). Seed mass temperatures in the layer with dried seeds and in part of the transition zone are above the recommended values, and thus dry more quickly, showing the fastest desorption rates. Hence the importance of knowing the maximum time span allowed for drying, to prevent temperature from rising above recommended limits (Moraes, 2000).

Artificial drying maintains seed quality, when conducted under technical criteria that define exposure times and temperatures (Ahrens *et al.*, 2000). The main advantages of the artificial method are to allow the control of the temperature, the drying air flux, and the exposure time of the seeds to the heated air, fundamental factors to assure the efficiency of the process (Cavarini *et al.*, 1998). Since small scale farmers sun dry the grain to be used as seed, there is need to establish drying conditions that could be used to ensure that the quality of the seed is maintained.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Experimental sites

The research was conducted at the lower eastern Kenya which extends between 38° 15' E and 39° 30'E as well as 1° N and 3° S. The study covered four regions of lower eastern varying in agro-climatology namely; Mbeere, Makueni, Kitui and Mutomo which are major sorghum growing areas in Kenya (Fig. 3.1). The regions range from Zone IV (Semi Humid to Semi Arid) to Zone V (Semi Arid) (Jaetzold and Schmidt, 1983). The Mbeere and Kitui sites are classified as Lower Midland (LM) with some regions in transitional zone towards Upper Midland (UM). Makueni and Mutomo sites are classified as Lower Midland (LM) (Jaetzold *et al.*, 2006).

Mbeere region where sorghum is grown receives an annual rainfall ranging from 800 - 1000mm and an altitude of 840 - 1189 meters above the sea level (Jaetzold *et al.*, 2006). Makueni area receives an average annual rainfall ranging from 600 - 800mm and an altitude of 914 - 1600 meters above the sea level. Kitui receives an annual rainfall ranging from 600 - 1181mm and an altitude of 1036 - 1115 meters above the sea level while Mutomo receives 500 - 700mm annual rainfall and is at an altitude of 914 meters above the sea level (Jaetzold *et al.*, 2006).

The soil types in Mbeere range from Ferralsols - Acrisols - Cambisols - Arenosols and are low in fertility while in Kitui, the soil is poor in fertility ranging from Regosols - Lithosols - Cambisols - Arenosols - Luvisols. In Mutomo, the soils are poor and strongly leached ranging from Regosols -

Luvisols while in Makueni the soils are high to low in fertility ranging from Luvisols - Ferralsols - Acrisols - Vertisols - Nitisols with eutric Nitisols (Jaetzold *et al.*, 2006).

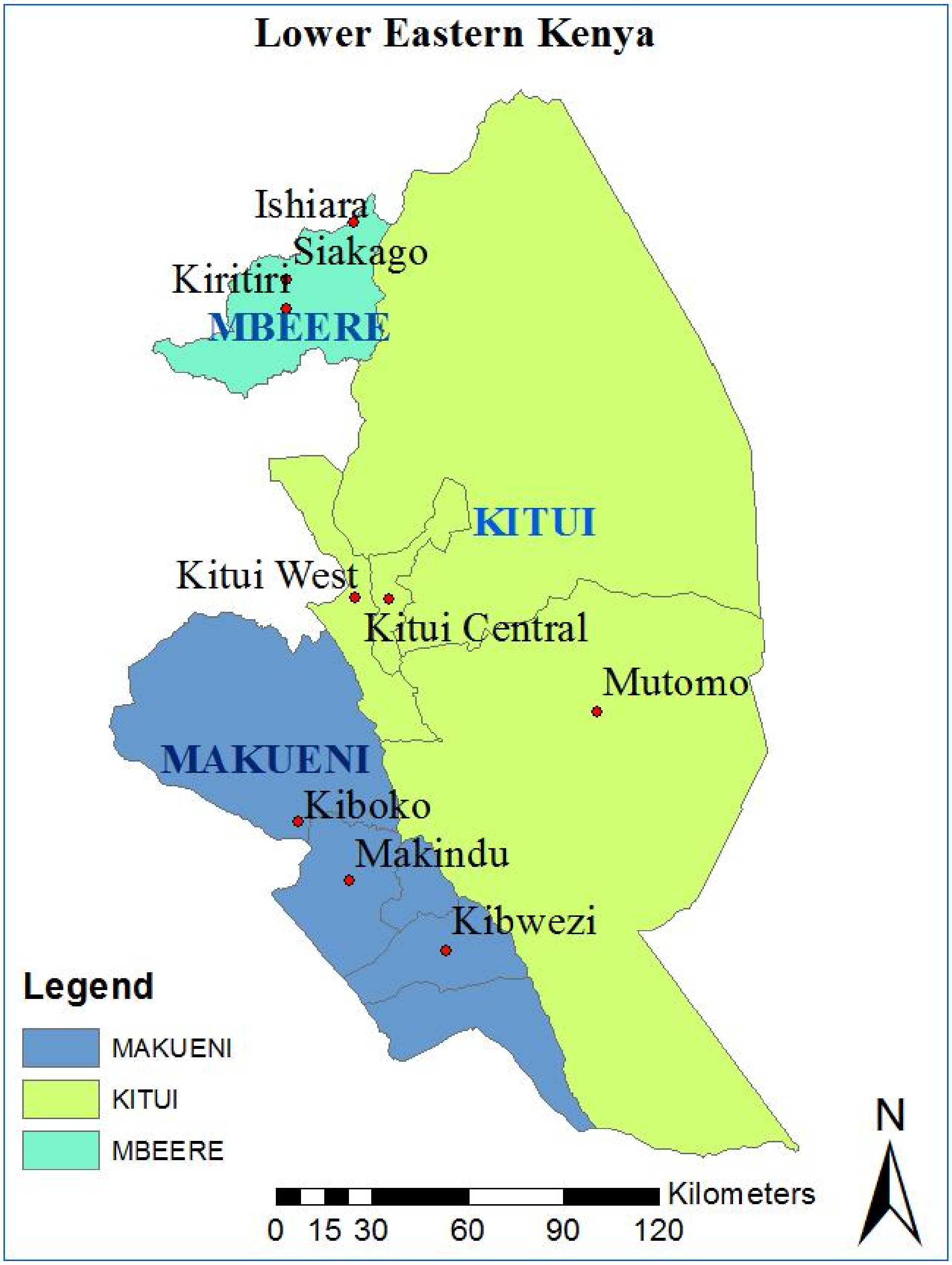

Figure 3.1: Map showing the study area in lower eastern Kenya

3.1.1 Kiritiri, Mbeere

The farm lies between latitude 0° 20' and 0° 50' S and longitudes 37° 16' and 37° 56' E. The area has a bimodal pattern of rainfall with the first rains falling between April and June while the second rains are experienced from October to December. The rainfall ranges between 823 - 896 mm per year (Jaetzold *et al.,* 2006; ALRMP, 2009; KFSSG, 2009). The altitude is 1143 meters above sea level. The site is a representation of Lower Midland (LM_4) agro ecological zone (Jaetzold *et al.,* 2006).

3.1.2 KARI - Kiboko

KARI - Kiboko station lies between latitude 1° 30' 36' S and longitudes 37° 15' 36' E (KFSSG, 2008). The station area is a representative of Lower Midland (LM_5 and LM_6). The altitude is 975 meters above sea level (Jaetzold *et al.,* 2006). The district has a bimodal pattern of rainfall with the first rains falling between April and June while the second rains are experienced from October to December. The rainfall ranges between 436 - 566 mm per year.

3.1.3 KARI – Ithookwe

KARI - Ithookwe is located between longitudes 37° 45' and 39° 0' E and latitudes 0° 3.7' and 3° 0' S (KFSSG, 2008). The station area is a representative of Lower Midland (LM) to Upper Midland (UM) 3 - 4. The altitude is 1158 meters above sea level. The area receives an annual rainfall of 835 - 1079 mm (Jaetzold *et al.,* 2006). The first rains are experienced between April and May and second rains in November and December. The district experiences high temperatures throughout the year, which range from 16 °C to

34 °C. The hot months are between June and September; and January to February (ALRMP, 2009).

3.1.4 Mutomo

The farm is located between longitudes 37° 45' and 39° 0' E and latitudes 1° 3.7' and 1° 0' S (KFSSG, 2008). The farm area is a representative of Lower Midland (LM) 4 - 5. The altitude of the area is 914 meters above sea level. The annual rainfall ranges between 562 - 844 mm (Jaetzold *et al.*, 2006). The first rains are experienced between April and May and short rains in November and December. The area experiences temperatures ranging between 20 °C to 30 °C (ALRMP, 2009).

3.2 Field and Laboratory methods

3.2.1 Identification of sorghum landraces grown in lower eastern Kenya

3.2.1.1 Factors affecting sorghum production and use

A baseline survey was carried out between May - June, 2010 in lower eastern Kenya in the major sorghum growing agro-ecological zones to identify sorghum landraces, factors affecting production and use (Appendix 1-3). The survey covered four region varying in agro-climatology namely; Mbeere in LM_3, LM_4; Makueni in LM_5, LM_6; Kitui in LM_3, LM_4, LM_5; and Mutomo in LM_4, LM_5 (Jaetzold *et al.*, 2006).

Structured questionnaires were used to collect information on socio-economic factors, farming systems, landraces grown, source of seed, traits preference, cultural practices, pre-and-post harvest handling, utilization and constraints in sorghum production in lower eastern Kenya region (Appendix 4).

Information obtained from Agricultural office indicated that about 150 farmers were purely sorghum farmers in this region. A sample size of 120 farmers was arrived at using the table (Appendix 5) and standardization equation,

$$n = \frac{n_o}{1 + \frac{(n_o - 1)}{N}}$$

where; N is the known population; n is sample size; and n_o is the unknown population (Cochran, 1963; Krejcie and Morgan, 1970). The required sample size for each agro-ecological zone was calculated using the formula according to Cochran (1963). Farmers to be interviewed were picked randomly ensuring whole coverage of the area with the assistance of Agricultural extension officers.

Random sampling of farmers in different agro ecological zones per district was done to cover 120 farmers. In Kibwezi (LM_5) and Mutomo zone 1 (LM_4), 17 farmers were interviewed from each agro-zone. Sixteen farmers were interviewed in Kitui central (LM_3); 15 in Siakago (LM_3); 14 in Kitui west (LM_3); 13 in Kiritiri (LM_4) and 3 in Mutomo zone 2 (LM_5). In Ishiara (LM_4), 12 farmers were interviewed while five and eight farmers were interviewed in Makindu (LM_5) and Kiboko (LM_5; LM_6) respectively. In every agro-ecological zone of the district, a random selection method was used to identify farmers to be interviewed.

3.2.1.2 Participatory identification and evaluation of the landraces germplasm

Sorghum landraces the farmers had for planting next season were collected between July - August, 2010 in the region covered in baseline survey based on the information gathered from farmers interviewed earlier. Landraces were collected separately from the interviewed 120 randomly sampled farmers. Information on passport data, grain utilization and traits preferred by farmers were recorded for each accession. The color of the seeds was recorded using Munsel color chart for plant tissues (Anonymous, 1972). The germplasm was reserved for use in seed quality tests, morphological and molecular characterization to enable elaborate evaluation of diversity for documentation and crop improvement program.

3.2.3 Seed quality tests

Seed quality tests were carried out on 44 accessions available form farmers and identified in section 3.2.1.2 before planting to assess their planting quality. Similar tests were carried out on commercial varieties; Seredo, Serena, KARI Mtama 1 and Gaddam for comparisons. The 48 seed samples were assigned reference numbers for ease of identification (Table 3.1). The tests were conducted at Kenya Plant Health Inspectorate Services (KEPHIS) seed testing laboratory, Lanet and at the department of Agricultural Science and Technology and Botany laboratories, Kenyatta University, Nairobi. The seed quality was determined by purity, seed viability, seed vigor and seed health tests. These tests were to enable quality comparisons between what the farmers use for planting and what is produced through basic procedures of seed production.

Table 2.1: Reference numbers for 48 sorghum seed accessions used in laboratory and field experiments

No.	Accession Identity	No.	Accession Identity	No.	Accession Identity
1	Kitui West white	17	Mbeere Kiritiri local A	33	Mbeere Kiritiri mubaku
2	Mbeere Kiritiri Gatengu	18	Kitui West white brown	34	Kitui Central brown white
3	**Serena commercial**	19	Mutomo black red	35	Mbeere Ishiara red
4	Mbeere Siakago white	20	Makueni Kiboko dirty white	36	Makueni Kibwezi brownwhite
5	Kitui Central brown	21	Makueni Makindu brown	37	Kitui West brown 1
6	Mbeere Kiritiri purple	22	Kitui Central white	38	Kitui West brown 2
7	Mbeere Kiritiri mwitia	23	Mutomo brown white	39	Mbeere Kiritiri thiriku 2
8	Mbeere Kiritiri ciakiondo	24	Kitui Central brown white	40	Mbeere Siakago red Seredo
9	Makueni Makindu white	25	Makueni Kiboko brown white	**41**	**Gaddam commercial**
10	Makueni Kibwezi brown	26	Mbeere Kiritiri thiriku 1	42	Kitui West brown 3
11	Mbeere Kiritiri karuge 2	27	Mbeere Siakago thiriku	43	Mutomo white
12	**KARI Mtama 1commercial**	28	Mutomo brown	44	Kitui Central brown red
13	Mbeere Kiritiri karuge 1	**29**	**Seredo commercial**	45	Kitui West white mweruba
14	Mbeere Kiritiri local B	30	Makueni Kiboko red	46	Makueni Kibwezi red
15	Makueni Makindu red	31	Makueni Kiboko brown	47	Mbeere Kiritiri muthiriku
16	Kitui Central red 1	32	Mbeere Siakago Serena	48	Kitui Central red 2

3.2.3.1 Purity analysis

Samples were drawn from the 44 collected seed lots and four commercial varieties separately. Each sample was mixed thoroughly before dividing to obtain a working sample of an estimated weight as specified by ISTA (2012) rules. Using an analytical balance, an exact weight of 90g (recommended for sorghum) was weighed. The weighed seeds were poured on a separating table and separation done visually. The seeds were separated into pure seed, inert matter and other crop seeds using a spatula. Pure seed was the actual species under test; including intact seed units and pieces of seed units larger than half the original seed size. Inert matter was the seed units and other matter and structures not defined as pure seed or other seed. Other seed was any seed units of any plant species other than sorghum seed. After separation, each portion was weighed in grams and expressed as a percentage of the total weight of the sample (ISTA, 2012).

3.2.3.2 Seed viability

3.2.3.2.1 Germination test

A working sample of 400 seeds was drawn from the pure seed sample obtained in purity test for each of the forty four accessions. Samples were also drawn from four improved varieties for germination as controls. Seeds were arranged in four replicates of 100 seeds. The seeds were placed on sand in germination trays then put in a germination cabinet at 25 °C (± 5) with illuminated light during the whole period of the test. The first count of emergent seedlings was taken on the fourth day and the final count and seedling evaluation were done on the tenth day. Seedlings were assessed as normal seedlings; abnormal seedlings; hard seeds; rotten seeds; or diseased seedlings in accordance with ISTA rules (2012). Normal seedlings included intact seedlings, seedlings with slight defects and seedlings with secondary infection. Abnormal seedlings included damaged and decayed seedlings. Ungerminated seed include hard seeds, fresh seeds and dead seeds. The percent germination was determined by the proportion of normal seedlings on the tenth day.

Germination percentage (G_P) of the normal seedlings was calculated based on the initial seed number planted per replicate as follows:

$$G_P = \left(\frac{N_f}{N_t} \right) \times 100$$

Where, N_f is the final number of normal emerged seeds and N_t is the total number of seeds sown (ISTA, 2012).

3.2.3.3 Seed vigor

3.2.3.3.1 Speed of germination (Mean germination time)

Seeds assessed for germination test were also used for speed of germination test. The count of emerged seedlings in each sample was taken on a daily basis (after every 24 hours) until the tenth day from the sowing date. The mean germination time was then calculated using the following equation:

$$MTG = \sum (D \times G)/N$$

Where: MTG is the mean germination time; D is the number of days after sowing; G is the number of seedlings germinated within D days; and N is the total number of seeds germinated at the end of test period (Walters *et al.*, 1998; Khan *et al.*, 2003; Babiker *et al.*, 2010).

3.2.3.3.2 Seedling growth rate

Samples of ten seeds each were drawn from each of the forty four accessions and four commercial varieties for seedling growth rate tests. Each sample was replicated three times. The seeds were germinated in plastic containers containing soil and put in a glass house at the Department of Botany, Kenyatta University. Seven days after planting, five seedlings were removed from each sample randomly for determination of initial dry weight (W_1). Final dry weight was determined on the remaining seedlings after twenty one days according to Beadle (1982) and Agboola (1998). Individual whole seedlings were put in small envelopes and dried in an oven at 70 °C for three days until a constant weight was attained. The final dry weight (W_2) was taken using an analytical balance for each seedling. The total growth rate (GR) was calculated according to Hassan (1991) as follows:

$$GR = \frac{W_2 - W_1}{T_2 - T_1}$$

Where, GR is the growth rate (mg day^{-1}), W_2 is the dry weight of seedling at the end of test period (T_2), W_1 is dry weight of seedling after emergence (T_1).

Before drying the seedlings at the end of the test period, leaf area was determined manually using chart paper and estimated as mm^2 per individual plant; shoot length (mm) and root length (mm) were measured using a centimeter scale.

3.2.3.4 Seed health test

A sample of 400 seeds was taken from each of the 44 accessions and 4 improved varieties (Table 3.1). Seeds were arranged in four replicates of 100 seeds. The seeds were surface sterilized using 70% ethanol by submerging in the solution for five minutes to eliminate surface contaminants; then dried using blotter papers. The seeds were placed on Potato Dextrose Agar (PDA) agar media in petri dishes. The media was prepared by dissolving 39 grams of PDA in 1 L of sterile distilled water. The solution was put in an autoclave at 121 °C for 15 minutes at 15 pound pressure, then left to cool to avoid killing the pathogens. The samples were then incubated at a room temperature of 25 °C (± 5) for 7 days (Amusa *et al.*, 2007; Bariyewu *et al.*, 2007). The number of infected seeds was counted and recorded to get the percentage infection level per sample. The resulting pathogens were sub-cultured to fresh PDA media then incubated at a room temperature of 25 °C (± 5) for 5 days (Gwary *et al.*, 2006; Abdulsalaam and Shenge, 2011). The colonies that formed were examined to identify the pathogens using growth habits of the various pathogens. Slide preparations of the various fruiting structures were made and observed under a microscope for identification. The various types of pathogens were identified using identification keys (Abdulsalaam and Shenge, 2011).

3.2.4 Morphological characterization

Morphological characterization was done to assess the variability and identify the promising accessions for different traits. The trial was carried out during the second rain season (September - December, 2010) and first rain season (March - August, 2011) which are the normal planting periods for Mbeere, Kitui, Mutomo and Makueni districts in lower eastern Kenya. The rainfall amount received in the two cropping periods is as indicated in Table 3.3. The land was tilled by hand and levelled before being demarcated. The experiment was laid in a Randomized Completely Block Design (RCBD).

Forty four sorghum landraces were planted each in a separate plot in a block. Serena, Seredo, Gaddam and KARI Mtama 1 which are commercial varieties were planted for comparisons (Table 3.1). The forty eight entries were randomly placed within a block and replicated three times in the four locations. Seeds were planted at a spacing of 75 cm between rows and 25 cm between plants at a depth of 3 - 5 cm (Grain sorghum, 2010). A total of 875 m^2 of land was used in each site. Individual plot size was 200 cm x 100 cm leaving a path of 100 cm in between the plots and between blocks. There were two rows per plot each with nine plants giving a population of 18 plants per plot. Ten randomly picked plants in each plot were tagged for assessment of qualitative and quantitative characters. The characters recorded were as indicated in Table 3.2. The characters used to differentiate the accessions are as indicated in sorghum descriptors (IBPGR/ICRISAT, 1993).

Gaddam, an improved variety was planted as guard rows round the whole plot in all the sites. Each experimental site had a total of one hundred and forty four plots. At planting, single super phosphate (SSP) was applied to supply phosphorous (P_20_5) at a rate of 30 kg ha^{-1} and calcium ammonium nitrate (CAN) to supply nitrogen (N) at a rate of 40 kg N ha^{-1} four weeks after emergence (Ashiono *et al.*, 2006). Two weeding were done per cropping season.

Table 3.2: Qualitative and quantitative characters used to characterize sorghum accessions found in traditional farming system in eastern Kenya

Qualitative	Leaf pigmentation	middle stage
	Leaf color	middle stage
	Leaf orientation	middle stage
	Midrib color	middle stage
	Glume color	at harvest
	Glume covering	at harvest
	Awns	at harvest
	Seed size	at harvest
	Seed color	at harvest
	Grain shape	at harvest
	Pest resistance	type and level
	Disease resistance	type and level
	Drought resistance	level
Quantitative	Days to 50% emergence	50% germination
	Seedling vigor	Week four
	Number of leaves	middle stage
	Plant height (cm)	at maturity
	Days to 50% flowering	50% emergence
	Leaf length (cm)	third from top
	Leaf width (cm)	third from top
	Ear head shape	at harvest
	Ear head compactness	at harvest
	Ear head length (cm)	at harvest
	Ear head width (cm)	at harvest
	Stem thickness (cm)	lower ⅓ of plant
	Days to harvesting	at harvest
	Plant dry weight (g)	at harvest
	Grain yield (t)	at harvest
	100-seed weight (g)	at harvest

Table 3.3: Rainfall at Kiboko, Mutomo, Mbeere and Kitui in lower eastern Kenya during the 2010/2011 and 2011 cropping seasons, respectively

Months	Rainfall (mm)			
	2010/2011			
	Kiritiri	Kitui	Mutomo	Kiboko
September	0.0	0.0	0.0	1.0
October	105.7	147.2	26.0	21.7
November	23.4	195.8	49.9	147.5
December	0.0	18.3	0.0	53.0
January	5.0	20.3	9.2	7.5
February	0.0	72.9	124.4	56.5
Total	134.1	454.5	209.5	287.2
	2011			
March	31.4	140.0	105.4	236.0
April	20.4	70.6	29.3	5.7
May	58.0	59.3	10.9	2.0
June	0.0	0.8	0.0	0.0
July	0.0	0.0	0.0	0.0
August	0.0	0.8	0.0	5.0
Total	109.8	271.5	145.6	248.7

3.2.5 Selecting accessions for quality traits

Plants expressing quality traits in section 3.2.5 were selected and tagged in the four experimental sites in the field. Traits selected for included high vigor, resistance to pest and diseases, tolerance to low moisture, early flowering and maturity, high yields and a 100-seed weight. This gave an indication of the varieties that are superior to others and can be promoted for planting by farmers in the region.

3.2.6 Genetic Variability of Kenyan Sorghum Landraces Based on Simple Sequence Repeats (SSRs) Markers

Forty eight sorghum accessions including forty four landraces grown by the farmers and four commercially released cultivars were used to assess the genetic diversity (Table 3.1). Seeds for each accession were sown in trays containing soil and seedlings raised under standard glasshouse conditions at International Crops Research Institute for Semi-Arid Tropics (ICRISAT), World Agroforestry campus, Nairobi between July and September, 2012. Leaves were taken from two weeks old individual plants, from each accession. Young tissues contain more cells per weight resulting in higher DNA yields. They also contain smaller amounts of polysaccharides and polyphenols reducing contaminations in the resulting DNA extracted.

3.2.6.1 DNA extraction

DNA extraction was done using Cetyl Trimethyl Ammonium Bromide (CTAB) according to Mace *et al.*, (2003). Single plant leaf samples weighing 25 mg were harvested and placed in strip tubes with stainless steel grinding balls. This was followed by addition of 450 µl of preheated extraction buffer comprising of 100 mM Tris–HCl (pH 8), 1.4 M NaCl, 20 mM EDTA, CTAB (2.5% w/v), β-mercaptoethanol (3% v/v) to each sample. The tubes were covered with strip caps. The samples were put in a GenoGrinder for 20 minutes at a rate of 1500 resolutions per minute (GenoGrider 2000, Spex Certiprep

Inc.). The homogenate was incubated at 65 °C for 1 hour with occassional mixing to disperse lumps.

Four hundred and fifty µl of chloroform - isoamyl alcohol (24:1 v/v) was added to each sample and centrifuged at 4000 rpm for 15 minutes at 24 °C (Allegra 25R centrifuge, Beckyman Coulter). The clear aqueous phase was transferred to new strip tubes.

To each sample, 450 µl isopropanol was added and incubated at -20 °C for 2 hours. The mixture was then centrifuged for 20 minutes at 4 °C and 3500 rpm to precipitate the DNA. The supernatant was decanted and pellets left to dry for 30 minutes. To each sample, 200 µl low salt TE (10 mM tris, 0.1 mM EDTA (pH 8)) and 3 µl RNase A (10 mg/ml) was added before incubating for 30 minutes at 37 °C.

Two hundred µl chloroform - isoamyl - alcohol was added to each sample and centrifuged at 24 °C for 15 minutes. To each sample, 315 µl ethanol - sodium - acetate solution was added, then placed at -20 °C for 60 minutes. The samples were centrifuged at 4 °C for 15 minutes before decanting the supernatant from each sample. The pellets were then washed with 100 µl of 70% ethanol. The samples were centrifuged for 5 minutes before draining the ethanol. The pellets were air dried then resuspended in 100 µl of low salt TE buffer and stored at 4 °C (Mace *et al.*, 2003).

3.2.6.2 DNA quality analysis and quantification

A mixture of 3 µl genomic DNA with 5 µl loading dye for each sample was prepared. The quality of genomic DNA was assessed by loading the mixture into agarose (0.8%) gel in 0.5 x TBE buffer containing 40 mM Tris - acetate and 1 mM EDTA (pH 8.0). Electrophoresis was done at 100 volts for 2 hours and the gels photographed. Quality of the DNA was assessed using gel documentation transilluminator (UV Tech). The DNA was quantified at 260 and 280 nm using a spectrophotometer nanodrop 2000 thermoscientific. The DNA samples were diluted to final concentration of 10 ng/µl and stored at -20 ºC for Polymerase Chain Reaction (PCR) (Mace *et al.,* 2003).

3.2.6.3 PCR DNA amplification

Polymerase Chain Reaction amplifications were performed in 60 µl reaction mixture which consisted of of 1 x PCR buffer, 2mM $MgCl_2$, 0.16 mM dNTPs, 0.16pmol fluorescent dye, 0.04pmol forward and reverse primers and 5 units Taq polymerase. Twenty primers of known sequence were used in amplification of the 48 samples (Billot *et al.,* 2012). 10 µl of the reaction mixture was put in three 384 well plate which were loaded in the programmable PCR thermal cycler machine (GeneAmp® PCR system 9700, Applied BioSystems) for amplification. The amplification was carried out using the following profile as developed by Folkertsma *et al.,* (2005): 1 cycle of initial denaturation at 94 °C for 15 minutes, 35 cycles of denaturation at 94 °C for 30 seconds, annealing at 50 °C for 1 minute and elongation at 72 °C for 2 minutes. This was followed by 1 cycle of final elongation at 72 °C for 20 minutes and holding time ∞ at 4 °C.

The PCR product was loaded on 2% agarose gel in TAE buffer containing 40 mM Tris-acetate, 1 mM EDTA at a pH of 8.0. The gel was stained with gel red (0.5 µl/ml) and DNA fragments visualized by illumination device with UV light. The success of amplification was indicated by presence of one or two sharp bands within the size range of upto 100 bp.

3.2.6.4 Simple Sequence Repeats (SSR)

The PCR products were loaded for DNA fragments denaturation and size fractioning using capillary electrophoresis. A mixture of 1000 µl of GS500LIZ and 12 µl Formamide (HiDi) was prepared from which 8 µl was picked and added to each PCR product. The plates were put in the PCR thermal cycler machine to denature the PCR products at 95 °C for 5 minutes. The products were then cooled rapidly in ice. Fragment size fractioning was done using ABI 3730 automatic DNA sequencer (Perkin Elmer-Applied Biosystems). The Genemapper software Version 4.0 (Perkin Elmer-Applied Biosystems) was applied to size peak patterns, using the internal ROX 400 HD size standard and for allele scoring.

3.2.7 Improvement of on-farm seed quality

The field research was conducted at KARI - Kiboko between September, 2011 - February, 2012 to come up with optimum production strategies that can be disseminated for use by sorghum farmers. Two varieties with compact ear heads, Gatengu (landrace) and Seredo (commercial) that performed best in the four locations were selected for planting in this experiment. The experiment was laid in a Randomized Completely Block Design (RCBD) with 2 (varieties) x 3 (blocks) x 14 treatment combinations.

3.2.7.1 Land preparation

The land was deep ploughed by tractor to ensure no hard pan at the root zone. This ensures enough moisture is retained by the loose soil, adequate aeration and good soil structure for root system development. The land was levelled, any trash and large colloids removed before being demarcated. A total of 377 m^2 of land was used with individual plots measuring 100 cm x 100 cm. Footpaths of 100 cm were left in between the plots and between blocks. There were a total of eighty four plots with fourteen treatments replicated three times (Table 3.4).

Table 3.4: Different treatments used to assess their effects on sorghum seed quality

Experiment	Treatment	activity undertaken
Position of seed on panicle	1	upper part of panicle
	2	mid part of panicle
	3	lower part of panicle
	4	whole panicle
Time of sun drying seeds	5	9.00 a.m. – 12.00 noon
	6	12.00 noon – 3.00 p.m.
	7	3.00 p.m. – 6.00 p.m.
	8	9.00 a.m. – 6.00 p.m.
	9	drier (control)
Storage vessels	10	gunny bags
	11	gourds
	12	metallic tins
	13	earthen vessels
	14	traditional woven baskets

3.2.7.2 Planting

Seeds of Gatengu (landrace) and Seredo (commercial) were planted at a spacing of 75 cm between rows and 25 cm between plants at a depth of 3 - 5 cm (Grain sorghum, 2010). Two seeds were placed per hole then thinned to leave one plant per hill. There were two rows per plot each with 5 plants giving a population of 10 plants per plot. In addition, Gaddam was planted as guard rows round the whole plot. Single super phosphate (SSP) was applied to supply phosphorous (P_20_5) at a rate of 30 kg ha^{-1} was applied at planting (Ashiono *et al.*, 2006). The fertilizer was put in holes and mixed with the soil before placement of seeds to avoid scorching. Monocarp® pesticide was applied to the soil before planting to control any soil borne pests and diseases.

Weeding was done twice during the growing period to ensure unwanted plants did not compete with the crop for nutrients and also act as alternative hosts for pests and diseases. Nitrogen was applied at a rate of 40 kg N ha^{-1} when the crop was about four weeks after emergence. The crop received optimum moisture which was supplemented through irrigation whenever the crop showed water stress before booting stage.

Duduthrin® mixed with foliar feed was applied to the crop immediately after germination to control shoot fly. This was repeated every 3 days for one month. Buldock® was applied to control stalk borers when the crop was one month and two months old respectively.

3.2.7.3 Harvesting

Harvesting was done by hand where the panicles were cut from the main stalk by use of a knife. Each panicle was put in a separate khaki paper bag and clearly labeled. At harvesting the moisture content of the seeds was determined and ensured it was between 18 - 20%. The crop was harvested after 103 days after sowing when it had reached physiological maturity and the grain was hard and did not produce milk when crushed.

3.2.7.4.1 Quality of seed from different panicle parts

At maturity, all panicles in a plot were harvested and put in Khaki paper bags each separately. The seeds were sun dried in the open until they attained a moisture content of 12% in the open air. During drying period, the panicles were turned frequently to avoid over heating of seeds on one side. The whole panicle was divided into three parts; with the ⅓ part towards the tip termed as upper; ⅓ part at the middle as mid and the ⅓ part towards the basal as lower.

After drying, seeds from upper, mid and lower parts of the panicles were removed separately by hands for quality tests as compared to seed from the whole panicle. Seed viability and vigour were determined as outlined in section 3.2.3.2 and 3.2.3.3.

3.2.7.4.2 Effect of storage conditions on seed quality

At maturity, panicles were harvested from all plants per treatment and put in Khaki paper bags each separately. Drying was done in the open until the seeds attained 12% moisture content. Threshing was done by hand to avoid mechanical damage on the seeds. The seeds were stored in gunny bags, gourds, metallic tins, earthen vessels and traditional woven baskets at room condition for 12 weeks (3 months) at Kenyatta University to act as control conditions. This was because the sorghum seeds obtained earlier from farmers were stored in different containers under different environments. Samples were drawn from each treatment for viability and vigour tests after every 4 weeks as outlined in section 3.2.3.2 and 3.2.3.3.

3.2.7.4.3 Effect of drying time on seed quality

At maturity, panicles were harvested from all plants per treatment and put in Khaki paper bags each separately. The panicles were dried for eight weeks (2 months) in the open and in a drier in the laboratory as a control to attain 12% moisture content. Drying in the open was at varied hours of the day as shown in Table 3.5 while drying in the drier (control) was continuous. During drying period, samples were drawn at an interval of one week for viability and vigour tests as outlined in section 3.2.3.2 and 3.2.3.3. Temperature and relative humidity were recorded from day one to end of drying period (Table 3.5).

Table 3.5: Range of temperature (°C) and relative humidity (%) prevailing during different sorghum seed drying regimes for various weeks at Kiboko

	1		2		3		4								5	
	Temp	RH	Temp	RH	Temp	RH	Temp				RH				Temp	RH
wk 1	26-35	83-87	37-38	87-89	39-31	89-88	26	35	37	31	89	87	89	88	20	15
wk 2	27-34	87-89	34-36	89-89	36-30	89-86	27	34	36	30	87	89	89	86	20	15
wk 3	27-35	91-91	35-36	91-91	36-30	91-88	27	35	36	30	91	91	91	88	20	15
wk 4	26-36	91-88	36-36	88-90	36-30	90-90	26	36	36	30	91	88	90	90	20	15
wk 5	28-35	91-92	35-36	92-91	36-30	91-88	28	35	36	30	91	92	91	88	20	15
wk 6	27-35	90-90	35-35	90-90	35-30	90-90	27	35	35	30	90	90	90	90	20	15
wk 7	26-32	91-90	33-34	90-91	34-29	91-91	26	32	34	29	91	90	91	91	20	15
wk 8	27-35	91-91	35-35	91-91	34-30	91-92	27	35	34	30	91	91	91	92	20	15

Where1 =9.00 a.m.-12.00 noon; 2 =12.00 noon-3.00p.m; 3 =3.00p.m-6.00p.m; 4 =9.00a.m-6.00p.m; 5 =drier; RH =relative humidity; wk = week

3.3 Statistical analysis

Data was analyzed using PROC GLIMMIX model of the Statistical Analysis Systems software (SAS Institute, 2005) and GenStat Release 13.3, (2012). Baseline survey data, germplasm identification and evaluation parameters were expressed as percentages. Statistical analysis on seed purity, germination percentage, mean germination time, seedling growth rate and infection by pathogens of the accessions from farmers was done. Also the parameters were subjected to Analysis of Variance (ANOVA), means separated using Least Significance Difference (LSD) at P= 0.05 based on Turkey's B test. Using the 'binned' dataset, PowerMarker v.3.25 (Liu and Muse, 2005) was used to calculate the total numbers of alleles, the numbers of common alleles with frequencies of at least 5%, the observed allele size ranges (bp), the polymorphic information content (PIC) values (Botstein *et al*., 1980; Smith *et al*., 2000) and gene diversity. DARwin v.5.0 (Perrier *et al*., 2003; Perrier and Jacquemoud-Collet, 2006) was used to calculate pair-wise genetic dissimilarities of accessions using simple matching. The dissimilarity coefficients were used to perform principal coordinates analyses (PCoA) and construct weighted neighbour-joining trees (Saitou and Nei, 1987). Variation between and within accessions was assessed using AMOVA (Analysis of Molecular Variance) using Arlequin v.3.1 (Excoffer *et al.,* 2006). Data on qualitative and quantitative characters were subjected to analysis of variance, means separated using Least Significance Difference (LSD) at P= 0.05 based on Turkey's B test. Also, correlation coefficient was used and comparisons of the traits done using Chi square, Kruskal-wallis test (GenStat Release 13.3, 2012). Effect of panicle section, storage containers and drying regimes on seed viability and vigor was determined using analysis of variance and least significance difference used to separate the means at 0.05 level of confidence and varieties compared using students't-test (GenStat Release 13.3, 2012).

CHAPTER FOUR

RESULTS

4.1 Baseline survey on factors affecting sorghum production and use in lower eastern Kenya

4.1.1 Gender, Occupation and education level of farmers interviewed at Kitui, Mbeere, Makueni and Mutomo in lower eastern Kenya

Kitui and Mutomo had the highest percentage (100%) of interviewees who were farming on full time basis while Mbeere had the highest percentage (10%) of interviewees who were employed and did farming as a secondary occupation. Makueni had the highest percentage (20%) of farmers who were also involved in business (Table 4.1). The percentage of farmers involved in business as a secondary source of income differed significantly ($P \leq 0.05$) between Makueni and Kitui, Mbeere, Mutomo; while the percentage was not significant between Kitui and Mbeere; Kitui and Mutomo; Mbeere and Mutomo (Table 4.1).

Kitui had a significantly ($P \leq 0.05$) higher percentage (43%) of farmers who had never gone to school and also a higher percentage of farmers with secondary (27%) and tertiary (10%) education compared to all the other districts. Makueni had the highest percentage of farmers with primary education while Kitui had the lowest percentage (20%). The percentage of farmers with primary education in Kitui was significantly ($P \leq 0.05$) lower than in Mbeeere, Makueni and Mutomo (Table 4.1).

Table 4.1: Gender, occupation and education level percentage means of farmers interviewed at Kitui, Mbeere, Makueni and Mutomo in lower eastern Kenya

	Farmers (%)								
	Gender		Occupation			Education			
	Females	Males	Farmer	Business	Employed	Primary	Secondary	Tertiary	None
Site									
1	63a	37a	100a	0b	0b	20b	27a	10a	43a
2	63a	37a	83a	7b	10a	63a	20a	0a	0c
3	60a	40a	73a	20a	7ab	77a	17a	6a	0c
4	67a	33a	100a	0b	0b	67a	20a	0a	13b
LSD	37	18	57	10	7	24	12	15	2

*Means having a common letter within a column are not significantly different at 5% level of significance according to Turkey's B test

Where: - 1 Kitui site; 2 Mbeere site; 3 Makueni site; 4 Mutomo site

4.1.2 Sorghum varieties grown

Of all the farmers interviewed, 96% grew sorghum while only 4% from Makueni who did not grow the crop. The percentage of farmers growing sorghum in Makueni (82%) was significantly ($P \leq 0.05$) lower compared to the other three regions where 100% of farmers interviewed were growing sorghum (Table 4.2). In Makueni, the percentage of farmers growing commercial sorghum varieties was significantly ($P \leq 0.05$) higher than in all the other districts (Table 4.2). The percentage of farmers growing local varieties of sorghum in Makueni (84%) was significantly ($P \leq 0.05$) lower than in Kitui, Mbeere and Mutomo which had 100% of the farmers growing landraces (Table 4.2).

The percentage of farmers growing sorghum for food was significantly ($P \leq 0.05$) higher in Makueni (100%) than in Kitui (50%). Kitui had the highest percentage (17%) of farmers who sell the harvest while Mbeere had the highest percentage (37%) of farmers growing sorghum for both food and for sale. Makueni had a significantly ($P \leq 0.05$) higher percentage of farmers using sorghum as food than in Kitui and Mbeere. Mbeere had a significantly ($P \leq 0.05$) higher percentage of farmers using the crop for sale and food than in Makueni and Mutomo. The percentage of farmers who sell sorghum grain was significantly ($P \leq 0.05$) higher in Kitui (17%) than in Makueni (0%) (Table 4.2).

4.1.3 Farming systems practiced by farmers

Mbeere had a significantly ($P \leq 0.05$) higher number of farmers practicing mixed farming system by intercropping sorghum with cowpeas, maize, green grams and pigeon peas compared to Makueni, Mutomo and Kitui. The percentage of farmers practicing mixed crop farming in Kitui (50%) and Mutomo (60%) was significantly ($P \leq 0.05$) lower than in Mbeere (87%) and Makueni (84%) (Table 4.2). The number of farmers practicing mono- cropping system by growing either sorghum, pigeon pea, maize, cowpea, green grams per season was highest in Mutomo and differed significantly ($P \leq 0.05$) with the number of farmers practicing mono cropping in Kitui, Mbeere and Makueni. More farmers in Kitui practiced strip farming than in all the other districts. The percentage of farmers practicing mono- cropping farming system in Mbeere (13%) and Makueni (13%) was significantly ($P \leq 0.05$) lower than in Kitui and Mutomo which had 33% and 40% of farmers respectively (Table 4.2).

4.1.4 Use of farm inputs in sorghum production

The percentage of farmers using organic fertilizer was significantly ($P \leq 0.05$) higher in Mbeere than in Kitui, Makueni and Mutomo while the percentage of farmers using both inorganic and organic fertilizers was significantly ($P \leq 0.05$) higher in Makueni. Mutomo had the highest percentage of farmers planting sorghum without any type of fertilizers (Table 4.2). Mbeere had the highest percentage (77%) of farmers using organic fertilizer which differed significantly ($P \leq 0.05$) with Makueni (7%), Mutomo (12%) and Kitui (27%), but there was no difference between Makueni (7%) and Mutomo (12%) (Table 4.2). The percentage of farmers that use inorganic fertilizer was significantly ($P \leq 0.05$) higher in Makueni (13%) than in Mutomo (7%), Kitui (3%) and Mbeere (0%). Percentage of farmers that use both organic and inorganic fertilizer was significantly (*P*≤0.05) higher in Makueni (13%) compared to Mbeere (0%). Mutomo had a significantly (*P*≤0.05) higher percentage (67%) of farmers who do not use any fertilizer compared to Kitui (23%), Mbeere (6%) and Makueni (3%) (Table 4.2).

The percentage of farmers using chemicals to control pest and diseases was significantly (*P*≤0.05) higher (77%) in Makueni while Mutomo had significantly (*P*≤0.05) higher percentage (80%) of farmers that do not use any chemicals to control pests and diseases on sorghum (Table 4.2). The percentage of farmers using chemicals was significantly (*P*≤0.05) lower in Mutomo (20%) compared to Kitui (67%), Mbeere (63%) and Makueni (77%) (Table 4.2).

4.1.5 Source of sorghum seed used by farmers

Kitui had a significantly (*P*≤0.05) higher percentage (70%) of farmers who save own seed for planting than Makueni. The percentage of farmers who borrowed seed for planting was significantly (*P*≤0.05) higher in Makueni (37%) than in Kitui (20%) and Mutomo (20%) (Table 4.2).

Table 4.2: Farmers growing sorghum under different agronomic practices and use in Kitui, Mbeere, Makueni and Mutomo in lower eastern Kenya

		Farmers (%)																
		Varieties		Farming System			Fertilizer Use				Chemicals		Seed Source			Purpose		
	Growing Sorghum	Local	Hybrid	Mixed	Mono	Strip	Organic	Inorganic	Both	None	Use	None	Saved	Market	Borrow	Food	Sell	Both
1	100a	100a	0b	50b	33b	17a	27b	3c	47a	23b	67a	33b	70a	10a	20c	50b	17a	33a
2	100a	100a	0b	87a	13c	0b	77a	0d	17a	6b	63a	37b	60a	10a	30b	60b	3c	37a
3	82b	84b	16a	84a	13c	0b	7c	13a	60ab	3b	77a	7c	13b	33a	37a	100a	0d	0b
4	100a	100a	0b	60b	40a	0b	12c	7b	13ac	67a	20b	80a	47a	33a	20c	87a	6b	7b
LSD	17	15	11	14	2	1	14	2	39	20	39	31	28	28	5	19	1	18

*Means having a common letter within a column are not significantly different at 5% level according Turkey's B test
Where: - 1=Kitui site; 2=Mbeere site; 3=Makueni site; 4=Mutomo site

4.1.6 Traits preferred by farmers and constraints in sorghum production in the region

Traits preferred by the farmers in the sorghum landraces grown were high yields, high vigor, good taste, ease in cleaning, resistance to drought, early maturity, resistance to birds and other pests. Farmers preferring resistance to drought and insect pests in sorghum was only reported in Mbeere while none were reported in the other three regions (Table 4.3). Kitui had a significantly ($P \leq 0.05$) higher percentage of farmers (27%) preferring resistance to birds than Mbeere (3%). Percentage of farmers preferring early maturing sorghum varieties was higher in Kitui (33%) than in Mbeere (30%). Landraces with good taste were significantly ($P \leq 0.05$) preferred more in Mbeere (40%) than in Kitui. High yielding varieties were more preferred in Mutomo (73%) than in all the other regions. Varieties high in vigour were only preferred in Makueni (20%) while those that are easy to clean were preferred only in Kitui (7%) (Table 4.3).

The major constraints cited by farmers interviewed in sorghum production were susceptibility to pests such as shoot fly, birds, ants, aphids and borers. Diseases reported included smut and honey dew. Farmers cited weevil infestation as a major drawback in sorghum storability.

Table 4.3: Preferred traits in sorghum landraces grown by farmers in the study area of lower eastern Kenya

	Farmers (%)								
	Drought Resistance	Pest Resistance	Bird Resistance	Early maturity	Good taste	High yield	Vigor	Ease of cleaning	All traits
1	0b	0b	27a	33a	10b	20b	0b	7a	20a
2	30a	3a	3b	30a	40a	20b	0b	0b	7b
3	0b	0b	0b	0b	0c	63a	20a	0b	0b
4	0b	0b	0b	0b	7b	73a	0b	0b	20a
LSD (*P*=0.05)	19	1	11	7	15	24	3	2	5

*Means having a common letter within a column are not significantly different at 5% level of significance according to Turkey's B test

Where: - 1=Kitui site; 2 =Mbeere site; 3=Makueni site; 4=Mutomo site

4.1.7 Farm size and sorghum grain production

Farm sizes were quite variable ranging from 0.4-6 ha across the region. Majority of farmers interviewed had farms ranging around 2 ha in Makueni (88%), Mbeere (78%), Mutomo (53%) and Kitui (52%). Of the farmers interviewed, only 5% allocated more than 0.1 ha for sorghum production while 30% allocated less than 0.05 ha of land to sorghum. Most farmers had sorghum grain yield ranging from 1.0 to 3.5 t ha^{-1} which is low compared to the research potential yield of more than 4.0 t ha^{-1}.

4.2 Participatory identification and evaluation of sorghum (*Sorghum bicolor* (L.) Moench) landraces from lower eastern Kenya

The color of the landraces varied considerably between and within the germplasm (Appendix 6; Plate 4.1). The landraces which were white in color occurred in the four districts while dirty white (5RP 8/2) occurred only in Kitui and Makueni. Brown and brown white types were available in Kitui, Mutomo and Makueni while dark brown and brown red types occurred in Kitui only. However, the brown germplasm had four different types based on the color while brown white had five different types. Brown red found at Kitui occurred as a mixer of two color codes (5R 6/8 and 7/4) (Appendix 6). The red type was present in all districts except Mutomo which had a unique black red type. The red germplasm had four different color codes. Purple, purple pink, cream pink, pink brown, mixture of purple, pink, white, and mixture of purple, pink, white, brown occurred only in Mbeere. The purple germplasm had two different color codes while purple pink germplasm had four different codes. Pink brown germplasm had two codes while the mixed germplasm with purple, pink and white had two different codes.

Mbeere region had the highest percentage number of landraces with 38.6%, followed by Kitui with 27.3%, Makueni with 25% while Mutomo had the lowest percentage of 9.1% (Table 4.4). The results showed that landraces with brown color schemes were more in the region with 18.2%, followed by white color schemes with 13.6%, brown white and red color schemes with 11.4%. Purple and purple pink had a percentage of 9.1% respectively, followed by pink brown and mixture of purple, pink, white with 4.5% and finally dirty white, dark brown, brown red, black red, cream pink and mixture of purple, pink, white, brown with 2.3% (Table 4.4).


5RP 8/2


5RP 5/2


5RP 7/2


5RP 5/6


N/A


5RP 6/2


5RP 6/4


10R 6/4

Plate 4.1 A sample of few sorghum germplasm collected from the farmers in Mbeere, Mutomo, Kitui and Makueni in lower eastern Kenya

Table 4.4: Sorghum landraces collected from the study area in lower eastern Kenya

	Sites					
Landraces	Kitui	Mutomo	Makueni	Mbeere	Total	LSD (*P*=0.05)
White	6.8a	2.3b	2.3b	2.3b	13.6	4.0
Dirty white	0.0b	0.0b	2.3a	0.0b	2.3	1.5
Brown white	4.5a	2.3b	4.5a	0.0c	11.4	2.0
Brown	6.8a	2.3b	9.1a	0.0b	18.2	3.6
Dark brown	2.3a	0.0b	0.0b	0.0b	2.3	2.0
Brown red	2.3a	0.0b	0.0b	0.0b	2.3	1.7
Red	4.5b	0.0a	6.8a	4.5b	11.4	2.1
Black red	0.0a	2.3a	0.0a	0.0a	2.3	1.7
Purple	0.0b	0.0b	0.0b	9.1a	9.1	1.0
Purple pink	0.0b	0.0b	0.0b	9.1a	9.1	2.8
Cream pink	0.0b	0.0b	0.0b	2.3a	2.3	1.5
Pink brown	0.0b	0.0b	0.0b	4.5a	4.5	3.9
Mixture of purple, pink, white	0.0b	0.0b	0.0b	4.5a	4.5	2.3
Mixture of purple, pink, white, brown	0.0	0.0b	0.0b	2.3a	2.3	1.1
TOTAL	27.3	9.1	25	38.6	100%	

* Means having a common letter within a row are not significantly different at 5% level of significance according to Turkey's B test

4.3 Dermination of seed quality of sorghum accessions collected from the study districts

4.3.1 Seed purity

Of the seed samples collected, 96% had more than 99% purity (Appendix 8) which was above the stipulated 95% by ISTA rules. Only two samples (4%) had low pure seed of 72%. The seed purity ranged from 72 – 100 % with a mean of 99% (Table 4.5).

4.3.2 Sorghum accessions seed viability as determined by germination percentage

Of the samples tested, 58% had more than 90% germination of which 57% were samples collected from the farmers (Appendix 8). A total of 17% of the samples had a germination capacity of less than the minimum germination percentage of 70% as stipulated in the Seeds and Plant Varieties Act CAP 326 of the laws of Kenya (Constitution of Kenya, 1991). Five samples (10%) had germination percentage as low as 6% (Appendix 8). The seed samples had a mean germination percentage of 81%. The germination percentage significantly ($P \leq 0.05$) differed between the seeds from samples collected from the farmers (Appendix 8). Germination percentage ranged from 6 - 98% and was significantly ($P \leq 0.05$) higher in seeds from accessions 3, 12, 29 and 41 (Table 4.5).

4.3.3 Seed vigor

4.3.3.1 Seed vigor of accessions as determined by speed of germination (Mean germination time)

The seeds from 44 accessions and 4 improved varieties had a mean germination time ranging from 2.098 - 5.286 days (Table 4.5). Of the total seed samples, 63% had a mean germination time of between 2 to 3 days (Appendix 5). Seeds that germinated between 3 to 4 days were 27%, while 10% of the seeds had a mean germination time of more than 4 days. Mean germination time differed significantly ($P \leq 0.05$) between the seed samples. Accessions 1, 3, 4, 6, 8, 21, 37, 40, 41 and 44 recorded the highest germination time while 48 and 31 had the lowest germination time (Appendix 8). Accessions 1, 4, 6, 8, 21, 37, 40 and 44 had a mean germination time significantly ($P \leq 0.05$) higher than accessions 3, 12, 29 and 41, the commercial varieties.

4.3.3.2 Seedling growth rate

Out of the 44 accessions and 4 improved varieties tested for vigor, 60% of the seed samples had leaf length measuring between 20 - 30 mm after 21 days (Table 4.5). Of the seeds sampled, 33% had leaf length measuring between 10 - 20 mm while 6% had leaf length of less than 10 mm. The leaf length of the seedlings was significantly ($P \leq 0.05$) higher in accessions 6 and 39 while it was lower in accessions 16, 44 and 15 (Appendix 8). Accessions 5, 15, 16, 30 and 44 had a leaf length significantly lower than the 4 improved varieties. The leaf length for accessions 2, 6, 7, 8, 10, 11, 13, 33, 36 and 39 was significantly higher than the accessions 3, 12, 29 and 41 which were improved varieties used as control. The leaf length ranged from 3 - 26.3 mm (Table 4.5).

Leaf area of the seedlings ranged from 8 - 70 mm^2 after 21 days (Table 4.5). Of the 48 seeds from samples tested, 31% had a leaf area of between 60 - 70 mm^2, 48% had a leaf area ranging from 50 to 60 mm^2 while 15%, 4% and 2% had leaf area ranging from 40 - 50, 10 - 20 and less than 10 mm^2 respectively (Appendix 8). The leaf area was significantly ($P \leq 0.05$) higher in seedlings from accession 18 and lower in seedlings from accession 15. Accessions 5, 16, 22, 24, 34, 45, 44 and 48 had a leaf area significantly lower than seedlings from the improved varieties while twenty four of the landraces had leaf area higher than the four improved varieties.

Root length of the seedlings measured between 3 - 71.25 mm after 21 days (Table 4.5 and Appendix 8). Of the samples, 95% had root length more than 50 mm and only 5% had less than 50 mm. The root length was significantly ($P \leq 0.05$) higher in seedlings from accessions 8, 39 and 35 while it was lower in seedlings from accession 15 (Appendix 8). Accessions 5, 16, 22, 24, 34, 45, 44 and 48 had a root length significantly lower than seedlings from the improved varieties while ten landraces had leaf area higher than the four improved varieties.

Shoot length ranged from 2 - 47.75 mm after 21 days (Table 4.5). Seed samples with a shoot length between 30 - 50 mm were 92%, while 6% and 2% had a shoot length ranging from 10 - 30 mm and less than 10 mm respectively. The seedlings attained a mean shoot length of 41.51 mm long. The shoot length was significantly ($P \leq 0.05$) higher in seedlings from accessions 6 and 8 but was lower in seedlings from accession 15 (Appendix 8). Accessions 5, 15, 16, 30, 44 and 45 had a shoot length significantly lower than seedlings from the improved varieties while fourteen landraces had shoot length higher than the four improved varieties.

Seedling growth rate per day ranged from 1.0 x 10^{-4} to 4.16 x 10^{-4} mg/day after 21 days (Table 4.5). The seedling growth rate per day was significantly ($P \leq 0.05$) higher in seedlings from accession 40 while it was lower in seedlings from accession 15 (Appendix 8). Accessions 1, 8, 15, 18, 23, 24, 26, 34, 39, 43 and 44 had a growth rate significantly lower than seedlings from the improved varieties while fifteen landraces had a growth rate higher than the four improved varieties.

Table 4.5: Statistical summary analysis of seed purity, viability and vigor of 4 improved varieties and 44 landraces of sorghum accessions

	Minimum	Maximum
Seed Purity (%)	72.20	100.00
Germination (%)	6.00	98.00
Mean germination time (days)	2.09	5.28
Leaf length (mm)	3.00	26.30
Leaf area (mm^2)	8.00	66.10
Root length (mm)	3.00	71.25
Shoot length (mm)	2.00	47.80
Seedling growth rate (mg/day)	1.00	4.21

4.3.4 Seed infection by pathogens

The percentage of seeds infected by *Fusarium spp.* was significantly ($P \leq 0.05$) higher in accession 8 than in the other accessions (Appendix 9). Seeds infected by *Aspergillus niger* were significantly ($P \leq 0.05$) more in accession 28 while seeds infected by *Aspergillus favus* were significantly ($P \leq 0.05$) more in accession 30. Seeds infected by *Pencillium spp.* were significantly ($P \leq 0.05$) more in accession 1 than in other accessions. Seeds from accessions 9, 10, 12, 16, 17, 18, 21, 26, 37, 40, 43 and 47 had a significantly ($P \leq 0.05$) higher level of infection than the other accessions (Appendix 9). Seeds from samples were infected by *Fusarium spp.* (30%), *Aspergillus niger* (10%), *Aspergillus favus* (9%), *Pencillium spp.* (9%) and *Rhizorpus spp.* (12%). *Fusarium spp.* was significantly ($P \leq 0.05$) more prevelent in in the seeds from the accessions than *Aspergillus niger*, *Aspergillus favurs*, *Pencillium spp.* and *Rhizorpus spp.* (Fig. 4.1 and Appendix 9).

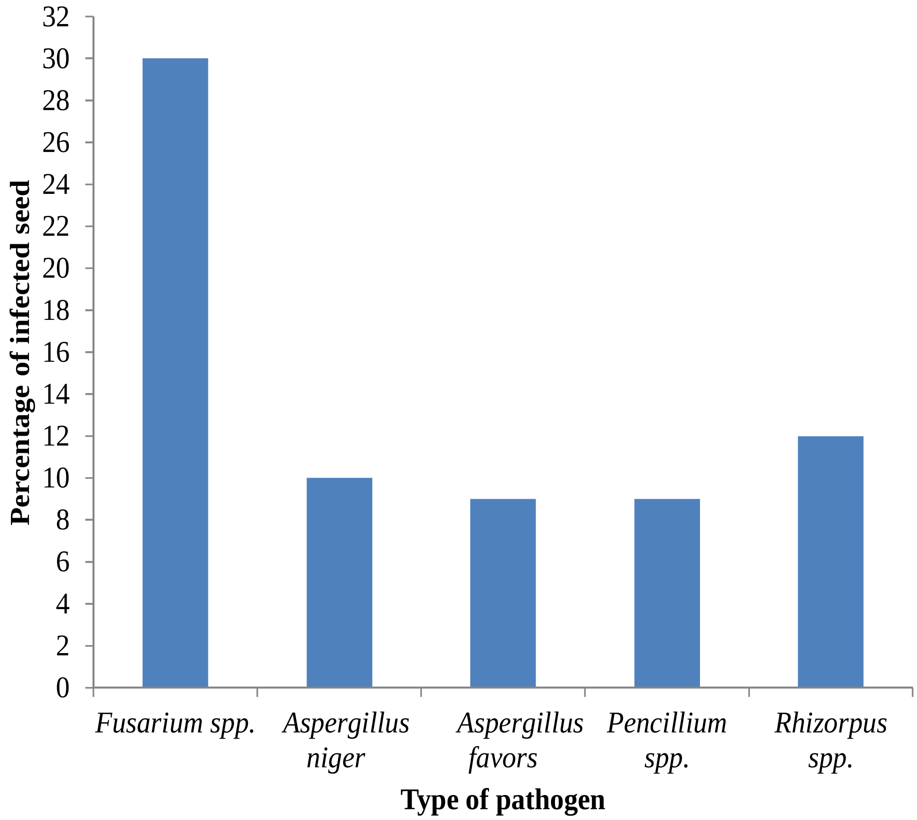

Figure 4.1: Mean percentages of seeds from 48 sorghum accessions infected by *Fusarium spp.*, *Aspergillus favurs, Pencillium spp.*and *Rhizorpus spp.*

4.4 Morphological Characters of sorghum landraces collected from farmers in lower eastern Kenya

4.4.1 Qualitative characters of the landraces

Morphological variation among accessions was high with regard to panicle compactness, glume color, glume covering and leaf midrib color (Table 4.6 and Appendix 10). Little variation was found in leaf orientation, leaf color, awns and grain shape. Most of the accessions (88%) had dark green leaf color while the leaf midrib color varied greatly ranging from brown (65%), light green (17%), dark brown (13%) to purple (6%). The panicle compactness varied greatly among the accessions where majority had compact panicles (49%). The semi compact panicles constituted 30%, while loose and semi loose panicle constituted 8% and 13% respectively. The most abundant glume colours were brown (48%) and dark brown (40%) while 12% had straw color. There were more accessions without awns (56%) than with awns (44%). The seed shape was either circular (85%) or elliptic (15%). The seed size ranged from large (23%), medium (67%) and small (10%). The seed color after harvesting was similar to that recorded before planting for each accession.

Table 4.6: Frequency of qualitative morphological characters of sorghum landraces collected from farmers in lower eastern Kenya

CHARACTERS	VARIATION	FREQUENCY (%)
Leaf color	Light green	12
	Dark green	88
Midrib color	Brown	65
	Dark brown	13
	Light green	17
	Purple	6
Leaf Orientation	Erect	46
	Droopping	54
Ear-head compactness	Compact	49
	Semi Compact	30
	Loose	8
	Semi loose	13
Glume color	Brown	48
	Dark brown	40
	Straw	12
Glume cover	25%	69
	50%	27
	75%	4
Awns	Present	44
	Absent	56
Grain shape	Circular	85
	Elliptic	15
Grain size	Large	23
	Medium	67
	Small	10

4.4.2 Quantitative characters of the sorghum landraces

Comparisons of number of days taken by seeds of the accessions to germinate between the four locations in season one, two and in both seasons was highly significant ($P \leq 0.05$). Comparisons of the seedling vigor significantly ($P \leq 0.05$) differed between the four locations in season one, two and in both seasons (Table 4.7).

The number of leaves in plants of the accessions differed between the four locations in season one and two and was highly significant (*P*≤0.05). Leaf length was highly significant in season two, but was not significant in season one and in both seasons between the locations. The leaf width varied significantly (*P*≤0.05) between the accessions in the four locations in both seasons (Table 4.7).

The plant height was significant (*P*≤0.05) between the accessions per season in the four locations and between the locations. Comparisons of plant height between the four locations in season one, two and in both seasons was highly significant (Table 4.7). The stem thickness differed significantly (*P*≤0.05) between the accessions per season in each site and between the locations. Comparisons of stem thickness between the four locations in season one, two and in both seasons was highly significant (Table 4.7). The dry matter accumulation of the plant stems and leaves was significant (*P*≤0.05) between the accessions in all seasons in the four locations and between the four locations. Comparisons of the plant dry matter between the four locations in season one, two and in both seasons were highly significant (Table 4.7).

Days to flowering ranged from 40 - 108 days in the four locations. Comparisons of days to flowering between the four locations in season one, two and in both seasons were highly significant (Table 4.7). Days to maturity differed significantly (*P*≤0.05) between the accessions, between seasons and between locations. Comparisons of days to maturity between the four locations in season one, two and in both seasons were highly significant (Table 4.7).

The head length significantly differed ($P \leq 0.05$) between the four locations. Comparisons of ear head length between the four locations in season one, two and in both seasons were highly significant. The ear head width differed significantly ($P \leq 0.05$) between the accessions per season and between the four locations. Comparisons of ear head width between the four locations in season one, two and in both seasons were highly significant (Table 4.7).

The grain yield from the accessions ranged from 0.3 - 4.5 t ha^{-1}. The grain yield differed significantly ($P \leq 0.05$) between the accessions in each season per location and between the locations. The grain yield was not significant in season one, two and in both between the locations (Table 4.7). The 100-seed weight differed significantly ($P \leq 0.05$) between the accessions in each season in the four locations. There was also a significant different ($P \leq 0.05$) between the locations in the weight of the 100-seed. The hundred seed weight was highly significant in season one, two and in both between the four locations (Table 4.7).

The stem dry matter, ear head width, grain yield and the 100-seed weight are the highly variable characters based on the coefficient of variance percentage (Table 4.8). The correlation coefficient of the grain yield and the 100- seed weight are highly correlated to the number of leaves, leaf length, leaf width, plant height, stem thickness, ear head width and length, while there was no correlation with seedling vigor and stem dry weight (Table 4.8).

Table 4.7: Comparisons of performance of the 44 sorghum landraces and 4 improved varieties between Mbeere, Kitui, Mutomo and Makueni

	chi square probability (*P*=0.05)		
Characters	Season 1	Season 2	Both seasons
Days after sowing (days)	< 0.001	< 0.001	< 0.001
Seedling vigor	< 0.001	< 0.001	< 0.001
Number of leaves	0.007	< 0.001	0.055
Leaf length (cm)	0.542	< 0.001	0.060
Leaf width (cm)	0.046	< 0.001	0.051
Plant height (cm)	< 0.001	< 0.001	< 0.001
Stem thickness (cm)	< 0.001	< 0.001	< 0.001
Stem dry matter (g)	< 0.001	< 0.001	< 0.001
Days to flowering (days)	0.048	< 0.001	< 0.001
Days to maturity (days)	< 0.001	< 0.001	< 0.001
Ear head length (cm)	< 0.001	< 0.001	< 0.001
Ear head width (cm)	< 0.001	< 0.001	< 0.001
Grain yield (t)	0.153	0.936	0.238
100-seed weight (g)	< 0.001	< 0.001	< 0.001

*****Any P-value greater than 0.05 is not significantly different according to Kruskal-Wallis one-way analysis of variance

Table 4.8: Correlation coefficient of yield attributing characters for the 44 sorghum landraces and 4 improved varieties

Characters	DAS	NOL	LFW	LFL	SVR	PHT	STS	SDW	DFL	DYM	EHL	EHW	GRY	HSW
Days after sowing	1													
Number of leaves	0.74**	1												
Leaf width (cm)	0.68**	0.93**	1											
Leaf length (cm)	0.75**	0.90**	0.89**	1										
Seedlingvigor	0.04	0.14	0.19	0.05	1									
Plant height (cm)	0.58**	0.73**	0.68**	0.76**	0.15	1								
Stem thick (cm)	0.68**	0.73**	0.66**	0.72**	0.09	0.68**	1							
Stem dry matter (g)	0.33*	0.18	0.13	0.35*	0.04	0.38**	0.33*	1						
Days to flowering	0.52**	0.82**	0.87**	0.77**	0.25	0.58**	0.62**	0.01	1					
Days to maturity	0.46**	0.80**	0.84**	0.72**	0.25	0.57**	0.58**	0.06	0.98**	1				
Earhead length (cm)	0.46**	0.76**	0.82**	0.68**	0.22	0.60**	0.62**	0.07	0.93**	0.94**	1			
Earhead width (cm)	0.48**	0.72**	0.79**	0.70**	0.24	0.58**	0.59**	0.11	0.89**	0.89**	0.89**	1		
Grain yield (t)	5.30**	7.49**	7.90**	7.16**	2.07	5.30**	5.82**	0.49	9.00**	8.92**	8.72**	8.23**	1	
100-seed weight (g)	3.88**	6.62**	7.52**	6.33**	2.41	4.75**	4.61**	1.21	9.03**	9.15**	8.87**	7.97**	8.82**	1

**significant at 1% level; *significant at 5% level; DAS=Days after sowing; NOL=Number of leaves; LFW=Leaf width; LFL=Leaflength; SVR=Seedling vigor; PHT=Plant height; STS=Stem thickness; SDW=Stem dry weight; DFL=Days to flowering; DYM=Days to maturity; EHL=Ear head length; EHW=Ear head width; GRY=Grain yield; HSW=100-seed weight; Grain yield (t) and 100-seed (g)10^{-7}

4.5 Selection of landraces showing superior traits across the four locations

Out of the 48 sorghum accessions, 43 emerged within the expected seven days in the four locations and were selected due to uniformity in germination (Appendix 11-18). Seedlings scoring from 1 - 3 were termed as vigorous and therefore selected. Accessions selected in the four locations included 1, 2, 3, 5, 17, 18, 20, 24, 26, 28, 31, 38, 41 and 42 (Appendix 11-18).

Nineteen accessions formed panicles in all the locations while 29 accessions produced flowers in some locations and no flowers in others. Out of the accessions that formed panicles, fourteen were selected for early maturity which ranged from 100 - 115 days after sowing (DAS). The accessions that matured within this range were 2, 3, 5, 9, 17, 20, 21, 22, 24, 28, 37, 38, 40 and 43 (Appendix 11-18).

Grain yield of best performing accessions in the four locations was between 1.46 – 4.44 tonnes ha^{-1}. Five accessions were selected based on grain yield with accession 2 having the highest grain yield of 4.44 tonnes ha^{-1} which was significantly higher than the other four (Table 4.9).

Table 4.9 Yield of five selected genotypes

	Grain yield (t/ha)			
	Kiboko	Kitui	Mbeere	Mutomo
Gatengu (Mbeere Kiritiri)	4.44	2.04	3.42	3.86
Brown white (Mutomo)	3.49	1.88	2.25	3.21
Brown white (Kitui central)	3.06	1.96	2.57	3.47
Seredo (commercial)	2.27	1.46	3.25	3.45
Brown (Makueni Kiboko)	3.03	1.73	2.02	3.78

Five accessions were tolerant to pests and diseases in the four locations were selected where those resistant were scored as 1 and those susceptible as 4. Accessions 2, 23, 24, 29 and 31 were selected for resistance to pest and diseases (Table 4.10).

Table 4.10 Plant vigor and tolerance to pests, diseases, low moisture of selected genotypes

	Vigor	Tolerance Pests	Tolerance Diseases	Tolerance low Moisture
Gatengu (Mbeere Kiritiri)	2	1	1	1
Brown white (Mutomo)	2	2	2	2
Brown white (Kitui central)	2	2	1	2
Seredo (commercial)	2	1	1	2
Brown (Makueni Kiboko)	2	2	2	1

Of the 48 accessions, 43 germinated in the eight field trials (four locations, two plantings each). Out of the 43 accessions that germinated, 35 survived the low moisture through the juvenile (vegetative phase) in all eight field planting and were selected for drought resistance. The accessions that were selected for successful panicle formation and maturity in the eight trials were only fourteen out of the 43 accessions that germinated.

The total rainfall recorded during the two cropping season for 2010/2011 and 2011 varied significantly (Table 3.3). The large difference between the two seasons is mainly because of differences in rainfall figures recorded with first season recording higher amount of rain compared to season two in the four locations.

4.6 Genetic Variability of Kenyan Sorghum Landraces Based on Simple Sequence Repeats (SSRs) Markers

4.6.1 SSR Polymorphism

Polymorphism among the 48 sorghum genotypes was assessed with 20 SSR markers. All the 20 SSR markers used were polymorphic across the 48 sorghum genotypes with PIC (Polymorphic Information Content) value ranging from 0.04 to 0.81 with a mean of 0.49. Of the 20 markers, 65% were highly polymorphic with a value greater than 0.5 indicating their usefulness in discriminating the genotypes (Table 4.11). Heterozygosity values of the 20 SSR markers ranged from 0.00 to 0.04, with a mean of 0.01 suggesting that each detected a single genetic locus and that each of the sorghum accession used was stable. The markers revealed a total of 98 alleles with a range of between 2 (gpsb067, mSbCIR24 and Xcup53) to 10 (Xtxp320) alleles and an average of 5.05 alleles per primer pair. The gene diversity ranged from 0.04 to 0.83 with a mean value of 0.53. All possible allele combinations found in the 48 accessions ranged from 2 to 10 while major allele frequency ranged from 0.32 to 0.98 (Table 4.11).

Genetic distances indicated by dissimilarity coefficient among genotypes varied from 0.15 to 0.90. Accessions 11 and 13 had the minimum genetic distance (0.15) while accessions 26 and 44 had maximum genetic distance (0.90).

Table 4.11: Characteristics of 20 SSR markers across 44 sorghum landraces and 4 commercial varieties

Marker	Repeat Motif	Major.Allele Frequency	Genotype No	Allele No	Availability	Gene Diversity	Heterozygosity	PIC
gpsb067	(GT)10	0.55	4	4	0.98	0.57	0.00	0.50
mSbCIR238	(AC)26	0.54	4	4	0.96	0.61	0.00	0.54
mSbCIR248	(GT)7.5	0.36	4	4	0.98	0.72	0.00	0.67
mSbCIR276	(AC)9	0.83	5	5	0.98	0.30	0.00	0.29
mSbCIR283	(CT)8 (GT)8.5	0.58	4	4	1.00	0.58	0.00	0.52
mSbCIR329	(AC)8.5	0.63	2	2	0.90	0.47	0.00	0.36
Xcup02	(GCA)6	0.59	6	6	0.96	0.58	0.00	0.53
Xcup53	(TTTA)5	0.79	3	3	1.00	0.34	0.00	0.31
Xcup61	(CAG)7	0.72	6	4	0.98	0.44	0.04	0.41
Xcup63	(GGATGC)4	0.71	6	6	1.00	0.47	0.00	0.43
Xtxp010	(CT)14	0.32	10	10	0.92	0.83	0.00	0.81
Xtxp012	(CT)22	0.52	4	4	0.96	0.61	0.00	0.54
Xtxp015	(TC)16	0.38	7	7	0.98	0.76	0.00	0.73
Xtxp021	(AG)18	0.39	10	9	0.98	0.78	0.02	0.76
Xtxp040	(GGA)7	0.96	3	3	1.00	0.08	0.00	0.08
Xtxp057	(GT)21	0.38	8	8	1.00	0.77	0.00	0.73
Xtxp141	(GA)23	0.25	9	8	1.00	0.83	0.02	0.81
Xtxp145	(AG)22	0.95	3	2	1.00	0.10	0.02	0.09
Xtxp146	(GAA)19	0.98	2	2	1.00	0.04	0.00	0.04
Xtxp320	(AAG)20	0.47	6	6	0.98	0.69	0.00	0.65
Mean		0.60	5	5	0.98	0.53	0.01	0.49

The weighted neighbour-joining clustering-based dendrogram generated using dissimilarity indices clustered the sorghum accessions into four major groups (Fig. 4.2 and 4.3). Cluster 1 comprised of genotypes from Kitui (west and central), Mbeere (Siakago and Kiritiri) and from Makueni (Kibwezi, Makindu and Kiboko) and Seredo (commercial variety). The genotypes varied in color from white, brown white, brown, red, black red and purple but distributed across the four regions. The cluster had three subgroups with genotype black red from mutomo very distinct from other genotypes. Cluster 2 had genotypes from Mbeere (Kiritiri, Siakago), Makueni (Kibwezi), KARI Mtama 1 and Serena, commercially released varieties. The cluster had four subgroups with genotypes 7 and 8 from Mbeere Kiritiri grouped together distinctly. Cluster 3 had genotypes from Makueni (Makindu, Kibwezi), Mbeere (Kiritiri, Ishiara, Siakago), Kitui (west and central) and Mutomo; and the commercial variety Gaddam. The cluster had five sub groups with seed color varying greatly. Cluster 4 consists of three genotypes from Mbeere (Kiritiri), Makueni (Kiboko) and Kitui central. Genotype 26 from Mbeere (Kiritiri) and 24 from Kitui central had a closer relationship than with 25 though in the same cluster (Fig. 4.2 and 4.3).

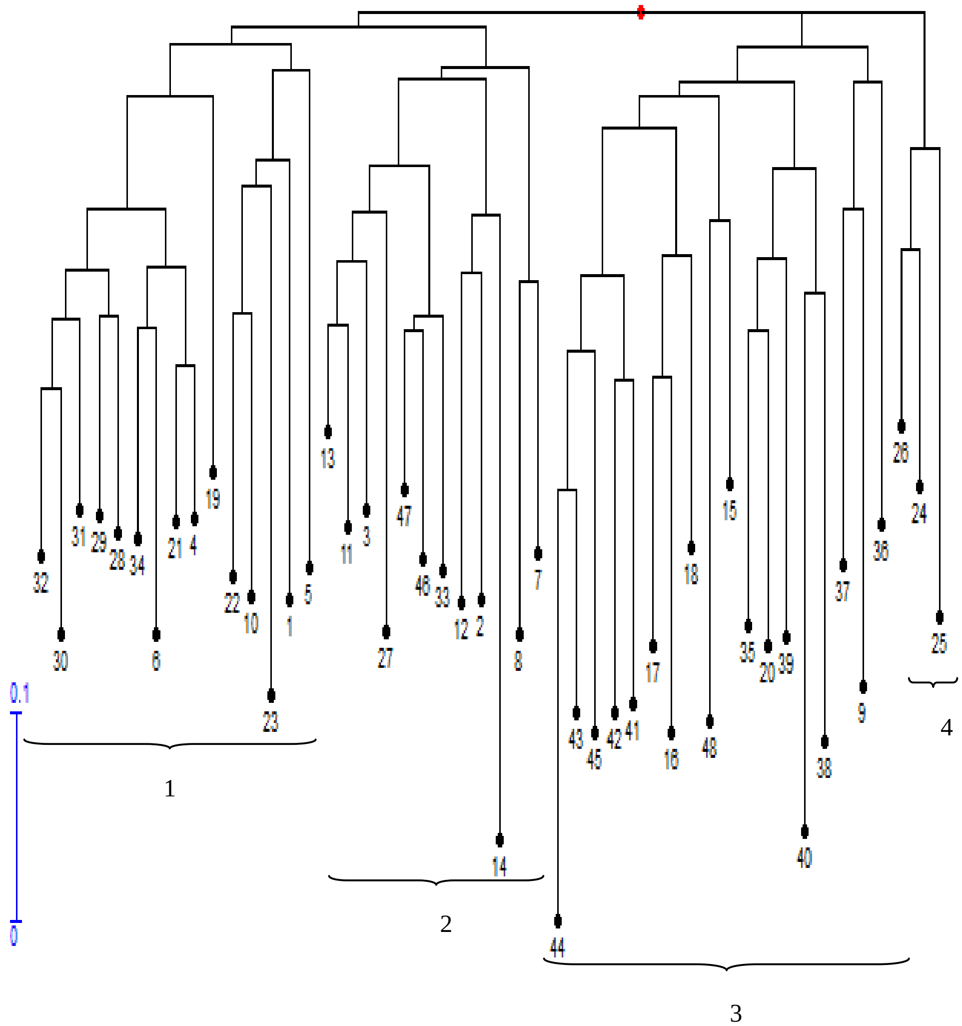

Figure 4.2: Tree constructed based on 20 polymorphic sorghum SSR markers using the simple matching dissimilarity index and weighted neighbor joining clustering for the 48 sorghum accessions.

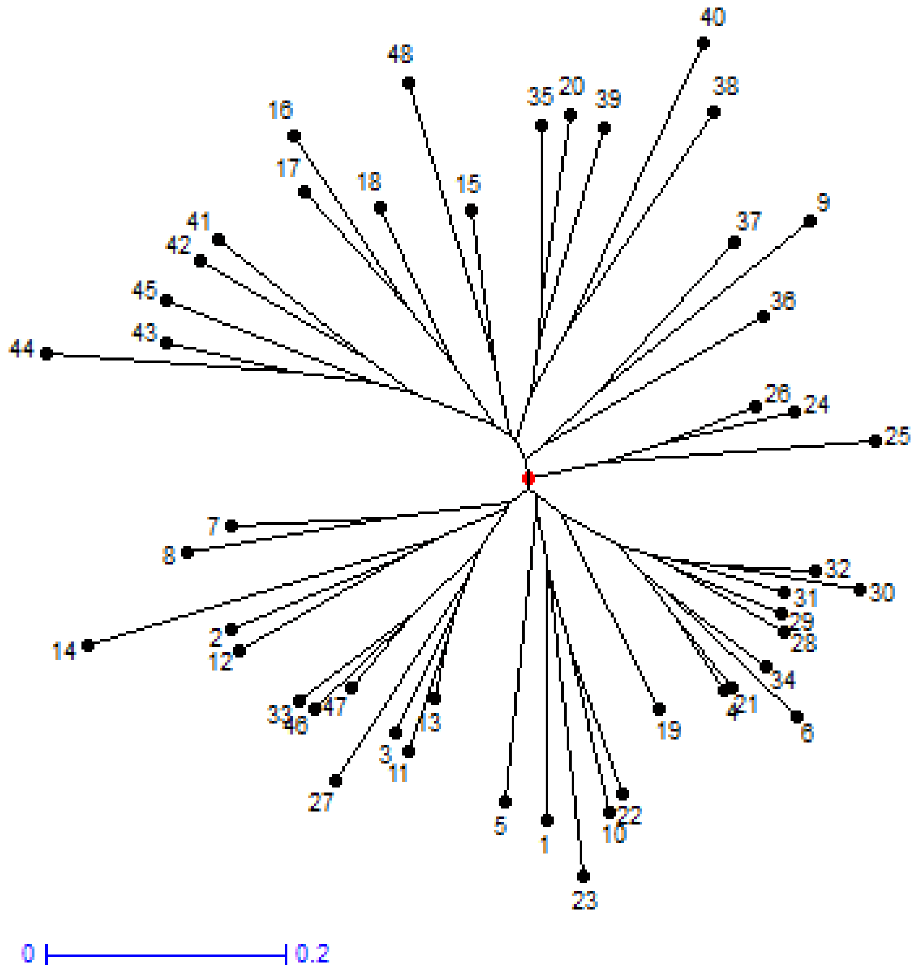

Figure 4.3: Tree constructed based on 20 polymorphic sorghum SSR markers using the simple matching dissimilarity index and weighted neighbor joining clustering for the 48 sorghum accessions expressing diversity.

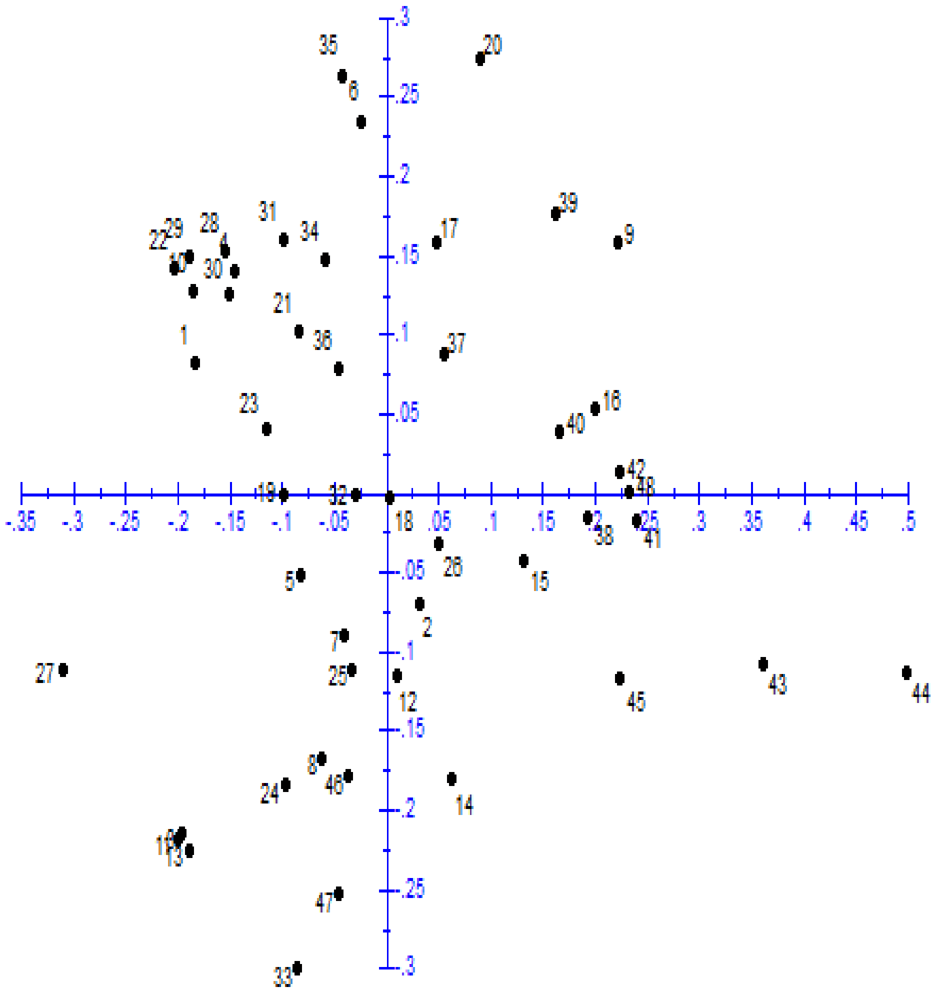

Figure 4.4: Plot of the axes 1 and 2 of the principal coordinate analysis based on the dissimilarity of 20 SSR markers for 44 sorghum accessions obtained from farmers in lower eastern Kenya and 4 improved varieties.

Genetic diversity among accessions was also confirmed by scatter plot derived through principal coordinate analysis (PCoA) (Fig. 4.4). Forty percent of the accessions were clustered in the right portions of the plot, while 60% accessions were clustered in the left portion of the plot (axes1/2). Groupings were similar to those detected by cluster analysis where the genotypes were clearly separated across the region except for the genotype 9 from Makueni (Makindu) and genotype 11 from Mbeere (Kiritiri) which had an overlap. Genotypes 20 from Makueni (Kiboko) and 33 from Mbeere (Kiritiri) followed by genotypes 27 from Mbeere (Siakago) and 44 from Kitui central were far much apart from other genotypes; an indication of maximum dissimilarity. Genotypes 11, 13 and 3 formed a solidarity group implying high relatedness in the genetic makeup. This was also observed in genotypes 10 from Makueni (Kibwezi), 22 from Kitui central, 28 from Mutomo, 3 (commercial), 30 from Kiboko and 4 from Mbeere Siakago (Fig. 4.4).

Analysis of Molecular variation (AMOVA) showed significant (P = 0.05) differences among the various genotypes evaluated (Table 4.12). There was a greater variance (91.61%) represented by individuals within populations, while the variance between the groups was less (2.75%) with least variance (1.14%) expressed by the individuals.

Table 4.12: Analysis of molecular variation (AMOVA) of 4 sorghum improved varieties and 44 landraces from farmers in different locations of Mbeere, Mutomo, Kitui and Makueni based on 20 SSR markers

Source of variation	Sum of squares	Variance components	Percentage of variation
Among populations	73.42	0.13	2.75
Among individuals within populations	354.10	4.63	91.61
Within individuals	2.50	0.05	1.14
Total	430.02	4.81	

Fixation indices between the commercial varieties and landraces from Mbeere Ishiara was highest (F_{ST} = 0.242; *P*= 0.001) followed by between Ishiara and Kitui central (F_{ST} = 0.191; *P*=0.001). Population pair wise fixation indices was lowest between Makindu and Kitui west (F_{ST} = 0.035; *P*=0.001) and between Mutomo and Kitui west (F_{ST} = 0.037; *P*= 0.001) and kiritiri siakago regions (F_{ST} = 0.016; *P* = 0.001) (Table 4.13).

Table 4.13: Pairwise FST estimates among 4 improved varieties and 44 landraces from different locations in Mbeere, Mutomo, Kitui and Makueni; and 4 improved varieties

	1	2	3	4	5	6	7	8	9
Kitui central									
Kitui west	0.04947								
Kiritiri	0.06672	0.07287							
Siakago	0.08234	0.09518	0.07393						
Ishiara	0.19055	0.06897	0.18737	0.09030					
Makindu	0.07124	0.03523	0.05419	0.12299	0.14758				
Kiboko	0.09667	0.11713	0.12840	0.01661	0.14327	0.12209			
Kibwezi	0.08037	0.07879	0.09231	0.10533	0.18943	0.17455	0.14180		
Mutomo	0.05847	0.03653	0.07289	0.07958	0.13146	0.06009	0.07036	0.10138	
Commercial	0.16788	0.16196	0.10243	0.09135	0.24249	0.17748	0.18301	0.15586	0.10933

Where; 1= kituicentral_landrace 2= kituiwest_landrace 3= mbeerekiritiri_landrace 4= mbeeresiakago_landrace 5= mbeereishiara_landrace 6= makindu_landrace 7= kiboko_landrace 8= kibwezi_landrace 9= mutomo_landrace 10= AS_improved

4.7 Improvement of on-farm saved seed quality of sorghum grown in eastern Kenya

4.7.1 Effect of panicle sections on seed viability and vigor in sorghum

Seed germination percentage was significantly ($P \leq 0.05$) higher in the lower part than in the upper part of the panicle in both Seredo and Gatengu (Fig. 4.5). Seeds from mid part had a germination percentage significantly ($P \leq 0.05$) higher than the upper part but lower than the lower part of the panicle. Seeds from the whole panicle had germination percentage significantly ($P \leq 0.05$) higher than from seed obtained from upper part but lower than mid and lower panicle parts in both varieties. Germination percentage significantly ($P \leq 0.05$) differed between seeds from lower part, mid part, upper part and whole panicle in Gatengu and Seredo. The germination percentage of all seeds tested was higher in Gatengu compared to Seredo. The germination percentage significantly ($P \leq 0.05$) differed between the two varieties (Table 4.15).

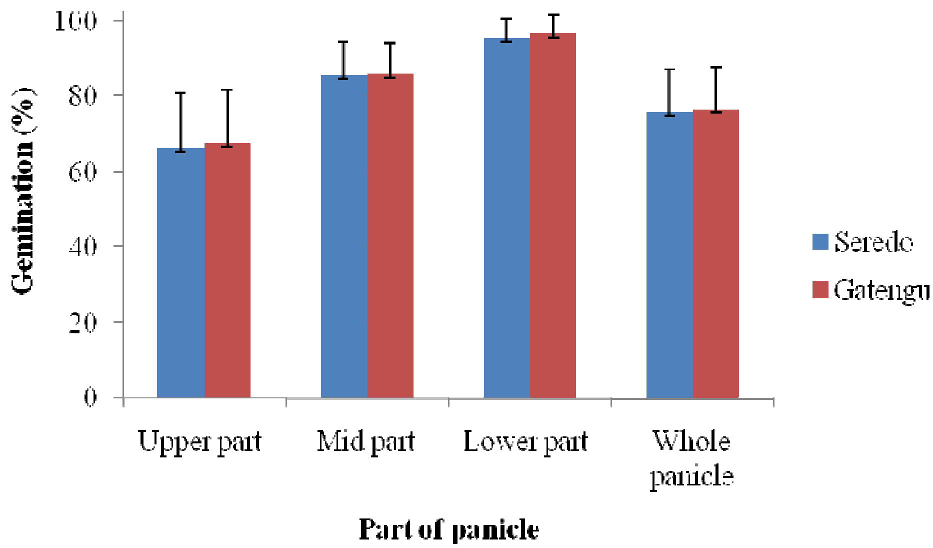

Figure 4.5: Germination percentage of sorghum seed of Seredo and Gatengu genotypes obtained from three different panicle sections and whole panicle (control)

Mean germination time of seeds was significantly ($P \leq 0.05$) higher in lower part than in the upper part of the panicle in both Seredo and Gatengu (Fig. 4.6). Seeds from the upper and mid parts of the panicle took more than four days to germinate while seeds from lower and whole panicle germinated within three days in Seredo. In Gatengu, the seeds from upper part germinated in more than three days while those from mid, lower and whole panicle germinated within two days. The mean germination time was significant ($P \leq 0.05$) between the treatments in both varieties except for lower and whole panicle. The mean germination time significantly ($P \leq 0.05$) differed between Seredo and Gatengu (Table 4.15).

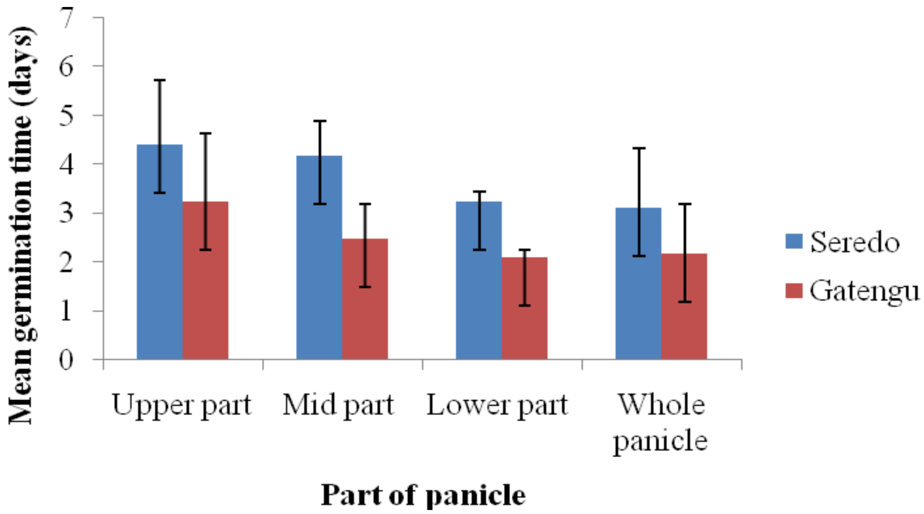

Figure 4.6: Mean germination time (days) of sorghum seed of Seredo and Gatengu varieties obtained from three different panicle sections and whole panicle (control)

Seed vigour was significantly ($P \leq 0.05$) higher in lower third part than in the upper third part of the panicle in both Seredo and Gatengu (Table 4.14). Seedlings from lower panicle part had the highest leaf length while those from the upper part had the shortest leaf length in the Seredo and Gatengu (Table 4.14). Growth rate per day was highest in seedlings from lower part while seedlings from upper part recorded the lowest growth rate per day. The growth rate per day significantly ($P \leq 0.05$) differed between the upper, mid, lower and whole in the two varieties except between upper and mid sections for both varieties (Table 4.14).

Leaves from seed obtained from mid and whole panicle were longer than those of seedlings from upper part but shorter than for those from lower part in the two varieties. The leaf length was significantly ($P \leq 0.05$) differed between seedlings of upper, mid, lower and the whole panicle in both Seredo and Gatengu seeds (Table 4.15). The leaf area, root length and shoot length was greater in Gatengu than in Seredo. The leaf area and the shoot length significantly ($P \leq 0.05$) differed between the two varieties.

4.14: Seedling leaf length, leaf area, root length, shoot length and growth rate (GR) of sorghum seeds of Seredo and Gatengu obtained from different panicle sections and whole panicle (control)

	Leaf length (mm)		leaf area (mm^2)		Root length (mm)		Shoot length (mm)		GR (mg/day)	
	Seredo	Gatengu	Seredo	Gatengu	Seredo	Gatengu	Seredo	Gatengu	Seredo	Gatengu
Upper part of panicle	66.1c	75.9c	62.7c	77.4c	72.9c	75.0c	110.3c	118.6c	0.3c	0.9c
Mid part of panicle	83.9b	92.1b	91.5b	96.0b	103.6b	104.7b	146.1b	155.9b	1.7c	2.3c
Lower part of panicle	102.4a	102.7a	105.8a	118.5a	133.5a	166.6a	172.4a	180.2a	10.9a	27.1a
Whole panicle	83.7b	92.1b	92.1b	101.0b	100.9b	101.3b	140.7b	157.1d	3.0b	4.3b
LSD (*P*=0.05)	8.5	9.6	11.8	14.9	15.9	19.2	11.0	12.5	1.5	2.0
SE	3.0	3.4	5.2	4.2	5.6	6.7	3.9	4.4	0.5	0.7
CV%	3.7	4.4	5.9	8.0	9.3	5.6	9.5	1.3	2.9	7.6

*Means having a common letter within a column are not significantly different at 5% level of significance according to Turkey's B test
*GR (mg/day) 10^{-3}.

Table 4.15: Comparison of seed viability and vigor of sorghum seed obtained from three different panicle sections and whole panicle (control) between Seredo and Gatengu varieties

	Null hypothesis that mean of Seredo – Gatengu is equal to 0 at *P*=0.05		
	SE	SD	*P* = 0.05
Germination (%)	0.2116	0.4232	0.023
Mean Germination Time (days)	0.333	0.1109	0.005
Leaf length (mm)	4.309	18.57	0.053
Leaf area (mm^2)	4.497	20.23	0.020
Root length (mm)	7.983	15.97	0.334
Shoot length (mm)	1.988	3.975	0.013
Growth rate (mg/day)	3.845	7.69	0.311

*****Any P-value greater than 0.05 is not significantly different according to student's t – test.

4.7.2 Effect of storage containers and duration on seed quality of sorghum

Germination percentage was significantly ($P \leq 0.05$) higher in seeds stored in gourd than in the seeds stored in the woven basket in both Seredo and Gatengu (Table 4.16 and 4.17). Seeds stored for four weeks had a significantly ($P \leq 0.05$) higher germination percentage than seeds stored for 8 and 12 weeks in all containers in both varieties. Germination percentage significantly ($P \leq 0.05$) differed between the different storage containers except between seed stored in gunny bags and metallic tins for the three sampling intervals in both Seredo and Gatengu (Table 4.16 and 4.17). The germination percentage significantly ($P \leq 0.05$) differed between the two varieties in seeds stored for four weeks (Table 4.22).

Table 4.16: Germination percentage of Seredo sorghum seed stored in gunny bags, gourds, metallic tins, earthen vessels and woven containers for 4, 8 and 12 weeks

	Number of weeks			
Containers	week 4	week 8	week 12	LSD (*P*=0.05)
Gunny bags	87.0c^{1}	78.3c^{2}	73.3c^{3}	4.1
Gourds	95.8a^{1}	90.8a^{2}	82.5a^{3}	2.9
Metallic tins	84.5c^{1}	75.5c^{2}	71.8c^{3}	1.6
Earthen vessels	92.3b^{1}	84.0b^{2}	80.8b^{3}	2.3
woven baskets	79.3d^{1}	73.0d^{2}	64.5d^{3}	4.1
LSD (*P*=0.05)	3.091	4.132	2.123	
SE	1.003	1.341	1.013	
CV%	2.3	3.2	2.4	

*Means having a common letter and number within a column and a row are not significantly different at 5% level of significance according toTurkey’s B test

Table 4.17: Germination percentage of Gatengu sorghum seed stored in gunny bags, gourds, metallic tins, earthen vessels and woven baskets for 4, 8 and 12 weeks

	Number of weeks			
Containers	week 4	week 8	week 12	LSD (*P*=0.05)
Gunny bags	$88.5c^{1}$	$79.3c^{2}$	$74.0c^{3}$	2.8
Gourds	$97.3a^{1}$	$95.0a^{2}$	$85.3a^{3}$	1.7
Metallic tins	$87.9c^{1}$	$77.8c^{2}$	$70.3c^{3}$	1.3
Earthen vessels	$93.5b^{1}$	$89.5b^{2}$	$80.0b^{3}$	5.5
woven baskets	$81.3d^{1}$	$76.5d^{2}$	$65.0d^{3}$	3.9
LSD (*P*=0.05)	3.649	2.574	4.03	
SE	1.184	0.835	1.308	
CV%	2.7	12	3.1	

*Means having a common letter and number within a column and a row are not significantly different at 5% level of significance according to Turkey's B test

Mean germination time was significantly ($P \leq 0.05$) higher in seeds stored in gourd and earthen vessels than in the seeds stored in the gunny bags in both Seredo and Gatengu (Table 4.18 and 4.19). Seeds stored in gunny bags germinated within 3.04-3.64 days in Seredo and within 3.35 – 3.77 days in Gatengu in the three sampling intervals. Seeds stored in metallic tins and woven basket germinated within 2.5 – 3.3 days for the two varieties in the three sampling. Gourd and earthen vessels recorded the shortest mean germination in both varieties for the three sampling.

Table 4.18: Speed of germination for Seredo sorghum seed stored in gunny bags, gourds, metallic tins, earthen vessels and woven baskets for 4, 8 and 12 weeks

	Number of weeks			
Containers	week 4	week 8	week 12	LSD (*P*=0.05)
Gunny bags	3.04c[1]	3.16c[1]	3.64c[1]	5.1
Gourds	2.12a[1]	2.17a[1]	2.20a[1]	3.2
Metallic tins	2.76b[1]	2.93b[1]	3.00b[1]	4.9
Earthen vessels	2.08a[1]	2.43a[1]	2.49a[1]	4.0
woven baskets	2.82b[1]	3.09b[1]	3.26b[1]	3.3
LSD (*P*=0.05)	0.164	0.296	0.364	
SE	0.053	0.096	0.118	
CV%	3.9	6.7	8.3	

*Means having a common letter and a number within a column and a row are not significantly different at 5% level of significance according to Turkey's B test.

Table 4.19: Speed of germination for Gatengu seed stored in gunny bags, gourds, metallic tins, earthen vessels and woven baskets for 4, 8 and 12 weeks

	Number of weeks			
Containers	week 4	week 8	week 12	LSD (*P*=0.05)
Gunny bags	3.35c^{1}	3.56c^{1}	3.77c^{1}	5.0
Gourds	2.11a^{1}	2.40a^{1}	2.57a^{1}	3.7
Metallic tins	2.64b^{1}	2.81b^{1}	3.07b^{1}	3.2
Earthen vessels	2.03a^{1}	2.28a^{1}	2.73a^{1}	2.8
woven baskets	2.53b^{1}	3.00b^{1}	3.14b^{1}	3.1
LSD (*P*=0.05)	0.192	0.335	0.188	
SE	0.062	0.109	0.061	
CV%	4.7	8	4.6	

*Means having a common letter and number within a column and a row are not significantly different at 5% level of significance according to Turkey's B test.

Seedlings sampled after four weeks had the longest leaf length, leaf area, root and shoot length and the highest growth rate per day. Seedlings of seeds stored in the gourd recorded the highest of the five variables measured while woven basket had the lowest (Table 4.20 and 4.21). The leaf length of seedlings from Seredo seeds stored in gunny bags was significantly ($P \leq 0.05$) shorter than of those stored in guards and in earthen vessels. The leaf length of seedlings from Gatengu differed significantly ($P \leq 0.05$) between gunny bags, gourds, metallic tins and earthen vessels (Table 4.21). Leaf length was significantly ($P \leq 0.05$) higher in week four than it was in week twelve in both varieties (Table 4.20 and 4.21). The leaf length was significantly (*P*≤0.05) higher in seedlings stored for four weeks decreasing with increase in storage time in all containers.

The leaf area differed significantly (*P*≤0.05) between seeds stored in gunny bags, gourds, earthen vessels and metallic tins in Seredo and Gatengu. Leaf area was highest in seed stored in earthen vessels and gourds while seed stored in gunny bags and woven basket had the lowest in Seredo and Gatengu (Table 4.20 and 4.21). The leaf area decreased with increase in storage duration in the two varieties.

Root and shoot length was significantly (*P*≤0.05) higher in seeds stored in gourds and earthen vessels while it was low in seeds stored in gunny bags in Seredo and Gatengu. Root and shoot length was significant (*P*≤0.05) between seeds stored in gunny bags, guards, metallic tins, earthen vessels and in woven baskets for the two varieties. Root and shoot length was significantly (*P*≤0.05) higher in seeds sampled after four weeks than in seeds sampled twelve weeks after storage in all the storage containers in both varieties. The leaf area, shoot length and growth rate per day was significantly higher in seedlings stored for four weeks decreasing with increase in storage time in all containers.

Growth rate per day was significantly (*P*≤0.05) higher in seeds stored in earthen vessels and gourds while it was lower in seeds stored in gunny bags and woven baskets in Seredo and Gatengu (Table 4.20 and 4.21). Growth rate per day of the seedlings differed significantly (*P*≤0.05) between gunny bags, gourds, metallic tin and earthen vessel while it was not significant between gunny bag and the woven basket (Table 4.20 and 4.21). The growth rate per day was highest in seeds sampled four weeks after storage while it was significantly ($P \leq 0.05$) lower in seeds sampled after twelve weeks in both varieties. The leaf length, leaf area, root length, shoot length differed significantly ($P \leq 0.05$) between Seredo and Gatengu (Table 4.22).

Table 4.20: Seedling leaf length, leaf area, root and shoot length and growth rate (GR) of Seredo seeds stored in gunny bags, gourds, metallic tins, earthen vessels and woven baskets for four, eight and twelve weeks.

	Leaf length (mm)			Leaf area (mm^2)			Root length (mm)			Shoot length (mm)			GR (mg/day)		
container	Wk4	Wk 8	Wk12	Wk4	Wk8	Wk12	Wk4	Wk8	Wk12	Wk4	Wk8	Wk12	Wk4	Wk8	Wk12
Gunny bags	85.2c	77.7c	72.4c	52.7c	39.7c	30.0c	71.4e	68.0e	65.5e	142.0e	136.7e	121.5e	1.56c	1.53c	1.35c
Gourds	197.9b	149.0b	91.0b	70.7b	61.0b	52.6b	88.5b	86.2b	80.0b	177.6b	166.6b	164.5b	1.81b	1.77b	1.69b
Metallic tins	94.0c	92.1c	90.6c	66.2b	56.5b	47.7b	81.8c	80.0c	78.0c	165.5c	142.0c	134.5c	1.76b	1.64b	1.45b
Earthen vessels	260.3a	168.0a	105.0a	92.1a	69.7a	67.6a	89.6a	87.0a	83.5a	185.2a	176.5a	171.5a	2.84a	2.71a	2.46a
woven baskets	87.0c	84.5c	80.2c	53.5c	43.6c	42.2c	77.0d	75.6d	74.6d	159.5d	139.5d	130.5d	1.68c	1.55c	1.40c
LSD (*P*=0.05)	26.6	16.7	12.5	11.1	5.3	6.4	3.3	1.9	1.6	2.8	2.0	1.9	0.42	0.37	0.25
SE	9.3	5.8	4.4	3.9	1.8	2.2	1.2	0.7	0.5	1.0	0.7	0.7	0.15	0.13	0.09
CV%	9.8	4.9	5.2	7.1	10.3	5.4	9.3	3.1	7.4	7.5	4.9	5.7	9.9	3.2	5.7

*Means having a common letter within a column are not significantly different at 5% level of significance according to Turkey's B test
Wk= week; GR (mg/day) 10^{-2}

Table 4.21 Seedling leaf length, leaf area, root length, shoot length and growth rate (GR) of Gatengu seeds stored in gunny bags, gourds, metallic tins, earthenvessels and woven baskets for four, eight and twelve weeks

	Leaf length (mm)			Leaf area (mm^2)			Root length (mm)			Shoot length (mm)			GR (mg/day)		
Containers	wk4	wk8	wk12	wk4	wk8	wk12	wk4	wk8	wk12	wk4	wk8	wk12	wk4	wk8	wk12
Gunny bags	96.5c	95.5c	93.0c	48.2c	46.8c	41.9c	80.7e	74.8e	69.0e	116.8e	104.8e	87.5e	1.65c	1.10c	1.00c
Guards	337.6b	260.0b	162.0b	103.0b	79.6b	54.6b	117.6b	104.1b	98.0b	203.0b	154.2b	137.5b	2.08b	2.00b	1.85b
Metallic tins	316.7c	253.6c	152.0c	98.7b	76.4b	54.3b	106.5c	98.1c	92.5c	128.8c	124.0c	117.0c	1.99b	1.94b	1.88b
Earthen vessels	383.4a	287.5a	190.3a	103.8a	92.5a	68.6a	123.0a	116.1a	111.0a	208.1a	187.5a	140.0a	2.64a	2.47a	2.15a
woven baskets	105.6c	101.7c	95.5c	56.1c	51.5c	49.0c	96.0d	92.9d	80.0d	120.2d	113.0d	90.5d	1.79c	1.52c	1.20c
LSD (*P*=0.05)	34.6	12.6	15.4	18	5.9	8.1	3.5	3	2.2	3.8	1.8	2.5	0.42	0.47	0.36
SE	12.1	4.4	5.4	2.8	2.1	2.8	1.2	1	0.8	1.3	0.6	0.9	0.15	0.16	0.12
CV%	9.8	8.5	7.2	6.1	6.6	6.5	4.1	9.4	6.7	7.4	4.2	9.1	4.7	8.4	2.8

*Means having a common letter within a column are not significantly different at 5% level of significance according to Turkey's B test
Wk= week; GR (mg/day) 10^{-2}

Table 4.22: Comparison of seed viability and vigor variables between Seredo and Gatengu genotype seeds stored gunny bags, gourds, metallic tins, earthenvessels and woven baskets for four, eight and twelve weeks

		Null hypothesis that mean of Seredo – Gatengu is equal to 0 at *P*=0.05		
	Duration	SD	SE	*P* = 0.05
Germination (%)	week 4	0.876	0.392	0.008
	week 8	1.731	0.774	0.013
	week 12	1.650	0.738	0.669
Mean Germination Time (days)	week 4	0.219	0.098	0.760
	week 8	0.247	0.110	0.650
	week 12	0.184	0.082	0.169
Leaf length (mm)	week 4	88.900	39.760	0.031
	week 8	64.870	29.010	0.042
	week 12	31.160	13.930	0.022
Leaf area (mm^2)	week 4	16.960	7.584	0.021
	week 8	7.251	3.243	0.009
	week 12	4.366	1.952	0.044
Root length (mm)	week 4	9.379	4.195	0.005
	week 8	7.890	3.529	0.007
	week 12	9.778	4.373	0.034
Shoot length (mm)	week 4	32.160	14.380	0.003
	week 8	24.312	7.125	0.009
	week 12	8.419	3.765	0.001
Growth rate (mg/day)	week 4	0.184	0.082	0.292
	week 8	0.308	0.138	0.817
	week 12	0.337	0.151	0.738

*****Any P-value greater than 0.05 is not significantly different according to student's t - test

4.7.3 Influence of drying method, duration and time of the day on seed quality in sorghum crop

Germination percentage was significantly ($P \leq 0.05$) higher in seeds dried for one week than in seeds dried for eight weeks in both Seredo and Gatengu for all drying regimes (Table 4.23 and 4.24). The germination percentage significantly ($P \leq 0.05$) decreased with increase in number of weeks the seeds were dried except in seeds dried in the drier (control) (Table 4.23 and 4.24).

Germination percentage of seeds was significantly ($P \leq 0.05$) higher in seeds dried between 3.00 p.m. - 6.00 p.m. than in seeds dried between 12.00 noon - 3.00 p.m. in Seredo and Gatengu (Table 4.23 and 4.24). Seeds dried in the drier recorded a germination percentage between 92 - 94.7% and 96 - 98% in Seredo and Gatengu respectively in the eight samplings. Germination percentage was highest in seed dried between 9.00 a.m - 12.00 noon and 3.00 p.m. - 6.00 p.m while drying between 12.00 noon - 3.00 p.m recorded the lowest germination percentage in both varieties. Seeds dried between 9.00 a.m - 6.00 p.m had germination lower than those dried between 9.00 a.m - 12.00 noon and 3.00 p.m. - 6.00 p.m but higher than between 12.00 noon – 3.00 p.m in both varieties.

Variation in germination percentage was significant ($P \leq 0.05$) between the different drying regimes in all the sampling intervals and between the two varieties (Appendix 19).

Table 4.23: Germination percentage of seredo seeds dried for 1, 2, 3, 4, 5, 6, 7 and 8 weeks and at different time of the day

No. of weeks	Time of the day 9.00 a.m-12.00 noon	12.00 noon-3.00 p.m	3.00 p.m-6.00 pm	9.00 a.m-6.00 p.m	Drier (Control)	LSD (*P*=0.05)
week 1	97.0a[1]	68.7a[2]	99.3a[3]	96.0a[4]	94.0a[5]	1.1
week 2	94.7b[1]	68.0b[2]	96.3b[3]	90.7b[4]	94.7a[5]	1.7
week 3	92.0c[1]	66.0c[2]	95.0c[3]	86.0c[4]	93.7a[5]	0.9
week 4	90.3d[1]	65.7d[2]	93.7d[3]	81.3d[4]	92.0a[5]	1.3
week 5	88.1e[1]	62.3e[2]	91.7e[3]	73.0e[4]	94.7a[5]	2.5
week 6	86.7f[1]	60.7f[2]	90.1f[3]	68.7f[4]	93.3a[5]	1.2
week 7	84.7g[1]	59.6g[2]	88.3g[3]	64.3g[4]	94.0a[5]	2.6
week 8	80.7h[1]	58.0h[2]	85.0h[3]	60.0h[4]	92.3a[5]	0.7
LSD (*P*=0.05)	1.246	0.593	1.238	3.857	3.526	
SE	0.411	0.525	0.54	1.272	1.162	
CV%	0.8	1.4	1	2.8	2.1	

*Means having a common letter and a number within a column and a row are not significantly different at 5% level of significance according to Turkey's B test

Table 4.24: Germination percentage of Gatengu seeds dried for 1, 2, 3, 4, 5, 6, 7 and 8 weeks at different time of the day

	Time of the day					
No. of weeks	9.00 a.m-12.00 noon	12.00 noon-3.00 p.m	3.00 p.m-6.00 pm	9.00 a.m-6.00 p.m	Drier (Control)	LSD (*P*=0.05)
week 1	98.3a[1]	68.3a[2]	99.3a[3]	95.3a[4]	96.7a[5]	1.2
week 2	97.3b[1]	66.3b[2]	95.7b[3]	88.0b[4]	96.3a[5]	0.1
week 3	97.0c[1]	65.0c[2]	93.0c[3]	83.0c[4]	98.0a[5]	1.0
week 4	95.3d[1]	63.6d[2]	91.0d[3]	73.3d[4]	96.3a[5]	1.0
week 5	95.0e[1]	62.3e[2]	89.1e[3]	67.7e[4]	98.0a[5]	1.6
week 6	94.0f[1]	61.0f[2]	86.0f[3]	62.3f[4]	97.3a[5]	1.5
week 7	92.7g[1]	59.7g[2]	84.3g[3]	58.3g[4]	98.0a[5]	2.0
week 8	92.0h[1]	58.1h[2]	81.7h[3]	54.4h[4]	97.3a[5]	3.1
LSD (*P*=0.05)	0.224	1.144	1.604	3.675	4.546	
SE	0.033	0.542	0.529	1.212	1.499	
CV%	1.3	1.5	1	2.8	2.7	

*Means having a common letter and number within a column and a row are not significantly different at 5% level of significance according to Turkey's B test

Mean germination time increased with increase in drying time for all the treatments except in seeds put in the drier in both Seredo and Gatengu (Table 4.25 and 4.26). Seeds dried in the drier had a mean germination time of 2.08 - 2.47 days in Seredo and 2.09 - 2.19 days in Gatengu within the eight weeks. Speed of germination was significantly ($P \leq 0.05$) higher in seeds dried at 3.00 p.m. - 6.00 p.m. while seeds dried between 12.00 noon - 3.00 p.m. had the lowest in both varieties. Seeds dried between 9.00 a.m - 12.00 noon and between 3.00 p.m - 6.00 p.m germinated within 2 - 2.94 days in Seredo and Gatengu. The mean germination time significantly ($P \leq 0.05$) differed between the sampling intervals in both drying regimes in the two varieties. Seeds dried between 12.00 noon - 3.00 p.m. germinated within 3.35 - 4.22 days in Seredo while in Gatengu the mean germination time was 3.00 - 3.89 days (Table 25 and 26). The mean germination time significantly ($P \leq 0.05$) differed between the samplings in both varieties. The mean germination time of seeds dried between 9.00 a.m - 6.00 p.m was between 2.91 - 4.81 days in Seredo and 2.25 - 3.64 days in Gatengu. Speed of germination significantly ($P \leq 0.05$) differed between sampling in both varieties for this drying regime. Speed of germination was significant in the drying regimes between the eight sampling intervals and between the two varieties (Appendix 19).

Table 4.25: Mean Germination time of Seredo seeds dried for 1, 2, 3, 4, 5, 6, 7 and 8 weeks at different time of the day

	Time of day					
No. of weeks	9.00 a.m-12.00 noon	12.00 noon-3.00 p.m	3.00 p.m-6.00 pm	9.00 a.m-6.00 p.m	Drier (control)	LSD (*P*=0.05)
week 1	2.108a[1]	3.345a[2]	2.098a[3]	2.913a[4]	2.082a[5]	0.01
week 2	2.258b[1]	3.474b[2]	2.184b[3]	3.089b[4]	2.174a[5]	0.01
week 3	2.313c[1]	3.567c[2]	2.270c[3]	3.268c[4]	2.187a[5]	0.03
week 4	2.391d[1]	3.644d[2]	2.380d[3]	3.557d[4]	2.218a[5]	0.01
week 5	2.432e[1]	3.731e[2]	2.464e[3]	3.683e[4]	2.324a[5]	0.02
week 6	2.489f[1]	3.832f[2]	2.598f[3]	3.808f[4]	2.384a[5]	0.13
week 7	2.500g[1]	3.954g[2]	2.696g[3]	3.943g[4]	2.393a[5]	0.17
week 8	2.688h[1]	4.228h[2]	2.853h[3]	4.813h[4]	2.467a[5]	0.13
LSD (*P*=0.05)	0.053	0.082	0.08	0.116	0.109	
SE	0.0176	0.02698	0.02647	0.0384	0.0359	
CV%	1.3	1.3	1.9	1.9	2.7	

*Means having a common letter and number within a column and a row are not significantly different at 5% according to Turkey's B test

Table 4.26: Mean germination time of Gatengu seeds dried for 1, 2, 3, 4, 5, 6, 7 and 8 weeks at different time of the day.

	Time of day					
No. of weeks	9.00 a.m-12.00 noon	12.00 noon-3.00 p.m	3.00 p.m-6.00 pm	9.00 a.m-6.00 p.m	Drier (control)	LSD (*P*=0.05)
week 1	2.004a[1]	3.000a[2]	2.001a[3]	2.251a[4]	2.085a[5]	0.001
week 2	2.108b[1]	3.107b[2]	2.114b[3]	2.487b[4]	2.112a[5]	0.001
week 3	2.261c[1]	3.353c[2]	2.273c[3]	2.668c[4]	2.186a[5]	0.050
week 4	2.379d[1]	3.500d[2]	2.399d[3]	2.896d[4]	2.128a[5]	0.017
week 5	2.476e[1]	3.630e[2]	2.567e[3]	3.044e[4]	2.133a[5]	0.034
week 6	2.569f[1]	3.701f[2]	2.699f[3]	3.222f[4]	2.147a[5]	0.001
week 7	2.692g[1]	3.826g[2]	2.808g[3]	3.377g[4]	2.152a[5]	0.021
week 8	2.786h[1]	3.893h[2]	2.944h[3]	3.640h[4]	2.143a[5]	0.011
LSD (*P*=0.05)	0.085	0.056	0.110	0.147	0.165	
SE	0.02825	0.0251	0.0364	0.0486	0.0544	
CV%	2.1	1.2	2.7	2.9	4.1	

* Means having a common letter and number within a column and a row are not significantly different at 5% level of significance according to Turkey’s B test

Seedling of Seredo seeds dried between 9.00 a.m - 12.00 noon had the highest leaf length and leaf area ranging from 124.97-134.6 mm and 61.87-66.73 mm^2 respectively (Table 4.27 and 4.29). Seeds dried between 12.00 noon - 3.00 p.m had the lowest leaf length (27.27 - 99.13 mm) and leaf area (20.8 - 50.93 mm^2) in Seredo. Seeds dried in the drier recorded a leaf length ranging from 122.67 - 129.67 mm and a leaf area from 58.8 - 63.33 mm^2. The leaf length and leaf area of seeds dried between 3.00 p.m - 6.00 p.m and 9.00 a.m - 6.00 p.m were lower than those in the drier and at 9.00 a.m - 12.00 noon. The leaf length and leaf area decreased with increase in drying time for all treatments except in the drier. The leaf length and leaf area significantly ($P \leq 0.05$) differed between the sampling intervals of seeds dried between 12.00 noon - 3.00 p.m. but was not significant ($P \leq 0.05$) in other drying regimes (Table 4.27 and 4.29).

Gatengu seeds dried between 9.00 a.m - 12.00 noon had the longest leaf length and leaf area ranging from 113.8 - 123.07 mm and 49.4 - 53.67 mm^2 respectively (Table 4.28 and 4.30). Leaf length and leaf area decreased with increase in time of drying for all drying regimes except in seed dried in the seed drier. Only leaf length and leaf area of seeds dried between 9.00 a.m - 12.00 noon significantly ($P \leq 0.05$) differed between the sampling intervals. In both Seredo and Gatengu, the leaf length and leaf area was significant between the drying regimes in all drying periods (Table 4.20 - 4.23). The leaf length and leaf area was significant between Seredo and Gatengu between the drying regimes in all sampling intervals (Appendix 19).

Table 4.27: Leaf length of seedlings of Seredo seeds dried for one, two, three, four, five, six, seven and eight weeks at five different time of the day

	Time of day					
No. of weeks	9.00 a.m-12.00 noon	2.00 noon-3.00 p.m	3.00 p.m-6.00 pm	9.00 a.m-6.00 p.m	Drier (control)	LSD (*P*=0.05)
week 1	134.60a	99.13a	119.00a	99.73a	129.67a	0.426
week 2	134.67a	86.87b	118.97a	99.13a	126.80a	5.330
week 3	134.33a	72.40c	118.47a	98.53a	122.67a	3.681
week 4	129.80a	63.40d	118.13a	96.40a	126.47a	0.123
week 5	127.53a	54.50e	117.60a	96.33a	126.27a	1.000
week 6	125.53a	45.23f	115.00a	95.60a	125.13a	0.002
week 7	125.20a	36.13g	114.67a	94.93a	124.27a	0.658
week 8	124.97a	27.27h	114.60a	92.67a	129.40a	4.000
LSD (*P*=0.05)	9.84	8.83	9.33	8.37	8.7	
SE	3.50	4.21	3.32	2.98	3.1	
CV%	3.5	6.4	2.8	1.4	4.3	

* Means having a common letter within a column are not significantly different at 5% level of significance according to Turkey's B test

Table 4.28: Leaf length of seedlings of Gatengu seeds dried for one, two, three, four, five, six, seven and eight weeks at five different time of the day

No. of weeks	Time of day					
	9.00 a.m-12.00 noon	12.00 noon-3.00 p.m	3.00 p.m-6.00 pm	9.00 a.m-6.00 p.m	Drier (control)	LSD (*P*=0.05)
week 1	123.07a	109.93a	117.97a	99.87a	113.40a	2.317
week 2	121.33a	101.27b	117.49a	99.73a	115.13a	1.012
week 3	121.07a	92.67c	116.71a	97.87a	113.47a	2.172
week 4	119.80a	83.60d	116.57a	97.53a	115.87a	0.572
week 5	118.13a	75.07e	114.67a	96.87a	113.67a	0.010
week 6	117.93a	66.60f	113.33a	95.93a	116.93a	0.932
week 7	115.07a	57.60g	109.12a	92.53a	114.33a	0.672
week 8	113.80a	48.07h	108.96a	92.07a	110.67a	1.297
LSD(*P*=0.05)	9.70	8.45	9.13	8.79	10.62	
SE	3.45	3.01	3.25	3.13	3.78	
CV%	3.30	1.30	2.80	2.0	1.70	

* Means having a common letter within a column are not significantly different at 5% level of significance according to Turkey's B test

Table 4.29: Leaf area (mm2) of seedlings of Seredo seeds dried for one, two, three, four, five, six, seven and eight weeks at five different time of the day

	Time of day					
No. of weeks	9.00 a.m-12.00 noon	12.00 noon-3.00 p.m	3.00 p.m-6.00 pm	9.00 a.m-6.00 p.m	Drier (control)	LSD (*P*=0.05)
week 1	66.73a	50.93a	58.73a	59.80a	62.60a	1.06
week 2	66.71a	47.23b	56.87a	59.73a	58.90a	0.58
week 3	66.63a	43.40c	56.80a	59.40a	62.53a	2.45
week 4	65.93a	39.10d	55.40a	58.75a	63.33a	1.73
week 5	65.71a	35.00e	55.07a	58.73a	61.87a	2.04
week 6	65.55a	30.87f	55.00a	57.33a	63.27a	2.12
week 7	63.03a	25.80g	54.73a	56.33a	60.67a	1.94
week 8	61.87a	20.80h	53.60a	55.13a	58.80a	0.04
LSD(*P*=0.05)	4.288	3.643	4.636	4.944	4.677	
SE	1.527	2.009	1.651	1.76	1.665	
CV%	1.9	4.9	2.5	2.4	9.6	

* Means having a common letter within a column are not significantly different at 5% level of significance according to Turkey's B test

Table 4.30 Leaf area (mm^2) of seedlings of Gatengu seeds dried for one, two, three, four, five, six, seven and eight weeks at five different time of the day

	Time of day					
No. of weeks	9.00 a.m-12.00 noon	12.00 noon-3.00 p.m	3.00 p.m-6.00 pm	9.00 a.m-6.00 p.m	Drier (control)	LSD (*P*=0.05)
week 1	53.67a	57.53a	50.40a	50.21a	57.93a	0.01
week 2	53.53a	52.47b	50.00a	49.53a	57.53a	0.19
week 3	52.80a	47.73c	49.33a	49.07a	60.53a	0.02
week 4	51.67a	41.27d	49.07a	49.01a	60.73a	0.03
week 5	50.87a	36.60e	48.33a	48.97a	57.93a	0.08
week 6	50.73a	31.97f	46.81a	46.67a	58.27a	0.11
week 7	49.97a	27.23g	46.64a	45.81a	59.07a	1.00
week 8	49.40a	21.78h	45.89a	45.20a	57.81a	0.62
LSD(*P*=0.05)	4.316	4.597	5.691	5.32	5.456	
SE	1.536	1.637	2.026	1.894	1.942	
CV%	2.1	1.9	5.6	3.3	1.1	

* Means having a common letter within a column are not significantly different at 5% level of significance according to Turkey's B test

Root and shoot length was highest in seeds dried in the drier in Seredo and Gatengu. For seeds dried in the open in different time of the day, the root and shoot length was longest in seeds dried between 9.00 a.m - 12.00 noon for Seredo and Gatengu (Table 4.31 - 4.34). Seeds dried between 12.00 noon - 9.00 p.m had the lowest root and shoot length in the two varieties. Drying of seeds between 3.00 a.m - 6.00 p.m and between 9.00 a.m - 6.00 p.m recorded root and shoot length shorter than drying at 9.00 a.m - 12.00 noon and in control (drier) but higher than in at 12.00 noon - 3.00 p.m in both varieties. The length of the root and shoot decreased with increase in drying time for all drying regimes. The root and shoot length was not significant ($P \leq 0.05$) between the sampling intervals for the different drying regimes (Table 4.31 - 4.34). However, the root and shoot length were significant between the drying regimes in all sampling intervals and between the two varieties (Appendix 19).

Table 4.31 Root length (mm) of seedlings of Seredo seeds dried for one, two, three, four, five, six, seven and eight weeks at five different ime of the day

	Time of day					
Number of weeks	9.00 a.m-12.00 noon	12.00 noon-3.00 p.m	3.00 p.m-6.00 pm	9.00 a.m-6.00 p.m	Drier (control)	LSD (*P*=0.05)
week 1	115.13a	82.07a	106.27a	99.91a	115.93a	0.74
week 2	113.87a	81.95a	106.07a	99.80a	113.53a	0.06
week 3	109.53a	81.33a	105.13a	99.53a	112.60a	1.00
week 4	107.33a	81.27a	102.07a	96.77a	111.47a	1.76
week 5	106.87a	80.73a	100.73a	94.53a	109.47a	2.17
week 6	102.27a	79.80a	99.33a	90.27a	108.67a	1.59
week 7	101.13a	78.93a	98.90a	90.20a	108.20a	2.05
week 8	99.07a	78.32a	98.29a	88.67a	107.20a	0.43
LSD(*P*=0.05)	18.97	4.92	8.12	12.79	10.48	
SE	6.75	1.6	2.89	4.55	3.73	
CV%	5.8	7.2	1.7	7.5	3.3	

* Means having a common letter within a column are not significantly different at 5% level of significance according to Turkey’s B test

Table 4.32 Root length (mm) of seedlings of Gatengu seeds dried for one, two, three, four, five, six, seven and eight weeks at five different time of the day

	Time of day					
Number of weeks	9.00 a.m-12.00 noon	12.00 noon-3.00 p.m	3.00 p.m-6.00 pm	9.00 a.m-6.00 p.m	Drier (control)	LSD (*P*=0.05)
week 1	128.87a	74.87a	105.67a	99.53a	129.73a	0.59
week 2	128.61a	74.53a	105.55a	99.27a	129.33a	0.61
week 3	126.44a	73.27a	103.73a	98.73a	128.00a	1.09
week 4	120.87a	72.33a	103.40a	98.51a	122.33a	1.00
week 5	117.00a	71.80a	100.00a	97.02a	121.67a	2.05
week 6	114.53a	67.07a	99.03a	96.60a	120.93a	3.12
week 7	110.17a	66.73a	95.67a	93.07a	119.98a	1.32
week 8	110.03a	63.73a	91.40a	91.87a	119.81a	0.02
LSD(*P*=0.05)	18.88	12.96	13.65	16.22	9.95	
SE	6.72	4.61	4.86	5.78	3.54	
CV%	6.5	6.7	8.7	2.7	2.7	

* Means having a common letter within a column are not significantly different at 5% level of significance according to Turkey’s B test

Table 4.33 Shoot length (mm) of seedlings of Seredo seeds dried for one, two, three, four, five, six, seven and eight weeks at five different time of the day

	Time of day					
Number of weeks	9.00 a.m-12.00 noon	12.00 noon-3.00 p.m	3.00 p.m-6.00 pm	9.00 a.m-6.00 p.m	Drier (control)	LSD (P=0.05)
week 1	177.33a	120.20a	229.87a	152.87a	198.60a	2.03
week 2	177.27a	119.73a	223.07a	152.81a	198.53a	4.09
week 3	176.40a	119.57a	220.93a	151.98a	197.13a	1.87
week 4	172.67a	118.07a	220.20a	151.74a	193.93a	2.12
week 5	170.64a	113.33a	218.80a	142.33a	190.53a	0.19
week 6	169.87a	113.20a	217.00a	139.97a	189.13a	3.28
week 7	166.40a	109.73a	216.67a	139.72a	188.67a	4.78
week 8	165.33a	106.40a	215.93a	138.60a	184.33a	2.12
LSD(P=0.05)	14.93	16.19	15.51	15.31	14.5	
SE	5.32	5.76	5.52	5.45	5.16	
CV%	2.1	1.8	1.6	1.5	1.5	

* Means having a common letter within a column are not significantly different at 5% level of significance according to Turkey’s B test

Table 4.34 Shoot length (mm) of seedlings Gatengu seeds dried for one, two, three, four, five, six, seven and eight weeks at five different time of the day

	Time of day					
Number of weeks	9.00 a.m-12.00 noon	12.00 noon-3.00 p.m	3.00 p.m-6.00 pm	9.00 a.m-6.00 p.m	Drier (control)	LSD (*P*=0.05)
week 1	199.67a	127.93a	188.73a	154.80a	194.87a	3.20
week 2	198.20a	126.07a	183.40a	151.53a	194.07a	0.65
week 3	196.13a	125.33a	182.27a	150.40a	192.53a	1.33
week 4	190.73a	123.20a	179.40a	148.20a	189.20a	0.15
week 5	187.40a	120.00a	179.07a	145.67a	188.13a	0.05
week 6	187.20a	119.47a	175.33a	143.93a	184.20a	2.03
week 7	186.07a	119.07a	171.67a	139.67a	183.73a	0.04
week 8	185.07a	118.33a	170.80a	136.80a	182.13a	1.63
LSD(*P*=0.05)	18.37	11.31	19.04	20.42	13.8	
SE	6.54	4.03	6.78	7.27	4.91	
CV%	5.1	7.6	3.4	4.5	1.4	

* Means having a common letter within a column are not significantly different at 5% level of significance according to Turkey's B test

Growth rate per day was highest in seeds dried between 9.00 a.m - 12.00 noon ranging from 6.6 x 10^{-4} - 7.9 x 10^{-4} g/day and 7.99 x 10^{-4} - 8.7 x 10^{-4} g/day in Seredo and Gatengu respectively (Table 4.35 and 4.36). Seeds dried between 12.00 noon - 3.00 p.m had the lowest growth rate per day in both varieties. Growth rate per day of seeds dried between 3.00 p.m - 6.00 p.m and at 9.00 a.m - 6.00 p.m was lower than drying in the seeds drier but higher than at 9.00 a.m - 12.00 noon in the two varieties. The growth rate decreased with increase in drying period but was not significant ($P \leq 0.05$) between the sampling intervals in both Seredo and Gatengu (Table 4.35 and 4.36). The growth rate was significant between the drying regimes in all the sampling intervals and between the two varieties (Table 4.35 and 4.36; Appendix 19).

Table 4.35: Growth rate (mg/day) of seedlings of Seredo seeds dried for one, two, three, four, five, six, seven and eight weeks at five different time of the day

	Time of day					
Number of weeks	9.00 a.m-12.00 noon	12.00 noon-3.00 p.m	3.00 p.m-6.00 pm	9.00 a.m-6.00 p.m	Drier (control)	LSD (*P*=0.05)
week 1	7.90a	3.00a	6.90a	5.00a	6.80a	0.020
week 2	7.70a	2.90a	6.75a	5.00a	6.80a	0.030
week 3	7.60a	2.87a	6.73a	4.98a	6.20a	0.080
week 4	7.60a	2.80a	6.70a	4.90a	6.40a	0.150
week 5	7.30a	2.79a	6.69a	4.50a	6.40a	0.020
week 6	6.80a	2.66a	6.61a	4.30a	6.40a	0.030
week 7	6.70a	2.53a	6.54a	4.23a	6.50a	0.010
week 8	6.60a	2.48a	6.20a	4.21a	6.60a	0.001
LSD(*P*=0.05)	1.313	0.91	0.76	0.81	1.062	
SE	0.467	0.326	0.273	0.29	0.378	
CV%	3.4	3.8	1.3	1.6	4.4	

* Means having a common letter within a column are not significantly different at 5% level of significance according to Turkey's B test;

GR (mg/day) 10^{-4}

Table 4.36 Growth rate (mg/day) of seedlings of Gatengu seeds dried for one, two, three, four, five, six, seven and eight weeks at five different time of the day.

	Time of day					
Number of weeks	9.00 a.m-12.00 noon	12.00 noon-3.00 p.m	3.00 p.m-6.00 pm	9.00 a.m-6.00 p.m	Drier (control)	LSD (*P*=0.05)
week 1	8.70a	4.50a	6.10a	5.23a	7.30a	0.37
week 2	8.60a	4.30a	6.09a	5.21a	7.80a	0.04
week 3	8.59a	4.29a	5.97a	5.20a	7.40a	0.29
week 4	8.53a	4.17a	5.80a	5.19a	7.00a	0.14
week 5	8.50a	4.02a	5.76a	5.10a	7.50a	0.18
week 6	8.23a	4.00a	5.50a	4.94a	7.70a	0.07
week 7	8.10a	3.95a	5.45a	4.61a	7.50a	0.92
week 8	7.99a	3.77a	5.34a	4.50a	7.40a	0.08
LSD(*P*=0.05)	1.02	0.88	0.88	0.82	0.955	
SE	0.365	0.315	0.315	0.293	0.34	
CV%	2.8	2.9	2.1	1.8	2.4	

*Means having a common letter within a column are not significantly different at 5% level of significance according to Turkey's B test; GR (mg/day) 10^{-4}

CHAPTER FIVE

DISCUSSION

5.1 Baseline survey on factors affecting sorghum production and use in eastern Kenya survey

Results that literacy level in lower eastern Kenya is low with majority of the farmers having only reached primary school (Table 4.1) imply that the farmers lack technical knowledge in sorghum production. This has contributed to the numerous poor crop agronomic practices reported in this region. Of the number of farmers interviewed, females were more than males. This was attributed to common belief in the region that farm activities are a woman's job as men search for income elsewhere (KFSSG, 2009). Women are fully involved in planting, bird scaring, harvesting and post harvest processing of most crops including sorghum (KFSSG, 2009).

Majority of people interviewed were farmers by occupation and only a few were employed or do business for livelihood (Table 4.2). Unemployment has been cited as a major cause of poverty in this region resulting to lack of income necessary for meeting basic needs (Ministry of Agriculture, 2003). Further the results showed that most farmers do not use fertilizers while planting and do not control pests and diseases. This agrees with findings that many small scale farmers in Sub-Saharan Africa do not apply fertilizers to their farms (Jama *et al.,* 1998). This is attributed to the fact that sorghum is often grown under marginal rainfall conditions and fertilizer prices are unfavorably high in relation to sorghum grain price. The fact that majority of the farmers interviewed could not afford farm inputs could have led to low sorghum production yield due to using poor seed quality at planting. Many soil nutrients are depleted over time as a result of continued cultivation (Swinkels *et al.*, 1997). Seeds produced under conditions of low soil fertility usually express poor germination and vigor (Songa *et al.,* 1995). Failure to control pests and diseases also has serious implications on the quality of farm saved seeds. The use of inputs in the region is limited by lack of money in most households which is a major constraint in sorghum production (Mwadalu and Mwangi, 2013).

This study also showed that sorghum is grown by majority of farmers in lower eastern Kenya with only 5% of the farmers not planting the crop at Makueni. Though the crop is grown by majority of the farmers, it's grown on very small portions occupying less than 0.05 ha either as inter crops or strips along the edges of the farm. Though sorghum is grown in small farm portions by small scale farmers, the crop is grown and used as human food by millions of people in Africa and India (Agrama and Tunistra, 2003).

5.2 Participatory identification and evaluation of sorghum landraces from eastern Kenya

The fact that Mbeere had the most landraces available with diverse colorations is an indication of a possibility of early existence of crop–wild complex of sorghum in this particular region compared to Kitui, Mutomo and Makueni. This is because research has shown that morphological diversity of sorghum in areas of origin occur (Clayton and Renvoize, 1982). Sorghum with high diversity have been reported in many sorghum growing regions of Africa, as indistinct races of *S. bicolor* that form a crop–wild complex (De Wet, 1978; Ejeta and Grenier, 2005).

Clusters of mixed landraces appeared to occur in different ecological zones while others were well spread across the region (Appendix 7). A wide range of sorghum landraces are cultivated under diverse agro-climatic conditions in Africa (Mutegi *et al.,* 2010) and lower eastern Kenya is not an exception in view of the wide spread of variation across the different climatic zones in this study is therefore expected in landraces of cultivated sorghum. Other studies have reported variations in sorghum landraces in many regions of origin (Tesso *et al.,* 2008; Mutegi *et al.,* 2010).

The color of the grain varied considerably within the sorghum landraces obtained (Table 4.4). The variation within an accession indicated mixtures of materials planted by the farmers and possibility of geneflow. It has been reported elsewhere that farmers grow a mixture of several sorghum landraces per field (Barnaud *et al.,* 2007). Sorghum is a self-pollinated crop but it has been observed that over time outcrossing of more than 10% occurs (Barnaud *et al*., 2008). Proportion of farmers in lower eastern Kenya using certified seed for sorghum were about 16% (Table 4.2). In Kenya, only 10% of farmers use certified seed for other crops while 90% relied on locally selected seeds including borrowing from farmer to farmer, grain purchasing from the market and keeping grains from the previous harvest for planning (KFSSG, 2008; Muui *et al.,* 2013). Seed exchange among farmers is a contributing factor to high variation among sorghum landraces in lower eastern Kenya. Seed exchange has also been reported in Tanzania and Zambia (Gwanama and Nichterlein, 1995; Nathaniels and Mwijage, 2000).

Preference of traits by farmers is driven by profits dictated by consumer preferences of the produce (Brocke *et al.,* 2010). Most families in lower eastern Kenya grow sorghum landraces which are used for making fermented and un-fermented porridge, ugali (thick porridge) and other traditional dishes (Ministry of Agriculture, 2010; Muui *et al.,* 2013). The color of the grain of landraces was related to a particular grain use (Appendix 7). Specific sorghum uses impose a positive selection pressure towards a certain trait by farmers (Tusekwa *et al.,* 2000; Manzelli *et al*., 2007). Grain color is recognized as an important consideration in cultivar selection with a greater preference for tan in Ethiopia and white in Mozambique, Zambia, and Zimbabwe as well as parts of Tanzania (Wortmann *et al.,* 2006). Red and brown grain types are preferred in Kenya, Rwanda, Uganda and Western Tanzania. Red and brown grain types are associated with higher tannin content thus preferred less by birds, and are less affected by mold (Wortmann *et al.,* 2006).

5.3 Seed quality of sorghum landraces collected from farmers

The purity of the seed samples from farmers was more than 99% which compared well with the commercial improved varieties (Appendix 8). The two samples with low pure seed were mixed up with pearl millet seeds. The impurities from other seeds in sorghum could have resulted during drying and in storage. The farmers have a tendency of drying different crop grains at the same time and storing at the same place which could result to admixtures (Armitage *et al.,* 2005).

5.3.1 Seed viability as determined by germination percentage

Seed germination is the emergence and development of the essential structures from the embryo which are indicative of the ability to produce a normal plant under favorable conditions (AOSA, 1991; Anonymous, 2002). About a quarter of the samples collected from the farmers had very low germination an indication of poor viability (Appendix 8). Seed field emergence is frequently lower than those observed in the laboratory germination (Marcos, 1999). Therefore, only seeds that attained germination percentage more than 90% have a higher probability of producing adequate seedling emergence under a relatively high variation of environmental conditions. The lower the germination in the laboratory, the poorer the performance in the field since deterioration has occurred (Khan *et al*., 2003, 2004). Loss of viability expressed by 36% of the seed samples from farmers is attributed to deterioration of the seed during pre - harvest and post - harvest seed aging. Low viability in seeds is caused by decreased membrane integrity as a result of storage deterioration (Qasim *et al.,* 2010). This fraction of seed with low germinability is significant in reducing the overall seed viability planted by farmers in this region. A study in Bomet, Kenya showed that about 29% of the total sorghum seeds planted by farmers expressed low viability (Ochieng *et al.*, 2012).

5.3.2 Seed vigor of sorghum landraces determined by speed of germination and seedling growth rate

The speed of germination time is done on the premise that, seeds high in vigor would have more seedlings emerge within the first few days after sowing compared to the seeds that are low in vigor (Miloševic, 2010). In this study, 62.5% of the seeds germinated in less than 2.9 days and was considered to be of high vigor. The assumption was that since all good quality seed samples from commercial varieties (Seredo, Serena, KARI mutama 1 and Gaddam) took less than three days to germinate, any seed lot that took more than three days to germinate was considered to be of low vigour.

The low vigor (more than three days) expressed by 37.5% of the seed samples indicated by the speed of germination test is due to inhibition of the proper functioning of the membranes or the membrane bound proteins (Copeland and McDonald, 1995). This resulted in the slow germination of seedlings in the first two days of the test. A study on sorghum seeds from farmers in Bomet, Kenya recorded 36.3% having a mean germination time of more than two days (Ochieng *et al.,* 2012).

Leaf length, leaf area and the root length was high and varied greatly between the seed accessions (Appendix 8). High leaf area and leaf length is associated with fast growth rate an indication of high vigor in plants (Grotkopp *et al.,* 2002; Lake and Leishman, 2004; Hamilton *et al.,* 2005; Leishman and Thomson, 2005). This allows higher capture of solar energy for use in photosynthesis which increases dry matter accumalation (Davis *et al.,* 2000; Blumenthal, 2005; Burns, 2004, 2006; Leishman and Thomson, 2005). Further, well developed roots allow a plant to anchor, and absorb water and nutrients from the surrounding soil associated to low precipitation (Mokany *et al.,* 2006). The well developed root system of seedlings in this study shows the ability of the plants to maximize moisture available in the soil and produce even under low moisture levels (Blum, 2011). These results (Appendix 8) also showed that, landraces with high leaf length, leaf area, long root and shoot length had a high growth rate per day. The results from this study show that germination percentage of a seed sample is highly related to the seedling performance in the field. Seed samples that had very low germination percentage had very low vigor (Appendix 8). Majority of the landraces are well adapted to the dry and hot environments while those that had low vigor were as a result of seed deterioration.

5.3.3 Seed borne pathogens on farmer-saved sorghum seeds from lower eastern Kenya

The widespread seed infestation implies the seeds were colonized during storage and is responsible for reducing plant population by 42% in the field. The consequence of such infestation is not only limited to reduction in plant population and hence yield losses, but also accounts for the build-up of mycotoxins in infected grains (Fakir, 1999; Islam *et al.,* 2009). The pathogen infestation in seeds in this study could have contributed to low vigor and viability attained in some accessions. Seed-borne pathogens have been reported to cause deterioration in seed quality during storage not only lowering seed germination, but also reducing seed vigor resulting (Abdulsalaam and Shenge, 2011).

5.4 Morphological Characters of sorghum landraces collected from farmers in lower eastern Kenya

5.4.1 Qualitative characteristics of the 44 sorghum landraces

Variations were observed for leaf color in the evaluated sorghum accessions from Mbeere, Kitui, Mutomo and Makueni where in most of the sorghum genotypes, dark green leaves were common while some of the genotypes had light green leaves. Results obtained on 400 sorghum accessions from Pakistan showed that majority of the landraces evaluated had dark green leaves (Elangovan *et al.,* 2007). Leaf midrib color among the sorghum genotypes displayed ample variation. Four different colors were observed for midrib ranging from brown, dark brown, light green and purple. Such variation was reported on accessions from Pakistan where the midrib color varied from white, light yellow, yellow, light green and dark green (Durrishahwar *et al.*, 2012).

Majority of the accessions in this study had compact and semi compact panicles compared to those that had semi loose and loose. The accessions also showed three different glume colors with brown (48%) and dark brown (40%) more prevalent. A wider variation was reported on 157 landraces evaluated in Karnataka, India but majority had more brown glumes (Elangovan *et al.*, 2007).

In this study, there were more accessions without awns compared to those that had awns. Absence of awns in sorghum is associated with the ability to reduce evapo-transpiration in dry lowland areas (Ayana and Bekele, 1998). On the other hand, the presence of awns may reduce bird damage, as reported in rice (Richards, 1986). Sorghum landraces are consistent for morphological characters and in most cases they are used by farmers in naming the landraces (Teshome *et al.*, 1997; Kudadjie, 2006). Audilakshmi *et al* (1999) evaluated twenty two sorghum genotypes for grain mould response and observed that harder grain, higher levels of seed phenols and darker glumes contributed to grain mould resistance. The variability of glume color in this study may be utilized for screening for moulds resistance in sorghum.

5.4.2 Quantitative characteristics of the sorghum accessions

Majority of the seeds emerged within 3–10 days which is the expected range under optimum conditions (Appendix 11-18). Seedling vigor in the four locations was in the same range though there was a great variation in the number of accessions per rating between the locations. Similar variation was observed in seedling vigor of the same seed carried out in the laboratory and in the green house before planting in the field. Landraces exhibited variations in number of leaves, length and width which determine how much a plant can manufacture its own food. The higher the number of leaves and more leaf area the more the amount of light intercepted. By the time panicle initiation takes place, total number of leaves (7–24) is realized and about one-third of total leaf area has developed (Balole and Legwaila, 2006).

A wide range of plant height was observed between the accessions ranging between 14 cm - 253.7 cm. In eastern Kenya, farmers were not keen on plant height unlike in Ghana where farmers preferred tall stalks for fencing and roofing (Kudadjie *et al.*, 2007). The overall stem thickness of the sorghum plants ranged from 1.2 cm to 8.8 cm. Stem thickness ranging from 1 - 2.9 cm was reported in Karnataka, India (Elangovan *et al*., 2007). Stem thickness is attributed to the strength of the plant in terms of capability to withstand lodging, support the panicle and mass translocation of nutrients.

Flowering is largely determined by prevailing temperature and it occurs soon after panicle emergence (booting stage). Number of days to 50% flowering ranged from 40 to 108 days across the four locations. Kudadjie *et al* (2007) broadly grouped sorghum accessions into three main categories as very early (less than 85 days), medium (86 - 105 days) and late (more than 105 days). In this study, 37.5% (18 accessions) of the accessions was considered early, 60.4% (29 accessions) as medium and 2.1% (1 accession) as late.

In the baseline survey conducted in eastern Kenya, farmers indicated that they preferred sorghum crop that matures within a short period to escape drought and to ease the food shortage. Also, it was reported that farmers in Ghana prefer a crop that matures early since they have only one planting season (Kudadjie *et al*., 2007). However, in Bomet Kenya, majority of sorghum farmers were reported to prefer late maturing sorghum (more than 180 DAS). This is because they plant the crop same time as maize and therefore would escape bird predation if the maturity is prolonged (Ochieng *et al.,* 2011).

The large difference in quantitative characters between the two seasons and between the four locations is attributed to the differences in rainfall recorded in the growing seasons. Water demand is high for plants at germination, booting and flowering compared to during grain filling and ripening. Dry spells at the beginning and during the growing season are usually detrimental on sorghum and millet crops (Kudadjie *et al.,* 2007). The large difference between the two seasons is attributed to differences in rainfall figures recorded (Table 3.3). For all traits evaluated in the 48 accessions, variations were observed between the accessions and between the different growing locations. In a study in Ethiopia, results obtained on traits were used to classify sorghum landraces (Teshome *et al.,* 1997). The high variation exhibited by traits indicated the potentiality of landraces as breeding materials (Tulole, 2009).

5.5 Selection of landraces showing superior traits across the four locations

The four landraces and one commercial variety selected for quality traits in the four locations could be promoted for use by the farmers across the region due to the superior performance.

There is limited contribution to agricultural research by small scale farmers (Farnworth *et al*., 2003). Yet, farmer participation could help research to become better focused on the actual problem (Gibbon, 2002; Röling *et al.*, 2004). Farmers also carry out their own research, do experiments and possess valuable knowledge on the landraces; and decide what to select (Eyzaguirre and Iwanaga, 1996; De Boef and Almekinders, 2000; FAO, 2004). Approaches such as participatory plant breeding (PBB) and participatory variety selection (PVS) could place more emphasis on the technical aspects of breeding (McGuire *et al*., 1999; Weltzien *et al.*, 2000).

5.6 Genetic variability of sorghum landraces based on simple sequence repeats (SSRs) markers

The genetic diversity among the sorghum accessions used in this study was high as indicated by polymorphic information content (PIC) and gene diversity values (Table 4.9). The PIC of a SSR marker gives an idea about the discriminatory power of that marker by taking into account the number of alleles detected and their relative frequencies (Smith *et al*., 2000). Markers with PIC more than 0.5 are efficient in discriminating genotypes and extremely useful in detecting the polymorphism rate at a particular locus (DeWoody *et al*., 1995).

Sorghum is primarily an inbreeding species resulting in a low level of observed heterozygosity, but the gene pool as a whole maintains a high level of allelic variation. The high level of allelic variability but low level of heterozygosity observed in this study agrees with findings on diversity analysis of Eritrean sorghum landraces with SSR markers (Ghebru *et al*., 2002). The low heterozygosity was a clear indication the genotypes were homozygous and thus a high level of stability in the population.

Genetic distances among the 48 genotypes varied greatly indicating a wide diversity (Table 4.9). Genotype Karuge 2 and Karuge 1 both from Mbeere (Kiritiri) had a low genetic distance (0.15). Though the seed color and geographical location of the two accessions was identical, the two are totally different genetically. The results in this study suggest that diversity of the landraces were structured more on geographical locations and on seed colorations than agro-ecological conditions. Reports of other studies in sorghum accessions have shown grouping primarily on the basis of origin, and clustering within groups as driven by racial classification (Hash *et al*., 2007; Sharma *et al.*, 2010). The main evolutionary forces responsible for producing genetic structure in plant populations are gene flow, selection associated with environmental heterogeneity and/or farmer preferences and random genetic drift (Hart and Clark, 1997; Neal, 2004).

The clustering of the landraces based on geographical locations was distinct with some overlaps where genotypes cut across the locations. Such intraregional genetic proximity in sorghum landraces would arise through seed exchanges among farmers. This was reported in the baseline survey conducted in sorghum seed systems in eastern Kenya which were found to be largely traditional, with farmers playing a major role in the selection and exchange of seeds (Muui *et al.*, 2013). A study conducted on sorghum production systems in Bomet, Kenya, indicated that farmers played a great role in seed selection, exchange and movement (Ochieng *et al.*, 2011).

The similarity in genotypes could be attributed to proximity of the regions though Mbeere appeared to be unique in the color of the seeds. Other studies showed that similarities in genotypes was as a result of region proximity in Africa for cultivated sorghum (Ayana *et al*., 2000b; Ghebru *et al*., 2002; Nkongolo and Nsapato, 2003; Deu *et al.*, 2008) and its wild relatives (Ayana *et al.*, 2000a). Results in this study showed that Mbeere had unique cluster. A study in Turkana and north-eastern Kenya showed that cultivated sorghum was clustered into a distinct and unique genetic group (Mutegi *et al*., 2010). This is attributed to the fact that Mbeere is relatively geographically remote from other sorghum growing regions. The gene pools from sorghum landraces tested in this study appear to be genetically distinct. A study conducted in Turkana and North eastern regions of Kenya on cultivated sorghum showed unique genetic clusters based on regions (Mutegi *et al.*, 2010).

Analysis of Molecular variation (AMOVA) indicated higher variation within populations than among the groups. Estimates of fixation indices revealed a strong genetic structure between commercial and Mbeere-Ishiara genotypes and between Mbeere-Ishiara and Kitui central genotypes. The presence of strong genetic structure indicates that these two groups are reproductively and genetically isolated from each other.

5.7 Influence of post-harvest handling methods on farm saved seed quality

5.7.1 Effect of different panicle sections on seed viability and vigor in sorghum

Germination of seed obtained from three different panicle sections varied greatly (Table 4.12). The whole panicle comprises of seeds that matured at different times which affected the overall viability of the seeds. Seed from the upper (top) third part had very low germination (less than 70%) an indication of poor viability. This is attributed to the fact that anthesis proceeds downwards in a sequential manner (ICRISAT, 1997; Balole and Legwaila, 2005). This implies that seed at the upper section matures earlier and are exposed to the environment vagaries much longer than the seeds on the lower section. This prolonged exposure results to seed deterioration over time lowering seed viability. Seeds high in vigor are assumed to have more seedlings emerging within the first few days after sowing. The mean germination time of seeds from lower third section of panicle germinated within the shortest time. Seed vigor precedes seed viability (Agrawal, 1986). From this study, seed that had a low germination percentage germinated within the longest mean germination time. Again, the seed that attained the highest viability had the highest vigor as indicated by mean germination time.

Seed performance which is determined during seed development is associated with seed position, which is determined by position of the ovules within the fruit and fruit positions on the mother plant (Muasya, 2001, K'Opondo, 2011). Each crop and plant species undergoes characteristic changes leading to seed ripening, which must be known to establish the best time to harvest when quality is at maximum (Muasya, 2001). As soon as seeds mature on the mother plant, they begin to deteriorate but the rate at which deterioration takes place depends on the environmental conditions at that particular period. Seed deterioration eventually leads to loss of viability and vigor or death when the seed is not able to germinate (Thomsen and Stubsgaard, 1998).

5.7.2 Effect of different storage containers and duration on seed viability in sorghum

Type of storage facility and the duration the seed was stored affected seed viability. Airtight storage control pests and prevents the seed from re-absorbing moisture from air. Storing seeds in the containers that were not air tight resulted in significantly higher moisture content increase than in closed storage. This moisture increase reduces the longevity of seeds since it is generally known that every 1% increase in seed moisture content reduces the storage period by half (Wambugu *et al.,* 2009). In other related studies, freshly stored seeds were reported to have the highest germination which reduced with increase in storage time in sorghum (Adam, 2010). The low germination percentage of the older seed is attributed to seed deterioration during storage known to occur due to impairment of specific biological or physiological functions (Aschermann-Koch *et al.,* 1992). Seeds undergo deterioration during storage regardless of storage environment or storage materials (Mettananda *et al.*, 2001; Adetumbi *et al.*, 2009). However, the rate of deterioration depends largely on storage temperature, moisture and storage duration (Copeland and McDonald, 2001).

Loss of seed viability in storage is mainly a function of temperature and seed moisture content resulting to seed ageing (McDonald, 1999; 2004). Seed ageing is caused by lipid peroxidation, inactivation of enzymes, decrease in proteins and disintegration of cell membranes (McDonald, 1999; Murthy *et al.*, 2003). The decrease in enzyme activity in the seed lowers the respiratory capacity, which in turn lowers both the energy (ATP) and assimilates supply of the germinating seed (Goel *et al.*, 2002; Bailly, 2004; McDonald, 2004; Lehner *et al.*, 2008). During storage, degradation products of thermo-labile lipid per-oxidation accumulate in the ageing seeds, finally resulting in complete loss of seed viability (Rao *et al.*, 2006).

Vigor of seed reduces with increase in storage period (Adam, 2010). Such results are attributed to deterioration with age as reported in pearl millet (Nauliyal *et al.*, 1988). Low viability and vigor attained with increase in storage duration, was caused by oxygen depletion leading to embryo death especially in metallic tins, gourds and earthen vessels (Krishnamurthy *et al.*, 1990).

The low viability and vigor in gunny bags and woven baskets is attributed to increase in moisture content from the surrounding environment. Moisture content of seeds is an important factor determining seed longevity during storage (Qaisrani, 2000). Most seeds are hygroscopic, and tendency of absorbing environmental moisture during storage is high (Copeland and McDonald, 1995). Seeds that have initially attained a safe moisture level during drying may absorb environmental moisture and loose quality during storage. Farmers store on-farm saved seed under various conditions such as granaries, bags, pots, baskets and gourds. Therefore, storage conditions which maintain seeds moisture content close to that of the newly harvested seed provide better storage.

5.7.3 Influence of sun drying sorghum seed at different time of the day and duration on seed quality

Sun drying seeds has been reported to greatly affect seedling radicle length, seedling dry weight and speed of germination (Babiker *et al.,* 2010). High temperature and ultraviolet radiation from the sun accelerate respiration rate and impose stress to the seed causing ageing which adversely reduce the stored food for use in germination and vigor. Seed ageing is caused by lipid peroxidation by free radicals, inactivation of enzymes, decrease in proteins, disintegration of cell membranes and genetic change (McDonald, 1999; Murthy *et al.,* 2003). The inactivation of enzymes lowers the respiratory capacity, which in turn lowers both the energy (ATP) and assimilates supply of the germinating seed (McDonald, 2004; Lehner *et al.*, 2008).

Seed drier gave the highest seed viability indicating that they ensure high initial quality of the seeds at start of storage (Babiker *et al.,* 2010). Artificial drying methods are efficient in removal of large amounts of moisture and hence commonly used (Carvalho, 1994). These methods afford the maintenance of seed quality, when conducted under technical criteria that define exposure times and temperatures (Ahrens *et al.,* 2000). The main advantages of the artificial method are to allow the control of the temperature, the drying air flux, and the exposure time of the seeds to the heated air, fundamental factors to assure the efficiency of the process (Cavarini *et al*., 1998).

Viability and vigor of seed is reduced during drying when the seed suffer serious mechanical damage. This results when the body alignment along the plasma membrane are affected during drying (Cordova-Tellez and Burris, 2002). Seed moisture content and drying temperature are important factors to consider in relation to seed storability and survival. Seed drying in the sun or in the air often experience moisture percentage fluctuation as a result of change in temperature and humidity of the natural environment (Ng, 1996; Franke *et al.*, 2008).

Overheating occurs when sun drying seeds, especially while the seeds are still having high moisture content. High temperature and ultraviolet radiation through direct sunlight, together with high moisture content may accelerate respiration and impose stress to the seed, thereby bringing about ageing, thus adversely affecting germinability, and may even kill the seed (Desai *et al.*, 1997; Thomsen and Stubsgaard, 1998). Overheating also causes seed breakage, bleaching, scorching, and discoloration, damage to seed coat and loss of nutritional quality (Desai *et al.*, 1997).

The relative humidity recorded over the eight weeks the seed was dried was high but remained near constant with minimal fluctuations. The assumption in this study could be that relative humidity had no effect on viability and vigor. This is because there was a significant effect on seed quality between the time of day and number of weeks the seed was dried. Low viability and vigor in seed dried the whole day is attributed to the drastic temperature changes recorded (Franke *et al.*, 2008).

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

- Farmers in the eastern parts of Kenya maintain sorghum landraces unique in their adaptation, biotic stress resistance, food quality and grain yield.
- Education level is low and there is lack of exposure of farmers to current technologies contributing to poor crop management practices which result to poverty and recurrent food shortages.
- Sorghum seeds used by farmers to plant their crop are of poor quality in relation to germination and vigor. This proportion of seed with inadequate quality does not only represent a risk for loss of valuable genotypes but can also lead to poor crop yield in the future when seeds of such inferior quality continue to be regenerated.
- Majority of the seed samples had at least one known pathogen responsible for reducing plant population resulting to low yields. Pathogen infestations mainly occur in storage and could be reduced by proper drying and storage of the seeds after harvesting.
- Landraces maintained by farmers has variable diversity in morphological characters and genetic makeup.
- Out of the landraces obtained from farmers, four perfomed best in the four locations and were selected by farmers for quality traits.
- Viability and vigor of seed positioned on the lower part of panicle was higher than seed from upper, mid part and from whole panicle.

- Gourd and earthen vessels were better storage materials than gunny bags, metallic tins and basket.
- Seed dried from 9.00 am – 12.00 noon and from 3.00 pm – 6.00 pm recorded higher viability and vigor.

6.2 Recommendations

- Since the region has a high agricultural potential, productivity for better food security and income could be improved by use of locally available germplasm adapted to this particular environment.
- There is need to create awareness to farmers on the importance of proper crop management and handling at farm level which can be achieved by working with farmers in demonstration farms and holding farmer field days to enhance quality of seed.
- High genetic diversity in sorghum landraces could be conserved and used in crop improvement.
- Gatengu which was collected in Kiritiri, Mbeere, brown white from Mutomo, brown white from Kitui central and brown from Kiboko in Makueni could be promoted for use by farmers across the region due to their high yields and tolerance to pests and diseases.
- Farmers in lower eastern Kenya could improve quality of farm saved sorghum seed by using seed from the lower part of panicle; storing seed in gourds and earthen vessels; and drying seed before noon and late in the evening.

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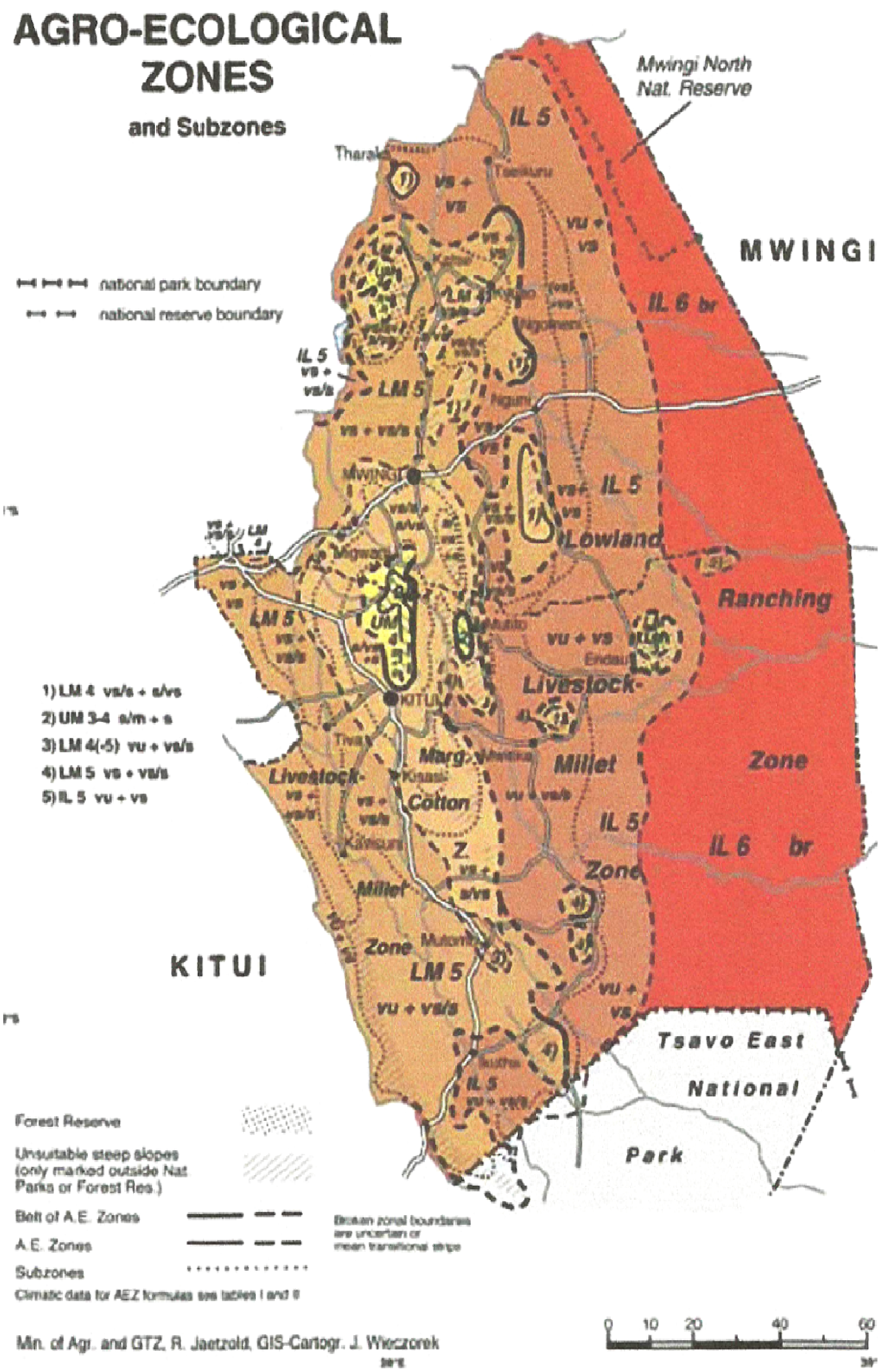
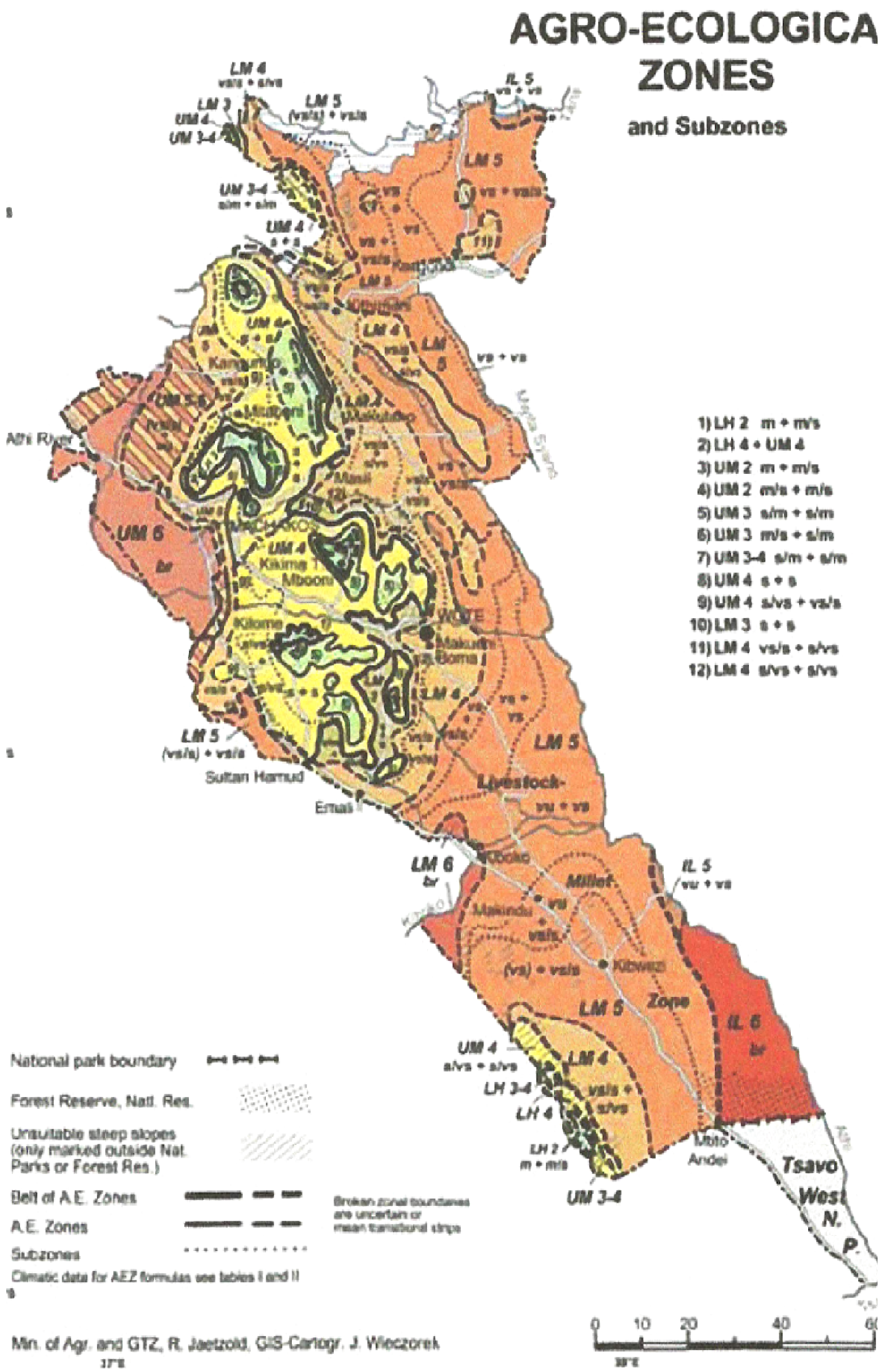
APPEDICES

Appendix 1: Agro-ecological zones for Kitui region indicating Mutomo, Kitui central and Kitui west



Appendix 2: Agroecological zones for Makueni indicating Kiboko, Makindu and Kibwezi



Appendix 3: Agro-ecological zones for Mbeere indicating Siakago, Ishiara and Kiritiri

Appendix 4: Questionnaire

1. Personal details(a) Name of interviewee..................... (b) Age.......................

(c) Gender............ (d) Education level............. (e) Occupation......................

2. Location details: District............................... Location..............................

Sub location....................... Nearest market/town..................................

3. How big is your farm?..(acres)

4. Do you grow sorghum?...

5. If Yes, which varieties (indicate landraces or hybrid).....................................

6. Which other crops do you grow in your farm?...

7. Which cropping system do you use?..

8. (a) Do you use organic or inorganic fertilizer for planting or none?................

(b) If organic fertilizer is used, where is it obtained from?............................

(c) Do you use other inputs?..

(d) If yes, which ones?..

9. Where do you get sorghum seeds for planting?..

10. (a) Do you separate seed crop from grain crop?..

(b) If yes, how do you manage the crop?..

11. How long does sorghum crop take to mature?..

12. How do you harvest the seed crop?...

13. How do you store your seed after harvesting?...

14. for how long do you store the seed before planting......................................

15. For what purpose do you plant sorghum crop?...

16. Which traits do you like in the sorghum variety that you grow?...................

17. Which are the constraints faced in sorghum production?..............................

Appendix 5: Sample size standazation table

Required Sample Size†

Population Size	Confidence = 95%				Confidence = 99%			
	Margin of Error				Margin of Error			
	5.0%	3.5%	2.5%	1.0%	5.0%	3.5%	2.5%	1.0%
10	10	10	10	10	10	10	10	10
20	19	20	20	20	19	20	20	20
30	28	29	29	30	29	29	30	30
50	44	47	48	50	47	48	49	50
75	63	69	72	74	67	71	73	75
100	80	89	94	99	87	93	96	99
150	108	126	137	148	122	135	142	149
200	132	160	177	196	154	174	186	198
250	152	190	215	244	182	211	229	246
300	169	217	251	291	207	246	270	295
400	196	265	318	384	250	309	348	391
500	217	306	377	475	285	365	421	485
600	234	340	432	565	315	416	490	579
700	248	370	481	653	341	462	554	672
800	260	396	526	739	363	503	615	763
1,000	278	440	606	906	399	575	727	943
1,200	291	474	674	1067	427	636	827	1119
1,500	306	515	759	1297	460	712	959	1376
2,000	322	563	869	1655	498	808	1141	1785
2,500	333	597	952	1984	524	879	1288	2173
3,500	346	641	1068	2565	558	977	1510	2890
5,000	357	678	1176	3288	586	1066	1734	3842
7,500	365	710	1275	4211	610	1147	1960	5165
10,000	370	727	1332	4899	622	1193	2098	6239
25,000	378	760	1448	6939	646	1285	2399	9972
50,000	381	772	1491	8056	655	1318	2520	12455
75,000	382	776	1506	8514	658	1330	2563	13583
100,000	383	778	1513	8762	659	1336	2585	14227
250,000	384	782	1527	9248	662	1347	2626	15555
500,000	384	783	1532	9423	663	1350	2640	16055
1,000,000	384	783	1534	9512	663	1352	2647	16317
2,500,000	384	784	1536	9567	663	1353	2651	16478
10,000,000	384	784	1536	9594	663	1354	2653	16560
100,000,000	384	784	1537	9603	663	1354	2654	16584
300,000,000	384	784	1537	9603	663	1354	2654	16586

Appendix 6: Frequency occurrence based on color of different landraces collected from the study districts in eastern Kenya

Landrace	Seed color code	Kitui	Mutomo	Makueni	Mbeere	Total
White	N/A	2	1	1	1	**5**
Dirty white	5RP 8/2	1	0	1	0	**2**
Brown white	2.5 YR 7/4	0	1	0	0	**5**
	10 R 7/4	1	0	0	0	
	7.5 YR 7/4	0	0	1	0	
	2.5 Y 8/4	0	0	1	0	
	5 YR 6/6	1	0	0	0	
Brown	2.5 YR 7/6	0	1	1	0	**7**
	5 YR 7/4	2	0	1	0	
	5 YR 6/6	1	0	0	0	
	7.5 YR 8/4	0	0	1	0	
Dark brown	5 YR 5/6	1	0	0	0	**1**
Brown red	5 R 6/8;7/4	1	0	0	0	**1**
Red	5 R 7/8	3	0	2	0	**8**
	2.5 YR 7/8	0	0	1	0	
	5 R 4/6	0	0	0	1	

	5 R 5/6	0	0	0	1	
Black red	10 R 3/4	0	1	0	0	**1**
Purple	5 RP 5/2	0	0	0	1	**4**
	5 RP 6/2	0	0	0	3	
Purple pink	5 RP 5/2	0	0	0	1	**4**
	5 RP 6/2	0	0	0	1	
	5 R 6/4	0	0	0	1	
	5 RP 7/2	0	0	0	1	
Cream pink	5 RP 8/2	0	0	0	1	**1**
Pink brown	10 R 6/4	0	0	0	1	**2**
	2.5 YR 6/4	0	0	0	1	
Mixture of purple, pink,white	5 R 6/2	0	0	0	1	**2**
	5 RP 7/2	0	0	0	1	
Mixture of purple, pink, white, brown	5 R 6/2;7/2	0	0	0	1	**1**
TOTAL		**12**	**4**	**11**	**17**	**44**

Appendix 7: Preferred traits and grain use of landraces grown by farmers in different agro-ecological zones in the study districts

			Traits preferred by farmers								Grain use					
Color/name	Source	AEZ	DR	PR	BR	EM	GT	HY	Vig	EC	Fer	Por	Ug	Pil	Mu	Bak
White mweruba	kw	LM_4	-	-	-	+	+	-	-	-	-	+	+	+	+	+
White	kw	LM_5	-	-	-	+	+	-	+	+	-	+	+	+	+	+
Whitebrown	kw	LM_4	+	+	-	+	+	+	+	+	-	+	-	-	+	+
Brown 1	kw	LM_4	+	+	+	+	-	+	+	+	-	+	-	-	+	+
Brown 2	kw	LM_5	+	+	+	+	-	+	+	+	-	+	+	-	+	+
Brown 3	kw	LM_5	+	+	+	+	-	+	+	+	-	+	+	-	+	+
Brown	kc	LM_3	+	+	+	+	-	+	+	+	-	+	+	-	+	+
Red 1	kc	LM_3	+	+	+	+	-	+	+	+	+	+	-	-	+	-
White	kc	LM_3	+	-	-	+	+	+	+	+	-	+	+	+	+	+
Brownwhite 1	kc	LM_3	+	+	-	+	+	+	+	+	+	+	+	+	+	+
Brownwhite 2	kc	LM_3	+	+	-	+	+	+	+	+	+	+	+	+	+	+
Red 2	kc	LM_3	+	+	+	+	-	+	+	+	+	+	-	-	+	-
Brownred	kc	LM_3	+	+	+	+	-	+	+	+	+	+	-	-	+	-
Blackred	mu	LM_4	+	+	+	+	-	+	+	+	+	-	-	-	+	-
Brownwhite	mu	LM_4	+	+	-	+	+	+	+	+	+	+	+	+	+	+

Brown	mu	LM_5	+	+	+	+	-	+	+	+	-	+	-	-	+	+
White	mu	LM_5	+	-	-	+	+	-	+	+	-	+	+	+	+	+
Creampink gatengu	mb k	LM_4	+	+	-	+	+	+	+	+	+	+	+	+	-	+
Purple	mb k	LM_4	+	+	+	+	-	+	-	+	-	-	-	-	+	-
Pinkbrown mwitia	mb k	LM_4	+	+	+	+	-	+	+	+	-	+	-	-	+	-
maroon ciakiondo	mb k	LM_4	+	+	+	-	-	+	-	+	+	-	-	-	+	-
Purple karuge 1	mb k	LM_4	+	+	+	-	-	+	-	+	+	-	-	-	+	-
Purple karuge 2	mb k	LM_4	+	+	+	-	-	+	-	+	+	-	-	-	+	-
Purplepink local B	mb k	LM_4	+	+	+	+	-	+	+	+	+	-	-	-	+	-
Purplepink local A	mb k	LM_4	+	+	+	+	-	+	+	+	+	-	-	-	+	-
Purple thiriku	mb k	LM_4	+	+	+	+	-	+	-	+	+	-	-	-	+	-
Purple mubaku	mb k	LM_4	+	+	+	-	-	+	-	+	+	-	-	-	+	-
Purple thiriku 2	mb k	LM_4	+	+	+	+	-	+	-	+	+	-	-	-	+	-
Pink brown muthiriku	mb k	LM_4	+	+	+	+	-	+	+	+	+	-	-	-	+	-
White	mb s	LM_3	-	-	-	+	+	+	+	+	-	+	+	+	-	+
Pinkpurple thiriku	mb s	LM_3	+	+	+	+	-	+	+	+	+	-	-	-	+	-
Purple	mb s	LM_3	+	+	+	+	-	+	-	+	-	-	-	-	+	-
Redbrown	mb s	LM_3	+	+	+	+	-	+	+	+	+	+	-	-	+	-

Red	mb i	LM_4	+	+	+	+	-	+	+	+	+	+	-	-	+	-
White	mb i	LM_4	-	-	-	+	+	+	+	+	-	+	+	+	-	+
White	m ma	LM_5	-	-	-	+	+	-	+	+	-	+	+	+	-	+
Red	m ma	LM_5	+	+	+	+	-	+	+	+	+	+	-	-	+	-
Brown	m ma	LM_5	+	+	+	+	-	+	+	+	-	+	-	-	+	+
Brown	m kz	LM_5	+	+	+	+	-	+	+	+	-	+	-	-	+	+
Red	m kz	LM_5	+	+	+	+	-	+	+	+	+	+	-	-	+	-
Brownwhite	m kz	LM_5	+	+	-	+	+	+	+	+	+	+	+	+	+	+
White	m kib	LM_6	-	-	-	+	+	-	+	+	-	+	+	+	-	+
Red	m kib	LM_5	+	+	+	+	-	+	+	+	+	+	-	-	+	-
Brown	m kib	LM_6	+	+	+	+	-	+	+	+	-	+	-	-	+	+

AEZ= Agro Ecological Zone DR= drought resistance PR= pest resistance BR= bird resistance EM= early maturity GT= good taste HY= high yield Vig= vigour EC= ease of cleaning + = preferred - = not preferred kw= kitui west kc= kitui central mu= mutomo mb k= mbeere kiritiri mb s= mbeere siakago mb i= mbeere ishiara m ma= makueni makindu m kz= makueni kibwezi m kib= makueni kiboko Fer= fermentation Por= porridge Ug= ugali Pil= pilau Mu= muthura (traditional dish) Bak= baking

Appendix 8: Pure seed, germination, germination speed and seedling growth rate of the 48 sorghum accessions

Acc.	Purity(%)	Germination(%)	germination speed (days)	Leaf length (mm)	leaf area (mm^2)	Root length (mm)	Shoot length (mm)	Growth rate(mg/day)
1	100.0	81	2.282	20.70	62.30	65.50	42.35	2.51
2	99.9	87	2.368	25.65	55.90	64.85	47.60	3.38
3	100.0	87	2.263	24.50	58.60	65.45	45.30	2.97
4	100.0	95	2.222	19.00	56.00	57.70	40.95	3.81
5	100.0	76	2.755	13.40	42.95	49.75	32.15	3.13
6	100.0	94	2.198	26.30	60.40	65.70	47.80	3.61
7	100.0	94	2.789	25.85	59.75	63.70	46.30	3.14
8	100.0	95	2.139	25.90	59.95	69.90	47.75	2.63
9	72.2	94	2.873	24.35	64.80	62.65	45.45	3.50
10	100.0	91	2.831	25.20	60.40	71.05	45.90	3.18
11	99.8	93	2.679	25.35	59.95	59.65	47.15	3.27
12	100.0	94	2.694	16.20	53.50	57.20	36.80	3.44
13	100.0	92	3.455	25.30	55.90	58.05	47.10	3.19
14	100.0	97	2.301	20.75	61.40	61.30	42.40	3.71
15	99.8	11	3.282	3.00	8.00	3.00	2.00	1.47
16	99.4	57	4.935	9.55	17.10	23.95	13.05	3.51
17	99.6	93	2.309	19.15	60.25	58.50	41.20	2.97
18	100.0	95	3.125	21.55	66.10	66.85	43.05	2.56
19	99.9	95	3.496	21.05	63.35	61.80	41.60	3.06
20	72.2	92	2.309	24.10	59.85	60.35	45.75	3.44
21	100.0	80	2.258	21.90	57.70	57.10	43.00	3.41
22	99.0	72	4.482	18.50	48.85	57.10	39.45	3.94
23	100.0	78	3.196	19.60	59.25	58.90	41.15	1.00
24	99.3	68	3.489	18.20	47.10	55.80	39.65	2.75

25	100.0	62	2.581	17.80	56.45	58.65	39.05	3.63
26	100.0	90	3.549	23.85	56.55	62.50	45.85	2.78
27	99.8	93	2.445	20.10	60.25	62.20	41.60	3.22
28	99.9	95	2.905	20.25	65.30	60.05	40.90	3.06
29	100.0	95	2.618	16.20	53.50	57.20	37.85	3.03
30	99.8	7	3.519	11.80	47.90	42.25	29.35	3.00
31	100.0	91	5.286	20.40	58.85	71.25	41.20	3.28
32	100.0	80	2.538	17.85	53.85	53.60	39.60	3.78
33	100.0	95	4.224	25.05	57.75	59.10	46.55	3.81
34	99.4	73	3.060	18.55	47.90	55.55	39.00	2.78
35	99.9	90	2.522	23.95	64.95	69.65	45.80	4.16
36	99.8	94	3.349	25.55	59.50	70.90	46.65	3.50
37	100.0	82	2.255	20.85	61.95	61.75	41.80	3.34
38	100.0	96	2.396	21.40	64.85	67.70	43.20	3.31
39	100.0	95	3.354	26.00	60.40	69.20	46.60	2.88
40	100.0	97	2.098	19.10	56.50	55.80	40.90	4.21
41	100.0	94	2.282	23.50	55.15	58.00	45.15	3.28
42	100.0	84	2.846	19.80	60.00	62.35	41.35	3.19
43	99.7	98	2.548	21.35	61.95	64.60	43.10	2.46
44	99.8	12	2.262	5.10	12.80	33.00	25.30	2.75
45	100.0	79	3.594	18.40	44.40	50.80	33.15	3.98
46	99.8	6	3.164	22.55	57.80	63.65	43.35	4.06
47	100.0	95	2.519	22.20	59.75	63.80	43.95	3.34
48	99.8	68	5.257	18.00	48.50	50.10	38.50	3.28
LSD		5	0.325	1.23	3.29	3.08	3.81	0.812
CV%		4	7.9	9.6	9.1	8.3	4.8	4.3

*growth rate (gm/day) 10^{-4} ; ACC. – accession

Appendix 9: Mean percentages of infected seeds per accession in the 48 sorghum genotypes by five pathogens

Accession	*Fusarium spp.*	*Aspergillus niger*	*Aspergillus favurs*	*Pencillium spp.*	*Rhizorpus spp.*
1	0	0	0	75	0
2	10	0	0	0	0
3	0	0	0	0	0
4	0	5	0	0	0
5	50	0	10	0	0
6	5	0	0	0	0
7	5	0	0	0	0
8	90	0	5	0	0
9	0	0	0	20	5
10	5	0	0	0	5
11	5	5	0	0	0
12	10	0	0	0	5
13	25	0	0	0	0
14	10	0	0	5	0
15	0	10	10	0	0
16	0	0	0	0	5
17	5	0	0	0	5
18	0	0	0	0	5
19	35	20	0	0	0
20	0	0	0	0	0
21	0	5	0	0	5
22	0	0	15	0	0
23	5	30	0	0	0
24	75	0	0	0	0
25	0	5	5	35	0

26	15	0	0	0	5
27	35	5	5	0	0
28	15	0	0	0	0
29	0	0	0	0	0
30	5	0	25	0	0
31	25	10	0	0	0
32	5	0	0	25	0
33	20	0	0	45	0
34	5	0	5	0	0
35	0	0	0	0	0
36	5	0	0	0	0
37	65	0	0	0	5
38	15	0	0	15	0
39	15	0	0	10	0
40	10	0	0	0	5
41	0	0	0	0	0
42	5	0	0	0	0
43	0	0	0	0	5
44	5	0	0	0	0
45	0	0	0	10	0
46	0	20	10	0	0
47	30	0	0	0	5
48	0	0	0	0	0
LSD	1.5996	0.701	0.7525	0.7523	0.7892
SE	0.5721	0.2507	0.2692	0.2691	0.2823
CV%	9.4	2.9	2.4	1.2	6.8

Appendix 10: Qualitative characters of 44 sorghum landraces collected from farmers in lower eastern Kenya and 4 improved varieties

Acc.	Leaf Color	Leaf Orientation	Midrib Color	Earhead Compact	Glume Color	Glume (%)	Awns	Grain Shape	Grain Size	Seed Color
1	Dark Green	Erect	Brown	Compact	Dark Brown	25	Present	Circular	Large	White
2	Dark Green	Erect	Brown	Compact	Dark Brown	25	Absent	Circular	Medium	Cream Pink
3	Dark Green	Drop	Brown	Compact	Brown	25	Absent	Elliptic	Large	Light Brown
4	Dark Green	Drop	Brown	Compact	Brown	50	Present	Elliptic	Medium	White
5	Dark Green	Drop	Dark Brown	S/Compact	Dark Brown	25	Present	Circular	Medium	Light Brown
6	Light Green	Erect	Pale Green	S/Loose	Brown	25	Present	Circular	Large	Purple
7	Dark Green	Erect	Brown	Compact	Dark Brown	25	Absent	Circular	Large	Pink Brown
8	Dark Green	Drop	Brown	Compact	Dark Brown	50	Absent	Circular	Large	Maroon
9	Light Green	Erect	Light Green	Compact	Straw	75	Absent	Circular	Medium	White
10	Dark Green	Drop	Brown	Compact	Brown	25	Absent	Elliptic	Medium	Brown
11	Dark Green	Drop	Brown	Compact	Dark Brown	25	Absent	Elliptic	Small	Purple
12	Dark Green	Erect	Light Green	S/Compact	Brown	25	Present	Circular	Medium	Cream White
13	Dark Green	Drop	Brown	Loose	Dark Brown	25	Absent	Circular	Medium	Pink
14	Dark Green	Drop	Brown	S/Loose	Dark Brown	25	Present	Circular	Large	Purple Pink
15	Dark Green	Drop	Brown	Compact	Dark Brown	25	Present	Circular	Large	Red
16	Dark Green	Drop	Brown	Loose	Black	25	Present	Circular	Large	Red
17	Light Green	Drop	Brown	S/Compact	Brown	25	Absent	Circular	Medium	Purple
18	Dark Green	Drop	Brown	Compact	Dark Brown	25	Absent	Circular	Medium	White Brown
19	Dark Green	Erect	Purple	Loose	Brown	25	Absent	Circular	Small	Black Red
20	Light Green	Erect	Light Green	Compact	Straw	25	Absent	Circular	Large	White
21	Dark Green	Drop	Brown	Compact	Dark Brown	50	Absent	Circular	Medium	Brown
22	Dark Green	Drop	Brown	Compact	Straw	50	Present	Circular	Medium	White
23	Dark Green	Drop	Brown	Compact	Brown	50	Present	Circular	Medium	Brown White
24	Dark Green	Erect	Brown	Compact	Brown	25	Absent	Circular	Medium	Brown White

25	Dark Green	Erect	Brown	S/Compact	Brown	25	Present	Circular	Small	Light Brown
26	Light Green	Erect	Light Green	S/Loose	Brown	50	Absent	Circular	Large	Purple
27	Dark Green	Erect	Brown	Compact	Black	50	Absent	Circular	Medium	Pink Purple
28	Dark Green	Drop	Brown	Compact	Dark Brown	25	Present	Circular	Medium	Brown
29	Dark Green	Erect	Brown	Compact	Brown	25	Absent	Circular	Medium	Dark Brown
30	Dark Green	Erect	Brown	S/Compact	Brown	25	Present	Circular	Medium	Red
31	Dark Green	Drop	Brown	Compact	Brown	25	Present	Circular	Medium	Brown
32	Dark Green	Erect	Dark Brown	S/Compact	Dark Brown	25	Absent	Circular	Medium	Brown
33	Dark Green	Erect	Dark Brown	S/Compact	Brown	25	Absent	Circular	Small	Pink
34	Dark Green	Drop	Brown	Compact	Straw	25	Absent	Elliptic	Small	Brown white
35	Dark Green	Drop	Purple	Loose	Dark Brown	25	Present	Circular	Medium	Red
36	Dark Green	Erect	Purple	Compact	Brown	50	Absent	Elliptic	Medium	Brown White
37	Light Green	Erect	Brown	S/Loose	Brown	50	Absent	Circular	Medium	Brown
38	Dark Green	Erect	Dark Brown	Compact	Brown	50	Absent	Circular	Medium	Brown
39	Dark Green	Erect	Light Green	S/Loose	Dark Brown	25	Present	Elliptic	Large	Purple Grey
40	Dark Green	Drop	Dark Brown	S/Loose	Dark Brown	25	Present	Circular	Medium	Red
41	Dark Green	Drop	Brown	Compact	Brown	50	Absent	Circular	Medium	White
42	Dark Green	Drop	Brown	S/Compact	Brown	25	Absent	Circular	Medium	Brown
43	Dark Green	Drop	Light Green	S/Compact	Light Brown	75	Absent	Circular	Medium	White
44	Dark Green	Drop	Brown	S/Compact	Brown	50	Present	Circular	Medium	Brown Red
45	Dark Green	Erect	Light Green	S/Compact	Straw	25	Present	Circular	Medium	White
46	Dark Green	Drop	Dark Brown	S/Compact	Black	25	Absent	Circular	Medium	Red
47	Dark Green	Erect	Brown	S/Compact	Brown	25	Present	Circular	Medium	Pink Brown
48	Dark Green	Drop	Brown	S/Compact	Brown	50	Present	Circular	Medium	Red

Appendix 11: Quantitative characters of the 48 sorghum accessions at Kiboko season one

ACC	DAS	V	NL	LL	LW	PH	ST	SW	DF	DM	HL	HW	GY	HS
1	7	2	9	67.2	7.4	116.6	6.5	65.1	60	129	24.5	6.5	1.5	2.2
2	7	2	8	55.1	4.3	184.5	6.4	55.2	59	131	24	5.7	4.8	9.1
3	7	2	8	73.2	8.4	133.5	8.4	84.8	61	131	24	8.1	1.1	3.2
4	7	5	6	65.1	3.4	144.8	5.3	43.2	0	0	0	0	0.0	0
5	7	2	8	73.1	8.4	93.3	8.4	94.2	73	126	24.3	7.9	0.6	2.2
6	8	2	6	33.1	1	83.1	6.3	44.9	0	0	0	0	0.0	0
7	7	2	11	82.9	6.6	164.4	7.5	154.1	78	129	33.8	16.5	1.6	1.8
8	7	3	7	93.8	3.6	152.6	8.4	44.3	0	0	0	0	0.0	0
9	7	3	8	54.4	5.4	184.8	5.4	183.2	56	129	13.9	6.1	1.6	3.3
10	7	2	9	62.7	6.4	122.7	5.4	95.5	69	129	23.6	7.7	1.4	2.5
11	7	2	10	54.3	6.4	184	8.3	174.3	70	130	15.5	12.3	1.6	3.2
12	7	2	10	74.5	8.4	183.7	6.5	115.2	65	128	23.2	9.4	0.4	4.1
13	7	2	9	64.3	4.4	145	6.5	84.1	60	129	34.2	10.2	1.4	2.1
14	7	2	8	55.3	7.4	175	7.4	45.1	56	129	15.1	6.6	1.5	2.5
15	0	0	0	0	0	0	0	0	0	0	0	0	0.0	0
16	7	4	10	64.1	7.4	122.9	8.3	46.7	67	131	23.5	7.6	2.1	1.9
17	7	2	8	44.3	4.5	94.5	5.4	64.7	56	130	16	6.4	1.4	2.6
18	7	3	10	53.9	5.3	65.2	7.3	84	0	0	0	0	0.0	0
19	7	3	9	34.1	4.3	114.7	5.3	158.3	66	130	15.7	8.4	2.2	1.8
20	7	2	7	53.7	5.5	184.3	8.5	112.2	68	134	22.5	8	1.3	2.4
21	7	2	12	63.9	7.4	123.9	3.3	83.1	68	129	31.7	7.6	2.6	2.2
22	8	2	7	63.7	1.9	93.9	6.5	281.6	64	130	15.7	7	1.5	3.1
23	7	2	9	53.7	5.3	85.4	7.5	94.7	68	129	24.6	8.5	3.5	2.4
24	7	2	8	54.9	5.5	64.9	5.3	104.5	68	127	15.7	7.8	2.1	2.3
25	7	2	10	64.5	5.3	122.8	6.5	73.8	70	124	23.1	6.6	1.4	2.2

26	8	3	12	65.2	8.4	81.4	3.8	45.3	0	0	0	0	0.0	0
27	7	2	8	43.7	3.4	145.1	6.4	124.7	70	132	20.7	8.1	1.5	3
28	7	2	9	54.2	1.5	115.2	7.2	135.4	77	129	15.3	8.4	1.2	2.1
29	7	2	9	54.4	5.5	85.4	6.8	84.9	76	129	23.1	8.3	2.3	1.6
30	0	0	0	0	0	0	0	0	0	0	0	0	0.0	0
31	7	2	7	64.3	7.1	154	6.4	105	65	131	24.8	10.8	3.7	2.9
32	7	1	8	55.2	6.9	120.5	6.4	84.8	61	130	22.9	7.3	1.5	2.1
33	7	4	8	54.8	6.4	0	0	0	0	0	0	0	0.0	0
34	7	1	8	63.6	6.5	122.8	6.5	74.4	62	131	15.3	8.1	1.6	2.1
35	7	1	8	54.3	4.4	154.3	5.3	55.5	53	133	23.7	10.3	1.5	2.6
36	7	1	9	54.6	5.4	214.1	7.1	34.7	0	0	0	0	0.0	0
37	7	3	9	65.7	7.3	174	6.4	144.8	69	129	24	8	1.4	2
38	7	3	10	84	5.4	121.2	6.1	135.3	71	130	23.7	12.2	1.4	2.2
39	7	3	9	55.5	0.6	214.6	7.7	274.5	0	0	0	0	0.0	0
40	7	2	8	35.5	6.5	123.3	5.4	55.3	62	131	31.3	10.9	0.3	2.2
41	7	2	8	64.1	5.4	93.3	7.2	66.1	63	132	14.2	7.3	1.5	2
42	7	2	8	54.8	7	143.7	5.2	75.7	88	131	22.8	11.2	0.3	2
43	7	3	7	64.5	4.3	147.2	4.4	84.5	69	132	23.4	7.6	1.1	2
44	0	0	0	0	0	0	0	0	0	0	0	0	0.0	0
45	7	2	8	34.6	8.4	75.8	5	314.9	68	134	15.8	7	1.3	2.9
46	0	0	0	0	0	0	0	0	0	0	0	0	0.0	0
47	7	2	9	73.9	4.3	215.3	23.2	10.7	0	0	0	0	0.0	0
48	0	0	0	0	0	0	0	0	0	0	0	0	0.0	0
SE	0.17	0.08	0.21	0.46	0.11	2.32	0.09	53.99	3.22	1.51	0.36	0.36	0.63	0.01
LSD	0.47	0.23	0.59	1.28	0.3	6.42	0.25	149.8	9.03	4.23	1	1.01	0.74	0.04
CV%	5	7	5.2	4.7	1.7	1.8	8.3	3.6	12	3	2.7	2.9	1.7	4.2

Appendix 12: Quantitative characters of the 48 sorghum accessions at Kiboko season two

ACC	DAS	V	NL	LL	LW	PH	ST	SW	DF	DM	HL	HW	GY	HS
1	6	3	7	63.8	3.4	94.4	5.5	65.5	61	106	24.1	7.4	2.4	2.5
2	6	1	7	54.2	2.5	143.4	4.4	55.5	52	105	24.1	6.1	4.2	2.6
3	6	1	7	64.7	3.5	83.9	5.2	45.2	55	105	15.4	6.8	2.4	2.4
4	6	2	6	84.3	4.5	154.8	5.4	148.2	80	106	25.4	8.7	1.4	2
5	6	2	6	54	2.5	94.5	6.4	16.4	72	106	23	7.1	2.4	2.4
6	6	4	7	64.8	3.4	84.7	6.2	54.3	61	106	23.3	6.7	1.4	2.4
7	6	1	6	85	4.4	164.9	7.3	138.6	71	106	35.4	33.3	1.4	1.6
8	6	2	7	95.3	4.3	204.1	6.2	457.2	78	119	24.4	7.6	1.4	1.2
9	6	1	7	64.9	2.4	114.3	5.4	55.2	55	106	14.9	6.1	2.4	2.5
10	7	3	6	65.7	3.5	95.5	6.2	54	68	106	24.4	8.6	1.2	2.2
11	6	1	6	103.4	3.5	164.5	6.5	314.7	108	158	15.6	13.6	0.6	0.9
12	6	4	7	84.7	4.4	115.1	7.4	71	65	110	24.6	7.1	1.5	2.9
13	6	1	7	63.9	2.5	124.1	4.4	285	62	105	15.5	9.6	1.4	1.5
14	6	1	6	43.8	2.5	134.8	3.5	55.4	56	106	29.7	7.4	2.4	2.4
15	7	5	6	66.1	3.5	94.1	5	43.8	55	106	21.1	5.7	2.5	2.1
16	6	3	6	54.2	2.6	84.9	6.5	33.4	67	110	33.2	6.9	2.5	2.4
17	6	2	7	54.8	3.4	105	4.6	49.5	51	106	23.3	7.5	0.6	2.8
18	6	1	7	84.4	4.5	204.5	7	442.8	99	119	25	13.2	2.5	1.6
19	6	3	6	65.1	3.3	164.4	5.4	55.2	67	106	15.1	7.1	1.4	1.4
20	6	2	6	54.8	3.4	154.2	4.9	35.6	61	106	23.4	7	2.4	2.6
21	6	2	6	64.7	3.4	84.4	8.2	45.5	64	106	24.5	8	1.5	2.4
22	7	4	6	74.1	3.5	74.9	8	106.4	56	106	14.4	7.4	0.3	1.7
23	6	1	6	65.3	4.4	95.4	5.4	65	66	106	24.4	7.9	2.4	2.4
24	6	3	6	74.5	3.5	63.6	6	84.9	67	105	20.9	7.3	3.6	2.5
25	6	1	6	85.4	5.2	224.5	6.2	144.6	96	105	14.5	9.8	2.3	1.9

26	6	2	6	103.6	4	154.5	8.8	644.2	93	110	23.8	10.5	0.6	1.2
27	6	1	7	104.7	4.1	203	8.4	204.5	89	118	23.5	10.5	1.4	1.8
28	6	2	6	64.9	3.6	83.7	5.5	35	78	106	25.1	7.7	1.4	2.2
29	6	2	6	65.5	3.7	95	6.4	54.2	60	106	25.1	8.4	2.5	2.3
30	6	5	0	0	0	0	0	0	0	0	0	0	0.0	0
31	6	2	6	73.9	4	145	7.9	44.2	70	107	16	11.1	3.5	2.8
32	6	2	6	64.9	3.3	99.6	5.8	60.5	59	129	21.5	6.7	2.4	2.2
33	5	1	7	95.2	3.9	253.7	6.9	264.6	72	111	21	10.6	1.4	1.6
34	6	1	6	74.7	3.6	84.4	6.1	54.3	65	110	23.9	9.3	1.5	2.3
35	6	1	6	54.3	2.9	134.5	4.5	25	51	104	21	12.7	2.2	2.6
36	6	1	7	78.2	4.4	234.5	6.9	215.5	89	132	15.4	11.2	1.0	1.6
37	6	1	6	71.3	3.5	133.2	7.8	56.8	65	106	23.8	11.3	1.4	2.3
38	6	1	6	67.7	3	95.3	5.2	24.9	64	110	20	10.3	1.2	1.9
39	6	2	6	91.8	3.8	244.3	7.3	460	66	119	23.8	8.8	1.7	1.2
40	6	3	7	54.8	3.2	147.5	4.9	42	50	106	24.1	15.6	2.8	2.7
41	6	2	6	64.4	3.6	83.3	7	46.6	66	106	20.4	9	2.5	2.2
42	6	2	6	75	3.5	92.1	7.3	63.7	68	106	22.6	13.7	3.7	2.2
43	5	1	7	63.7	3	139.7	4.5	55.5	50	106	23.4	7.7	1.8	2.8
44	6	5	7	72.9	4	86.1	8.2	55.9	61	106	25.9	10.5	1.5	2.3
45	7	5	6	71.5	3.5	84.3	6.1	57.9	66	106	25	7.1	1.0	2.2
46	6	5	4	74.5	4.2	79	8.7	77.1	69	106	28	10	1.7	3.1
47	5	2	6	85.5	3.9	187.8	6.9	262.6	70	111	24.6	11.4	2.0	1.4
48	6	5	7	74.4	3.4	63	8.2	46.4	66	119	27.1	13.9	1.4	2
SE	0.21	0.08	0.17	0.6	0.07	1.14	0.45	5.9	4.06	2.09	0.52	0.41	0.2	0.11
LSD	0.59	0.23	0.48	1.67	0.32	3.15	1.24	16.37	11.39	5.86	1.45	1.13	9.13	0.3
CV%	6	6	5.3	4.7	1.3	4.9	9.6	2.9	1.1	3	2.9	3.6	5.5	2.1

Appendix 13: Quantitative characters of 48 sorghum accessions at Kitui season one

ACC	DAS	V	NL	LL	LW	PH	ST	SW	DF	DM	HL	HW	GY	HS
1	7	2	9	55.1	4.6	34.9	4.5	34.4	63	114	6.3	5.3	1.4	1.1
2	8	2	11	64.3	5.4	73.7	4.5	40.9	64	107	12.9	7.5	2.0	2.5
3	8	3	10	54.2	4.6	55.6	5.4	33.3	62	102	9	5.7	1.5	1.2
4	8	3	10	58.1	5.5	95.4	3.4	42.7	58	116	10	4.9	1.5	1
5	8	2	8	54.4	5.2	65.9	4.5	35	55	107	10	4.9	1.4	1.3
6	8	2	8	45.5	4.6	55	2	23.8	59	98	5.1	5	0.6	0.9
7	8	4	8	55	5.3	63.5	4.6	54.3	58	100	8	4.8	1.5	2.1
8	7	2	9	54.2	4.5	63.8	4.4	24.3	68	107	6	5.5	1.5	2
9	8	4	8	57.1	4.6	65.4	3.5	39.5	78	117	6.3	5.2	1.3	2
10	8	3	9	64.4	5.4	64.9	6	35	57	97	5.6	4.9	1.1	2
11	8	4	8	56.8	4.6	66.2	4	13.7	0	0	0	0	0.0	0
12	8	4	9	46.1	4.6	54.7	3.5	63	67	119	5.6	5.9	1.5	1.5
13	8	2	11	46.2	5.5	66.3	4.6	35.5	65	107	7	4.8	0.6	1
14	8	4	9	43.3	3	90	6	40.1	54	99	5.5	5.4	0.5	1
15	5	5	0	0	0	0	0	0	0	0	0	0	0.0	0
16	8	4	8	47.5	5.1	45	4.6	33.8	77	121	5.3	5	0.3	1
17	8	1	11	55.8	6.5	114.1	7	35.1	58	95	4.6	5.6	0.5	1
18	8	3	8	45.2	4.6	120	4.3	35.5	76	126	5.6	5.3	1.5	2
19	8	3	9	34.3	5.5	54.6	5.5	14.1	61	107	7	5.7	1.5	2.5
20	8	2	10	53.2	3.4	63.5	3.1	34.6	62	99	8	5.4	1.2	2
21	8	4	12	54.1	5.3	64.3	7	44.3	67	114	6.1	5.1	1.3	2.5
22	8	2	10	57.4	2.4	55.4	4.4	33.9	65	111	5.3	5.3	1.5	2.5
23	7	2	11	54.8	3	56	2.5	14	62	111	5.3	5.4	1.9	2
24	8	3	8	64	5.3	44.6	7	40	66	106	5.1	5.3	1.9	2
25	8	5	8	43.7	5.2	55.2	4.7	25.8	0	0	0	0	0.0	0

26	8	2	8	57.8	5.3	123.2	5.4	35.5	77	127	5.3	6	0.5	1.9
27	8	5	8	57.6	3.4	466.4	8	111.7	0	0	0	0	0.0	0
28	8	2	9	44.7	4.5	64.2	8	55.1	66	107	9.2	5.3	1.6	3
29	7	1	8	56.4	4.6	84.4	5.2	34	60	102	7.2	5.1	1.8	3
30	7	2	7	56.2	5.7	59.7	4.7	21	71	126	5.5	4	1.7	3.2
31	8	2	10	54.9	6.3	65	6	35	68	105	5.5	5.3	1.6	3.2
32	8	3	11	56.7	6	84.6	5.2	34.1	59	102	8	5	1.6	3.2
33	8	5	8	55.8	5.2	65.8	4.8	32.4	62	104	5.5	5.5	0.6	1.8
34	8	4	10	57.6	4.5	74.1	5.2	42.6	64	107	6	5.7	0.5	1.6
35	8	2	11	56.8	4.6	63.4	5.2	78	65	115	6.1	5.1	0.5	1.5
36	8	2	8	66.8	6	65.1	4.7	24	0	0	0	0	0.0	0
37	7	1	8	55.7	5.3	84	4.7	36.2	69	109	5.3	6.6	0.6	1
38	8	1	11	55.7	4.7	73.9	5	23.9	64	118	5.2	6	0.5	1
39	7	4	9	55.5	5.2	66.5	4.7	63	0	0	0	0	0.0	0
40	8	4	10	55	7	73.6	6	24.9	64	107	7.3	5.4	0.0	0
41	8	2	8	55.3	7.7	66.4	3.5	41.9	64	120	5.1	5.2	0.0	0
42	8	2	8	57.1	4.9	74.7	5.2	43.7	64	107	5.2	4.9	1.6	2.2
43	8	2	9	45.7	5	64.2	4.7	33.7	76	109	5.3	4.9	1.4	2.2
44	8	2	11	55.5	5	41	5.1	48.5	68	120	7	5.2	1.5	2.2
45	7	4	8	56.3	4.4	65.7	3.5	94.2	54	98	5.9	6	0.4	0.9
46	8	4	9	55.2	4.8	65.7	5	37	67	107	6	4	1.2	3.2
47	7	5	8	50	5.2	55.4	3.5	27.9	0	0	0	0	0.0	0
48	8	2	11	54.4	6.3	66	5.2	34.1	60	116	5.6	5.2	1.4	2.2
SE	0.16	0.1	0.46	0.49	0.04	7.73	0.03	0.65	2.16	2.28	0.05	0.07	0.1	0.01
LSD	0.44	0.27	1.28	1.36	0.11	19.17	0.1	1.8	6.05	6.4	0.13	0.19	0.07	0.03
CV%	4	6	2.8	5.1	4.4	1.6	4	9.3	7	4	4.6	8.1	2.6	1.2

Appendix 14: Quantitative characters of the 48 sorghum accessions at Kitui season two

ACC	DAS	V	NL	LL	LW	PH	ST	SW	DF	DM	HL	HW	GY	HS
1	8	3	8	72.3	4.4	87	5.5	35	68	109	26.9	6.2	0.4	0.8
2	7	2	8	66.4	5.2	120	3.5	10	62	106	25.6	7.9	2.5	2.1
3	8	2	8	76.2	4.5	55.6	4.4	15	65	106	17.9	6.1	0.4	1.1
4	8	4	8	80.3	4.5	93.7	5.3	22	77	109	23.7	4.5	0.7	1
5	8	2	8	76.3	5.2	55.1	4.7	23	73	106	27.2	5	0.6	1.5
6	8	2	7	84.1	4.6	55.5	5.7	22	70	115	17	5	0.5	0.2
7	8	2	8	84.1	6	70	6.1	25	74	106	26.6	5.3	1.2	2
8	8	2	7	78	5.2	64.5	5.7	26	86	106	28.6	5.5	0.3	0.2
9	8	4	8	94.6	4.5	68	5.2	37	76	107	25.5	5.3	1.1	2.2
10	8	3	8	81	5.3	45.1	4.2	33	74	106	26.3	4.4	2.3	1.8
11	8	5	7	68.7	4.5	66.1	5.5	21	73	106	27.3	4	1.2	2.2
12	8	4	8	80.2	5.1	54.5	6.5	33	74	106	26.7	5.6	1.4	1.5
13	8	1	7	72.2	5.6	72	4.5	33	69	99	18	4.5	1.2	0.2
14	8	5	8	75.4	7	90	6.2	22	74	109	27.4	7.5	1.1	3.2
15	8	5	7	79.3	5	63.5	4.5	20	55	100	27.4	4.3	1.3	2.6
16	8	3	7	81.3	4.7	57.6	5.5	20	69	105	28	5.5	1.6	1.5
17	8	1	8	73.6	5.1	123.6	5.5	29	72	105	26.8	5.6	0.9	1.8
18	8	1	7	70.3	5.3	79	5.5	25	85	106	28	5.5	0.6	0.1
19	8	3	8	75.3	6.3	65.1	4.7	22	85	106	27.5	5.6	1.1	2.1
20	8	2	8	74.9	4.8	64.3	5.4	22	72	106	25.5	6.3	0.6	0.4
21	8	4	8	75.5	5.3	70	4.4	22	73	106	27.4	5.5	1.1	3
22	8	2	7	69.5	6	55.5	5.3	34	50	109	26.1	4.6	1.4	1.4
23	8	2	8	72.5	4.8	57	5.6	35	73	106	28.3	6	1.5	2
24	8	3	8	72.7	6	66.8	6	33	73	106	25.2	5.5	1.2	2.7
25	8	5	7	73.3	5.2	59.9	6	34	73	102	29	5.4	0.5	0.9

26	8	2	7	72.9	5.3	80	4.5	21	73	117	28	6.5	1.4	1.5
27	8	5	7	73.7	4.6	66.9	4	0	0	0	0	0	0.0	0
28	8	2	8	59.6	5.2	64.1	6	22	74	107	25.3	5.3	0.3	0.2
29	8	1	8	74.7	4.4	82	5.4	22	74	106	28.3	4.3	0.3	1
30	8	5	7	74.6	4.5	55	5.5	24	75	108	26.1	4	0.8	1
31	8	2	8	72.8	7.4	94.6	6.2	36	73	106	27.4	6	1.7	1.2
32	8	4	8	74.9	4	80.6	6.3	33	74	107	27.3	4.5	1.8	2
33	8	5	6	73.6	6	65	4.4	0	0	0	0	0	0.0	0
34	8	3	8	70.6	4.6	71.9	6.1	35	74	105	26.3	5.7	1.6	2
35	8	3	8	75.3	5.1	62.8	5.7	33	49	109	26.3	4.5	1.1	2
36	8	3	7	73.7	5.4	65.4	5.4	20	73	106	28.1	5	1.4	3
37	8	4	8	74.8	5.3	78.7	5.4	37	72	108	27.4	7	0.9	0.1
38	8	1	8	70.4	6	52	5.6	31	76	108	25.2	5	1.3	2
39	8	5	6	71.1	5.3	67.2	4.6	0	0	0	0	0	0.0	0
40	8	3	8	72.6	8	73.2	5.5	38	74	108	28.2	5.5	1.0	2
41	8	2	8	76.6	7.3	99	4.6	45	71	108	25.5	4.4	1.4	2
42	8	2	8	70.3	4.9	72.5	5.4	47	74	106	28	4.4	0.9	1
43	8	2	8	74	5	62.3	4.7	33	51	106	26.6	5.1	1.3	3
44	8	2	8	75.8	5.2	81.1	5.5	33	50	108	26.4	5.3	1.8	2.6
45	8	5	8	75.4	6	65.7	5.4	31	71	109	27	6	0.3	0.3
46	8	5	7	71.6	5	65	5.7	25	50	110	26.3	4.8	1.5	3
47	8	5	7	74.9	5.2	99	4.5	23	55	98	26	4	1.5	2.9
48	8	2	8	74.6	6.3	63.8	5.6	39	72	106	27.5	4.3	1.6	1.4
SE	0.14	0.1	0.07	0.04	0.23	0.55	0.04	0.03	2.41	0.9	0.12	0.04	0.21	0.01
LSD	0.39	0.27	0.21	0.1	0.63	1.54	0.12	0.07	6.77	2.52	0.32	0.12	0.07	0.03
CV%	3	5	5.4	3.8	1.7	4.3	4.4	5.2	6	2	2.6	4.7	3.3	4.1

Appendix 15: Quantitative characters of the 48 sorghum accessions at Mbeere season one

ACC	DAS	V	NL	LL	LW	PH	ST	SW	DF	DM	HL	HW	GY	HS
1	10	2	9	71.5	9.2	180.1	2.3	47.3	83	141	23.4	6.8	2.9	2
2	10	2	8	67.1	8.4	174.7	2.1	44.6	85	136	21.7	7.9	3.3	2.6
3	10	2	9	67	8.6	204.8	1.9	54.9	90	136	23.1	8.3	3.0	2
4	8	4	9	0	0	0	0	0	0	0	0	0	0	0
5	11	2	9	67.6	8.8	97.9	1.7	56.5	90	142	22.8	6.9	3.1	1.9
6	8	2	0	0	0	0	0	0	0	0	0	0	0	0
7	10	3	0	0	0	0	0	0	0	0	0	0	0	0
8	11	0	0	0	0	0	0	0	0	0	0	0	0	0
9	10	1	9	81.8	8.6	98.5	1.7	69.6	88	152	9	6.2	2.9	2
10	10	2	10	67.4	9.6	116.2	1.8	70.6	85	124	19.8	6.9	1.8	2.3
11	11	2	0	0	0	0	0	0	0	0	0	0	0	0
12	9	2	10	65.5	9.9	71.1	1.8	82.6	90	136	21.2	7.2	1.8	2.7
13	10	5	0	0	0	0	0	0	0	0	0	0	0	0
14	9	3	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	11	3	10	22	10	101.3	1.3	65.3	86	128	20.3	7.1	1.5	2.1
17	9	3	8	71.2	7.7	114.8	1.6	50.2	88	125	24.8	6.5	1.3	1.9
18	11	2	0	0	0	0	0	0	0	0	0	0	0	0
19	11	2	9	65.4	8.7	87.8	1.7	47.1	90	136	7.5	5.7	1.1	2.3
20	9	1	9	83.2	8.7	101.7	1.5	54.7	88	105	22.3	6	1.9	2
21	11	2	9	69.8	9	83	1.2	45.3	88	139	19.9	6.6	1.6	2.6
22	9	2	9	73.8	9.2	97.4	2.1	47.1	85	136	21.9	8.7	1.1	2.8
23	10	2	8	70.1	8.3	161.9	1.8	47.9	88	136	20.6	7.6	2.0	1.6
24	11	2	8	62.5	8.2	105	1.5	41.7	88	139	15	6.2	2.5	1.7
25	11	0	0	0	0	0	0	0	0	0	0	0	0	0

26	10	1	0	0	0	0	0	0	0	0	0	0	0	0
27	11	2	0	0	0	0	0	0	0	0	0	0	0	0
28	10	2	10	69.6	9.6	89.2	1.7	47.2	90	143	19.9	5.4	1.6	2.6
29	11	3	10	67	9.9	112.2	1.6	43.2	90	127	19	7	2.7	2.4
30	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31	11	3	9	72.6	9.2	87.9	1.7	52.2	88	138	19.9	6.3	2.2	2.5
32	10	2	0	0	0	0	0	0	0	0	0	0	0	0
33	10	2	0	0	0	0	0	0	0	0	0	0	0	0
34	11	1	10	66.4	10	125.3	2	41.2	90	120	22.4	8.1	2.0	2.5
35	10	2	9	67.8	8.9	127.9	1.8	54.4	87	109	22.4	7.6	1.9	2.4
36	11	0	0	0	0	0	0	0	0	0	0	0	0	0
37	11	3	10	72.7	9.8	122.7	1.7	40.1	90	138	22	7.4	1.9	2.3
38	11	2	9	71	9	126.5	1.8	38.8	90	140	11.4	7.9	1.3	1.6
39	11	0	0	0	0	0	0	0	0	0	0	0	0	0
40	11	1	9	74.6	8.7	119.7	1.7	48.2	83	100	19.8	8.2	1.0	1.4
41	9	1	9	67.5	8.7	113	1.8	59.8	83	139	17	7	2.1	3
42	10	2	9	70.7	9.3	117	1.6	58.2	83	139	15.7	6.1	1.5	1.2
43	10	2	9	70.8	8.6	119.9	1.6	47.8	90	127	19.9	6.6	1.4	2.3
44	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45	11	0	0	0	0	0	0	0	0	0	0	0	0	0
46	10	0	0	0	0	0	0	0	0	0	0	0	0	0
47	11	1	0	0	0	0	0	0	0	0	0	0	0	0
48	10	1	9	51.9	9.2	111.3	1.4	51.5	87	144	16.5	7.1	2.2	2.1
SE	0.34	0	0.11	0.13	1.17	2.98	0.04	0.93	1.04	0.57	0.3	0.15	0.77	0.07
LSD	0.97	0	0.3	0.36	3.24	8.26	0.1	2.58	2.93	1.6	0.83	0.42	1.14	0.19
CV%	6	1	1.2	7.7	6.8	4.7	2.7	7.4	4	1	5.2	1.2	8.8	2.9

Appendix 16: Quantitative characters of the 48 sorghum accessions at Mbeere season two

ACC	DAS	V	NL	LL	LW	PH	ST	SW	DF	DM	HL	HW	GY	HS
1	10	2	9	65.4	7.5	89.7	3	42.6	83	141	16.6	6.2	1.6	1
2	10	2	8	67.3	5.6	170.5	3.4	53.9	85	136	15.6	5.9	3.2	1.8
3	10	2	8	73.9	7.3	138.7	3.2	45.9	90	136	15.5	6.2	1.4	1
4	8	4	8	66.1	6.6	0	0	0	0	0	0	0	0	0
5	11	2	9	65.7	6.7	119.8	3.2	85.3	90	142	18.7	7	1.5	1.9
6	8	2	8	69.2	6.9	0	0	0	0	0	0	0	0	2
7	10	3	8	70.3	7	190.8	3.3	93.5	90	140	21.9	17.2	1.6	2.6
8	11	0	0	0	0	0	0	0	0	0	0	0	0	0
9	10	1	8	69.8	8	134.7	2.6	72.5	88	152	21.7	6.9	1.4	2
10	10	2	9	69.2	6.9	132.7	3.1	45.7	85	124	21.4	6.1	1.5	2
11	11	2	9	70.2	7.1	0	0	0	0	0	0	0	0.0	0
12	9	2	8	71	7.1	110	4	80.8	90	136	21.6	8.3	1.4	2.7
13	10	5	9	66.9	7.1	0	0	0	0	0	0	0	0.0	0
14	9	3	8	70	6.3	147.1	3.4	42.7	83	144	22.6	7.3	0.4	1
15	0	0	0	0	0	0	0	0	0	0	0	0	0.0	0
16	11	0	0	0	0	0	0	0	0	0	0	0	0.0	0
17	9	3	8	67.3	6.5	116.1	2.5	37.5	88	125	20.4	4	0.4	1.7
18	11	2	8	68.9	7.6	0	0	0	0	0	0	0	0.0	0
19	11	2	9	65.7	6.2	153.7	2.4	26	90	136	13.5	8.4	0.9	1.5
20	9	1	9	71.2	6.4	150.4	2.6	58.9	88	105	22.3	7.5	1.1	1.5
21	11	2	9	68.1	5.9	116.4	3.4	36.5	88	139	21.1	6.6	1.1	1.8
22	9	2	7	71.1	7.2	109.6	3.4	54	85	136	15.4	6.1	1.5	2.1
23	10	2	8	69.4	6.3	121.6	2.5	44.3	88	136	17	7.6	2.1	1.3
24	11	2	9	73.1	7	119.9	3.3	84.1	88	139	13.2	6.3	2.5	1.7
25	11	0	0	0	0	0	0	0	0	0	0	0	0.0	0

26	10	1	9	73.5	7.4	0	0	0	0	0	0	0	0.0	0
27	11	2	8	68.3	6.6	0	0	0	0	0	0	0	0.0	0
28	10	2	9	70.5	7.5	123.8	3.2	80.7	90	143	22.6	7.6	1.6	2.2
29	11	3	9	70.2	6.4	135.2	3.3	93.7	90	127	21.6	8.7	1.2	4.1
30	0	0	0	0	0	0	0	0	0	0	0	0	0.0	0
31	11	3	10	71.8	7.1	115.9	3.3	36.6	88	138	21.3	8.4	1.9	2.8
32	10	2	8	69.7	6.4	161.1	2.5	77	90	138	21.5	8.1	1.2	2
33	10	2	9	71.2	7	0	0	0	0	0	0	0	0.0	0
34	11	1	9	74	7.7	94.8	3.3	34	90	120	22.3	7.7	0.9	1
35	10	0	0	0	0	0	0	0	0	0	0	0	0.0	0
36	11	0	0	0	0	0	0	0	0	0	0	0	0.0	0
37	11	3	8	70.6	7.1	122	3.2	23.4	90	138	21.6	8.4	0.5	1
38	11	2	9	73	7.3	112.8	3.3	66.8	90	140	21	7.7	1.3	1.7
39	11	0	0	0	0	0	0	0	0	0	0	0	0.0	0
40	11	1	9	72.4	7.3	145.9	3.2	63.2	83	100	22.4	10.2	1.9	1.6
41	9	1	9	67.1	7.8	127.4	3.6	36.1	83	139	21	6.6	1.4	1
42	10	2	9	69.5	7.5	151.9	3.5	53.8	83	139	22.8	8	1.4	1.3
43	10	2	9	72.3	6.9	128.9	3.2	33.2	90	127	20.9	6.3	1.1	1
44	0	0	0	0	0	0	0	0	0	0	0	0	0.0	0
45	11	0	0	0	0	0	0	0	0	0	0	0	0.0	0
46	10	0	0	0	0	0	0	0	0	0	0	0	0.0	0
47	11	1	9	63.9	5.8	114.6	2	55.2	83	144	23.1	6.6	0.9	1.4
48	0	0	0	0	0	0	0	0	0	0	0	0	0.0	0
SE	0.34	0.08	0.17	0.94	0.15	1.84	0.02	0.31	1.04	0.57	0.19	0.13	0.37	0.05
LSD	0.97	0.23	0.47	2.62	0.41	5.12	0.07	0.87	2.93	1.6	0.54	0.35	0.02	0.14
CV%	6	9	4.5	9.9	5.6	3.3	7.5	5.3	4	1	9.1	5.6	6.3	5.8

Appendix 17: Quantitative characters of the 48 sorghum accessions at Mutomo season one

ACC	DAS	V	NL	LL	LW	PH	ST	SW	DF	DM	HL	HW	GY	HS
1	8	2	9	61.4	5.6	65.9	4.5	35.3	59	86	17.6	7.6	2.5	3
2	8	2	8	50.9	5.5	64	4.3	24.7	61	87	12	5.6	3.8	4.1
3	8	2	12	63.9	6.6	63	6.9	55.1	60	83	22.2	9.2	3.3	3
4	9	3	8	58.8	5.2	15.6	4	17	0	0	0	0	0.0	0
5	11	1	11	65.5	6.4	84.5	5.5	30.6	59	86	21.7	8.3	2.4	3.1
6	8	2	8	68.7	6.2	34.3	6	13.4	83	98	21	6.2	2.5	1.4
7	8	3	7	67.9	6.4	74	6	24.7	75	103	20.9	6.3	2.3	2.2
8	9	2	7	61.3	6	84.4	6	34.9	82	108	22	7	1.4	2
9	8	3	5	55	6.4	14	5.4	10.2	60	74	16	8	1.4	2
10	8	5	0	0	0	0	0	0	0	0	0	0	0.0	0
11	11	4	8	70.7	8	36.4	7.1	15	88	108	18	5.8	1.3	2.8
12	11	5	0	0	0	0	0	0	0	0	0	0	0.0	0
13	8	2	12	72.3	6.7	33.9	6	54.2	63	83	21.3	9.9	1.4	2
14	8	3	9	57.6	6.1	43.3	4.8	34.7	51	76	27.6	8.6	7.8	1.3
15	8	5	0	0	0	0	0	0	0	0	0	0	0.0	0
16	8	3	12	62.3	7.3	94.3	11.3	54.2	60	96	23.7	10.7	0.6	1.7
17	8	1	12	62.6	7	142.3	5	34.5	50	78	14.5	9.1	1.8	1.6
18	8	2	5	64.6	6.3	33.3	7	33.3	83	110	23.7	7.1	2.3	3
19	9	4	7	0	0	0	0	0	0	0	0	0	0.0	0
20	8	2	11	52.2	6.1	23.1	4.4	10	62	89	17.6	6.7	1.4	2.8
21	10	3	6	55.1	7	33.9	5.3	17.9	64	88	17.2	7	2.0	3.7
22	8	3	11	47.6	4.9	110.9	5	21	60	74	14.9	6.7	1.4	1.9
23	8	4	4	40.1	5	52	5	10	69	92	15	5	3.2	2.4
24	8	2	10	62.5	7.1	93.9	6	63.4	74	84	24.5	10.5	3.4	3
25	8	3	8	65.4	8	33.8	6.2	94.3	67	94	21.8	11.9	2.2	3

26	8	2	10	73.1	6.5	162.9	7.4	16.1	82	97	15.3	7	2.6	2
27	8	3	8	83.5	7	44.3	7.5	65.2	82	106	24.4	7.1	1.6	1
28	8	2	12	74.8	7	101.8	6	63.2	64	81	23.4	10.5	2.3	1.2
29	8	4	7	65.4	7	24.2	6.5	75.4	63	87	23.4	9.2	2.7	3
30	8	5	0	0	0	0	0	0	0	0	0	0	0.0	0
31	8	2	5	64	7	14.4	5.9	62.5	80	111	26	11	2.1	3
32	11	3	11	64.7	7	83.3	5	17	61	80	18.7	7.7	1.7	2
33	8	5	6	0	0	0	0	0	0	0	0	0	0.0	0
34	10	3	7	68.6	7	44.8	6	15	64	92	20	7	1.4	2
35	8	2	10	62.9	6.1	124.6	4.1	24.3	54	72	22.3	10.2	1.4	2.5
36	8	3	6	53.7	6.9	23.1	6	14.8	66	75	15.3	6	1.2	1.9
37	8	2	11	75.1	7	93.4	5.3	44	67	86	23.6	9.4	2.6	3
38	8	1	11	64.4	6.8	94.4	5.7	54.6	66	87	24.5	10.8	2.4	3
39	8	2	11	64.4	6.6	143.6	7.2	34.8	74	108	15.2	7.2	1.3	1.4
40	8	3	8	52.4	6.7	50	4.5	43.9	51	74	32	6.7	1.2	1.7
41	8	2	5	0	0	0	0	0	0	0	0	0	0.0	0
42	9	3	5	0	0	0	0	0	0	0	0	0	0.0	0
43	9	2	5	83.9	6.2	102.1	4.7	54.1	54	79	24.6	10.1	2.9	3
44	9	5	0	0	0	0	0	0	0	0	0	0	0.0	0
45	9	1	12	83.8	6.1	35	6.2	26.8	73	103	25	15	1.4	2
46	8	5	0	0	0	0	0	0	0	0	0	0	0.0	0
47	8	2	6	0	0	0	0	0	0	0	0	0	0.0	0
48	8	5	0	0	0	0	0	0	0	0	0	0	0.0	0
SE	0.22	0.12	0.12	0.51	0.08	0.43	0.1	1.27	0.98	4.39	0.25	0.16	0.1	0.02
LSD	0.6	0.33	0.33	1.43	0.24	1.19	0.27	3.52	2.76	12.33	0.69	0.43	1.59	0.06
CV%	4	7	9	5.9	9.7	4.7	2	5.7	4	2	9	4	5.1	6.8

Appendix 18: Quantitative characters of the 48 sorghum accessions at Mutomo season two

AN	DAS	V	NL	LL	LW	PH	ST	SW	DF	DM	HL	HW	GY	HS
1	7	1	10	64.2	7.6	115.2	6.6	180	56	72	8	10	2.4	3
2	8	1	9	75.3	7.6	102.9	7.6	220	59	84	12.1	22.2	3.6	3
3	7	1	8	74	8	200.6	8.5	124.7	60	107	22	9	2.4	1.5
4	7	2	9	74.5	5.2	90	9	64.2	56	83	17.7	5.2	2.8	1.5
5	7	3	11	54.7	6.8	122	7.4	135.3	56	81	15.5	6.6	2.4	2.6
6	8	3	10	64.4	5.7	95	6	100	0	0	0	0	0.0	0
7	7	2	8	84.5	5.7	82	5.5	323.9	0	0	0	0	0.0	0
8	8	3	10	73.7	5.2	103.6	5	83	0	0	0	0	0.0	0
9	7	1	9	64	6.7	90	7.3	123	49	76	21.9	6.5	2.5	1.9
10	8	2	8	94.8	7.7	83.9	5.4	45.4	54	73	15.4	7	2.6	3.1
11	8	3	8	75	5.8	130.4	6.4	133.9	53	83	21	9	1.0	0.8
12	8	3	10	64	8	88	5.5	78	52	74	21.2	10.7	2.4	2.6
13	7	3	7	65	7	145	6	135	0	0	0	0	0.0	0
14	8	3	8	74	6.4	94.8	8	294.7	0	0	0	0	0.0	0
15	8	3	10	84.4	7.4	154	8.4	560	0	0	0	0	0.0	0
16	7	2	8	66.4	10.8	61	6.4	123.2	48	75	9	7.9	3.0	2.1
17	7	1	11	84.7	9	173.3	5	84.9	40	71	16.8	7.6	1.3	1.7
18	7	3	8	61.7	5.6	70	5	54.8	0	0	0	0	0.0	0
19	7	3	8	65.1	7	119	5.6	44.2	56	89	21.5	8.9	1.0	1.4
20	7	2	8	64.8	7.3	140	5	104.1	43	67	21.3	6.5	2.0	2
21	8	2	11	74.9	7.5	63.7	9	56.7	56	78	16.4	7	2.1	1.3
22	9	4	9	64	7.5	94.7	7	56	59	70	23	11.9	1.8	2
23	7	3	8	54.3	6	76.5	5	120	56	85	10	14.8	3.2	0.7
24	7	2	10	90	6.6	190	6	170	47	64	6	12	3.4	1.7
25	9	3	10	62.8	6	114.4	7	101.2	0	0	0	0	0.0	0

26	7	3	8	63.9	8.3	80	7	230	47	78	8	20	2.5	2
27	8	2	11	63.2	10	83.5	5	63.6	46	69	20.7	9	1.3	1
28	7	3	9	64.8	6.9	85	6.8	150	58	85	18	15.2	1.4	1.8
29	7	3	8	45	7	58.5	5.5	44.6	50	70	13	8.5	3.1	2
30	8	3	9	63.5	5.9	58.5	6	84.4	0	0	0	0	0.0	0
31	7	3	8	73	6	93	5	75	60	85	17	10	3.7	2
32	7	3	8	60	7.7	94.7	6	63	61	83	23.5	17	2.6	1
33	7	2	8	74.8	5.7	72.3	5.8	113.9	0	0	0	0	0.0	0
34	9	2	10	65.1	6	88	4	36	52	66	18	9	2.4	2.2
35	8	2	12	63.8	10	144.3	6	150	40	68	21.4	8.5	2.4	2.5
36	8	3	9	74	9	94.5	5.7	183.9	51	87	21	8.6	3.5	3.1
37	7	3	11	84.4	6.8	54.2	5.6	85	58	86	15.9	7	3.5	1
38	7	2	9	74.3	6.6	93.5	5	135	60	78	21	11	2.3	3
39	7	3	9	60	6.1	114.2	5	280	0	0	0	0	0.0	0
40	8	2	10	53	6	92	6	90	41	72	15.7	8.5	1.9	1.7
41	9	2	8	81.6	8	130	7.5	184.5	47	71	18.8	8.4	1.9	2
42	8	2	10	71	7.7	96	5	145	59	84	21.7	11	1.0	2
43	9	2	10	44	8	165	5	121	45	65	16.9	6	2.3	2
44	9	1	9	53	5.3	99	8	61	49	71	18	7.3	1.4	0.1
45	8	2	8	63.7	7.2	83.9	6.2	24.1	58	84	8	16.9	2.4	2
46	8	4	8	61.9	6	85.3	6.4	76	47	65	18	10	1.7	0.7
47	8	3	10	58	4	153	8	53	49	74	20	8	1.4	0.1
48	7	3	8	61	6	64.4	6	53	49	73	17	8	1.6	2
SE	0.12	0.12	0.11	0.44	0.27	6.79	0.07	4.26	1.45	1.3	0.22	0.16	0.3	0.01
LSD	0.33	0.33	0.29	1.21	0.75	18.84	0.21	11.83	4.06	3.66	0.6	0.44	0.03	0.03
CV%	3	8	6.4	3.5	2.2	3.6	6.5	1.6	6	4	9	1.3	5.3	3.8

Where in Appendix 11-18: - AN=accession number; DAS=days after sowing(days) V=seedling vigor NL=number of leaves; LL=leaf length(cm); LW=leaf width(cm); PH=plant height(cm); ST=stem thickness(cm); SW=stem weight(g); DF=days to flowering(days); DM=days to maturity(days); HL=head length(cm); HW=head width(cm); GY=grain yield(t/ha); HS=hundred seed weight(g)

Appendix 19: Comparison of seed viability and vigor between Seredo and Gatengu sorghum seeds dried for 1, 2, 3, 4, 5, 6, 7 and 8 weeks at different time of the day

	Drying regime	SD	SE	*P* = 0.05
Germination (%)	9.00 am-12.00 noon	3.167	1.12	0.001*
	12.00 noon-3.00 pm	0.9109	0.3221	0.011*
	3.00 am-6.00 pm	1.49	0.5269	0.003*
	9.00 am-6.00pm	2.376	0.8402	0.001*
	Drier (control)	0.8379	0.2963	0.001*
Mean Germination Time (days)	9.00 am-12.00 noon	0.1133	0.04005	0.030*
	12.00 noon-3.00 pm	0.1114	0.03937	0.001*
	3.00 am-6.00 pm	0.08287	0.0293	0.008*
	9.00 am-6.00pm	0.1998	0.07064	0.001*
	Drier (control)	0.1221	0.04317	0.013*
Leaf length (mm)	9.00 am-12.00 noon	1.944	0.6874	0.001*
	12.00 noon-3.00 pm	3.934	1.391	0.001*
	3.00 am-6.00 pm	1.865	0.6593	0.004*
	9.00 am-6.00pm	1.102	0.3898	0.007*
	Drier (control)	3.631	1.284	0.001*

Leaf area (mm^2)	9.00 am-12.00 noon	0.8853	0.313	0.018*
	12.00 noon-3.00 pm	2.155	0.762	0.006*
	3.00 am-6.00 pm	0.7457	0.2636	0.001*
	9.00 am-6.00pm	0.394	0.1393	0.001*
	Drier (control)	1.562	0.5521	0.002*
Root length (mm)	9.00 am-12.00 noon	2.588	0.915	0.001*
	12.00 noon-3.00 pm	2.775	0.981	0.001*
	3.00 am-6.00 pm	2.503	0.8849	0.025*
	9.00 am-6.00pm	2.421	0.8558	0.016*
	Drier (control)	1.756	0.6208	0.001*
Shoot length (mm)	9.00 am-12.00 noon	1.862	0.6585	0.001*
	12.00 noon-3.00 pm	2.241	0.7925	0.001*
	3.00 am-6.00 pm	2.409	0.8517	0.001*
	9.00 am-6.00pm	2.682	0.9482	0.001*
	Drier (control)	1.116	0.3947	0.001*
Growth rate (mg/day)	9.00 am-12.00 noon	0.2555	0.09032	0.001*
	12.00 noon-3.00 pm	0.08425	0.02979	0.001*
	3.00 am-6.00 pm	0.1553	0.05492	0.001*
	9.00 am-6.00pm	0.1712	0.06053	0.001*
	Drier (control)	0.2825	0.09989	0.001*

*Figures followed by an aesterick are significantly different at 5% level according to student’s t - test

Appendix 20: Publications emanating from the thesis

Muui, C. W., R. M. Muasya and D. T. Kirubi (2013). Participatory Identification and Evaluation of Sorghum (*Sorghum bicolor* (L.) Moench) Landraces from Lower Eastern Kenya. *International Research Journal of Agricultural Sciences,* Vol. 3(8): 283-290.

Muui, C. W., Muasya, R. M.and Kirubi, D. T. (2013). Baseline survey on factors affecting sorghum production and use in eastern Kenya. *African Journal of Food, Agriculture, Nutrition and Development,* Vol. 13(1): 7339 -7342.

Muui, C. W., R. M. Muasya and D. T. Kirubi (2013). Identification and Evaluation of Sorghum (*Sorghum bicolor* (L.) Moench) Landraces from Lower Eastern Kenya. *African Journal of Agricultural Research,* Vol. 8(36): 4573- 4579.

Muui, C.W., Muasya, R. M. and Kirubi, D. T. (2010). Promoting sorghum production and use through improved seed production technologies for food security in eastern Kenya. UniBRAIN/PanAAC Fair, Hilton Hotel, Nairobi. 26 - 27th November, 2010.