EVALUATION OF SELECTED INDUSTRIAL SORGHUM (*Sorghum bicolor* L. MOENCH) LINES FOR SUITABILITY TO DIFFERENT AGRO-ECOLOGICAL ENVIRONMENTS IN WESTERN KENYA

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DECLARATION AND RECOMMENDATION

Declaration

I hereby declare that this is my original work and has not been submitted in part or in whole for an award in any institution.

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Recommendation

This thesis has been submitted with our approval as supervisors for examination according to Egerton University regulations.

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DEDICATION

I dedicate this work to my lovely husband, daughter, parents and my siblings for their moral, emotional and financial support.

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ABSTRACT

Sorghum (*Sorghum bicolor* L. Moench) is a drought tolerant crop with a potential for industrial uses. Despite increase in demand for sorghum for industrial use, the local supply is low mainly due to to lack of high yielding sorghum genotypes. A number of genotypes with desirable properties for use in baking, malting and brewing have been identified however there is no information on the performance of these varieties in the agro-ecological zones traditionally used for sorghum production. The objective of the study was to contribute to an increase in sorghum production for industrial uses through determination and documentation of ideal environments for cultivation of the new sorghum lines. The specific objective of the study was to determine the effect of agro-ecological environment on yield, yield components and grain quality of selected industrial sorghum lines. The study was conducted in Mundika in Lower midland zone 2 (LM 2) in Busia County, Sinyanya (LM 3) and Masumbi (LM 1) both in Siaya County during the long rain season and in Sagam (LM 1), Nyahera (LM 3) both in Kisumu County and Mundika (LM 2) during the short rain season where agronomic and environmental suitability of nine sorghum lines identified for malting, brewing and for baking were evaluated. The experiments were conducted using a randomized complete block design (RCBD) with three replications. Planting was done at the onset of rains in each location. Data was collected from the two central rows per plot. To determine the effect of environment on sorghum grain quality, proximate analysis was done on the harvested and milled grains. All the data was subjected to analysis of variance using SAS version 8.1. Means were separated according to least significant difference (LSD) whenever the genotypic effects were significant ($P \leq 0.05$). Analysis of variance (ANOVA) revealed significant ($p \leq 0.05$) differences among sorghum lines for agronomic parameters, yield components and grain yield in all the sites. SDSA1 x ICSR43 recorded highest yields in LM 1 during the long rainy season which was 88.3, 36.0, 58.4, 73 and 87.2 % more than in LM 3 (short rainy season), LM 2 (long rainy season), LM 1 (short rainy season), LM 3 and LM 2 (short rainy season), respectively. Combined analysis showed that sorghum line x growing environment affected the nutritional quality of sorghum lines. The variances due to sorghum line were higher for starch content, protein content and amylose content, but the variability observed for tannin and amylopectin content were mostly due to agro-ecological environment of cultivation. The study showed that LM 1 in long rainy season is a stable agro-ecological environment for cultivation of the new sorghum lines. Cultivation of SDSA1 x ICSR43 line in LM 1 and LM 2 during the long rainy season and LM 2 during the short rainy season produces quality grains for malting and brewing with regard to tannin levels. Adoption of

these sorghum lines by the farmers and cultivation in the recommended areas will not only ensure sustainable production of quality grains to meet the increased industrial demand but will also contribute to national development and improvement of the livelihood of small holder farmers through increased food and income.

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LIST OF ABBREVIATIONS AND ACRONYMS

AEZ	Agro-Ecological Zone
ANOVA	Analysis of Variance
AOAC	Association of Analytical Communities
ASALs	Arid and Semi-Arid Lands
EABL	East African Breweries limited
FAO	Food and Agriculture Organization of the United Nations
LM	Lower midland zone
LSD	Least significant difference
MOA	Ministry of Agriculture
RCBD	Randomized complete block design
SAS	Statistical analysis system
KAPP	Kenya agricultural productivity programme

CHAPTER ONE

INTRODUCTION

1.1 Status of Sorghum Production in Kenya

Sorghum [*Sorghum bicolor* (L.) Moench] is a drought tolerant crop with a potential for industrial uses. Globally, it is the fifth most important cereal crop after wheat (*Triticum aestivum*), rice (*Oryza sativa*), maize (*Zea mays)* and barley (*Hordeum vulgare*) (Brink and Belay, 2006) while in Africa, it comes second after maize in terms of production. In sub-Saharan Africa, West Africa produces 60% of the total grain, which represent 25% of all sorghum grown in developing countries (FAO, 2010). Over the last one-decade sorghum production in Kenya ranged between 54,000 tons and 175,000 tons, varying significantly between years with production declining sharply in 2004 and 2008 (FAOSTAT, 2013). In 2004, decrease in production was mainly due to a reduction in yield, while in 2008 low production was strongly correlated with a reduction in both yield and total land planted to sorghum, resulting from post-election instability in 2007/2008 (Chemonics, 2010). Between 2008 and 2010, however, production tripled, increasing by almost 110,000 tons. Most of this growth was driven by expansion in the total area planted to sorghum, which was largely due to the promotion of sorghum as a drought-resistant crop in Kenya's Arid and Semi-Arid Lands (ASALs), emergence of EABL sorghum beer as well as attractive prices from increased consumption (MOA, 2011). Since 2008, total sorghum consumption in Kenya has increased once again, leveling off at more than 160,000 tons in 2010 to 2013 (MOA, 2010; FAOSTAT, 2013).

The impact of global warming and climate change has had an effect on rainfall distribution and patterns as well as temperature variations which are affecting crop performance. Barley, an essential raw material in the brewing industry, has been negatively affected by climate change resulting in insufficient quantities supplied to the East African Breweries Limited (EABL). Thus, the company has started utilizing sorghum in brewing owing to its ability to tolerate drought as well as lower cost of production and the lower excise tax compared to barley-made beers (EABL, 2013). Significant research on the utilization of sorghum as malt in brewing industries has been done in South Africa since the mid-20th century and in Nigeria during the 1970s (Palmer, 1992). Some of the desirable attributes which play a considerable role in sorghum grain for brewing include total starch, amylopectin, amylose, proteins, tannin content, germination energy and germination capacity. In Kenya, a recent evaluation of sorghum accessions from Eastern and Central Africa revealed the availability of sorghum lines with desirable attributes for malting and brewing.

For example, two genotypes namely SDSA 1 X ICSR 43 and SP 993520-1 submitted to East African Breweries for confirmatory test, were found to be suitable for brewing (Kiprotich *et al*., 2014).

As the only cereal species indigenous to Kenya, sorghum is produced throughout much of the country, even in areas with low agricultural potential. Sorghum can grow from sea level to 2,500 meters above sea level and requires a minimum rainfall of 250 mm per year and a minimum temperature of 10 °C (Chemonics, 2010). This is because the crop has extensive root system for maximum water absorption, leaves with waxy bloom to reduce water loss, C4 photosynthetic pathway and the ability to stop growth in periods of drought and resume it when conditions are favorable (Paterson, 2007; Ritter *et al*., 2007). In Kenya sorghum production is mainly concentrated within the Eastern, Nyanza, Western and Rift Valley regions, which accounted for about 43, 41, 9 and 7 percent, respectively, of Kenya's total sorghum production in 2011. Collectively, these regions produce 99 percent of the country's sorghum (MOA, 2012). However, despite the vast potentials of these areas, sorghum production in Kenya is too low to meet the increasing industrial demands. This is mainly due to lack of suitable genotypes and poor farming techniques leading to subsistence production. Nevertheless, production is expected to increase since more suitable sorghum lines for industrial uses have been identified and passed the National Performance Trial for release.

Commercial release of new sorghum cultivars for malting and brewing and for baking requires understanding the performance of potential genotypes in different environmental conditions. Genotype by environment interactions can complicate the recommendation of cultivars to different environments, making evaluation across varied agro-ecological environments necessary. The study of adaptability and stability allows the identification of genotypes with predictable behavior in specific or general environments, and the identification of genotypes sensitive to positive environmental variations (Cruz *et al*., 2004). With more than one improved sorghum varieties existing each with varying production, consumption and marketing traits, farmers are more likely to simultaneously adopt more than one variety in order to address their multiple needs. This study was aimed at enhancing sorghum production for industrial uses through determination and documentation of ideal environments for cultivation of the new sorghum lines.

1.2 Statement of the Problem

Owing to its ability to tolerate drought, sorghum is widely grown in marginal agro-ecological zones. Most sorghum farmers in Kenya are small scale subsistence farmers growing it for food while a few grow sorghum for sale. Sorghum is utilized by East African Breweries for malting and brewing where the industry had projected to use 45, 000 tons of sorghum by the year 2015 but only realized a third of this. Despite this increasing demand for sorghum for industrial use, the local supply is low mainly due to lack of high yielding sorghum genotypes. The projected increase in sorghum demand in the immediate future can only be realized if factors limiting their production are addressed. In response to increasing demand for grain sorghum, a number of genotypes with desirable properties for use in baking, malting and brewing have been identified. Some of these identified lines include SDSA1 X ICSR 43, IS 9203 and IS2556 which have passed the National Performance Trial for release. However, there is no information on the performance of these varieties in the agro-ecological zones traditionally used for sorghum production. The information regarding the effect of these agro-ecological zones on the grain quality attributes of sorghum desirable for baking, malting and brewing is lacking. The new sorghum lines therefore need to be evaluated across varying agro-ecological zones in the sorghum growing areas in order to develop proper advice to sorghum farmers for sustainable production of quality grains.

1.3 Objectives

1.3.1 General Objective

To contribute to an increase in production of sorghum for industrial uses in diverse agro-ecological environments of Kenya through documentation of ideal environments.

1.3.2 Specific Objectives

1. To determine the effect of agro-ecological environment on yield and yield components of selected industrial sorghum lines,
2. To determine the effect of agro-ecological environment on grain quality of selected industrial sorghum lines.

1.4 Hypotheses

1. Agro-ecological environments have no effect on yield and yield components of industrial sorghum.

2. Agro-ecological environments have no effect on the grain quality of sorghum for industrial uses.

1.5 Justification

In Kenya, over 80% of the land lies under arid and semi-arid regions (MAFAP, 2013) which form potential growing areas for sorghum owing to its ability to tolerate drought. The environment in which sorghum genotype is cultivated influences its ability to express its genetic potential for plant vigor, adaptability to abiotic and biotic stresses, grain quality, and yield potential as well as maturity period. In Kenya, sorghum production is largely at subsistence level mainly due to lack of high yielding genotypes. However, with availability of the high yielding sorghum lines with ready markets, more farmers in sorghum growing areas are likely to venture into sorghum production. Evaluation of high yielding sorghum lines across different sorghum growing areas provides information on their performance and suitability under different agro-ecological environments. Therefore, adoption by the farmers and the cultivation of these sorghum lines in suitable environments will not only ensure increased sorghum production to meet the increased industrial needs and decrease demand gap, but will also contribute to improved livelihoods through increased food and income. This will have a positive impact on the economy of the country through food security and revenue generation thus contributing to national development.

CHAPTER TWO

LITERATURE REVIEW

2.1 Origin and Geographical Distribution of Sorghum

Sorghum is thought to have originated from Ethiopia due to greatest diversity in both cultivated and wild types of sorghum (Brink and Belay, 2006). From North Eastern tropical Africa, the crop was distributed all over Africa and along shipping and trade routes to the Middle East and India. In India, it is believed to have been carried to China along the silk route, through the slave trade and the coastal shipping to the South. It was subsequently introduced to Australia and South America. It is now widely cultivated in drier areas of Africa, Asia, the Americas, Europe and Australia between latitude of up to 50˚N in north America and Russia and 40˚S in Argentina.

2.2 Taxonomy of Sorghum

Sorghum belong to the kingdom *Plantae*, Sub-kingdom *Tracheonionta*, Super-division *Spermatophyta*, Class *Liliopsida*, subclass *Commeliniadae*, order *Cyperates*, family *Poaceae* and genus *Sorghum* (Liu et. al, 2009). The species include *arundinaceum* (where common wild sorghum belong), *bicolor* (which consists of grain sorghum), *drummondii* (Sudan grass), *almum* (Columbus grass), and *halepense* or Johnson grass (Wiersema and Dahlberg, 2007). Harlan and de Wet (1972) published a simplified classification of sorghum which has been checked against 10,000 head samples. They divided cultivated sorghum into five basic groups or races: *bicolor*, *guinea*, *caudatum*, *kafir* and *durra*. The wild type and the shatter cane are considered two of the other spikelet types of *Sorghum biicolor*.

2.3 Ecology of Sorghum

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 which include: an extensive root system, waxy bloom on leaves that reduces water loss, and the ability to stop growth in periods of drought (Brink and Belay, 2006) and resume it when the stress is relieved. A rainfall of 500-800 mm evenly distributed over the cropping season is normally adequate for cultivars maturing in three to four months. Sorghum tolerates waterlogging and can be grown widely in temperate regions and altitudes up to 2300 m in the tropics. The optimum temperature (Dogget, 1988) is 25^0-31 ^{0}C but temperatures as low as 21^{o}C will not affect growth and yield significantly.

Sorghum is a short day plant with a wide range of reactions to photoperiod (Brink and Belay, 2006). Some tropical cultivars fail to flower or to set seeds at high latitudes**.** Sorghum is well suited to grow on heavy vertisols commonly found in the tropics, where its tolerance to waterlogging is often required but is equally suited to light sandy soils. Since it is one of the major rain-fed crops for food and fodder in tropics and subtropics of the world which are already towards the higher side of the tolerant range of temperature, a small change in climate could therefore drastically reduce the production of the crop (Vander *et al*., 2013). The soil, climatic characteristics and the potential crop productivity in many of the Agro-Ecological Zones (AEZs) around the world offer much hope for enhancing future crop production (Sivakumar and Valentin, 1997). Thus, AEZs approach would help to understand the multiplicity of agronomic, economic and environmental factors that determine the performance of an agro ecosystem and then determine the nature and extent of changes that need to be introduced to achieve greater productivity for more efficient land use resource in the future.

2.4 Sorghum Production

Sorghum is the fifth most important cereal crop after wheat, rice, maize and barley; and is the staple diet for more than 500 million people in more than 30 countries in the world. It is grown on 42 million hectares in 98 countries of Africa, Asia, Oceania and Americas (FAO, 2010). Nigeria, India, USA, Mexico, Sudan, China and Argentina are the major producers of sorghum in the world. In Sub-Saharan Africa, West Africa produces 60 % of the total grain, which represent 25 % of all sorghum grown in developing countries (FAO, 2010).

In India, the area under high yielding cultivars has increased from 0.7 million hectares in the early 1970s to 6.5 million hectares in the late 1990s. While the area for production in Eastern and South Africa has increased from the early 1970s to 2006, there is marginal (15 %) increase in yield from 800 kg per hectare in the early 1970s to just over 920 kg per hectare in 2006. In Western and Central Africa, substantial improvement in production was achieved from 700 kg per hectare in the early 1970s to 1080 kg per hectare in 2005 indicating increased production by 54 %. The area increased by almost two-folds, production increased nearly 2.5 times the early 1970s to 2006 (FAO, 2010).

In Latin America, the area increased marginally from 4 million hectares in the early 1970s to 5 million hectares in the early 1980s followed by a slight decrease till 2006, almost maintaining the level of the early 1970s (FAO, 2010). The production was 1.7 times from the early 1970s (9 tons) to the early 1980s (15 tons). This decreased steeply thereafter to 9 tons in the early 1990s. However, the production increased thereafter to 11 tons by 2006. The production increased from 200 kg per hectare in the early 1970s to 3100 kg per hectare in 2006.

Over the last one decade sorghum production in Kenya ranged between 54,000 tones and 175,000 tons, varying significantly between years with production declining sharply in 2004 and 2008 (FAOSTAT, 2013). In 2004, decrease in production was mainly due to a reduction in yield, while in 2008 low production was strongly correlated with a reduction in both yield and total land planted to sorghum, resulting from post-election instability in 2007/2008 (Chemonics, 2010). Between 2008 and 2010, however, production tripled, increasing by almost 110,000 tons. Most of this growth was driven by expansion in the total area planted to sorghum, which was largely due to the promotion of sorghum as a drought-resistant crop in Kenya's ASALs, as well as attractive prices from increased consumption (MOA, 2011). Total sorghum consumption in Kenya increased from 128,250 tons in 2005 to 139,637 tons in 2007, but decreased to only 33,000 tons in 2008 due to post-election instability and an affiliated decline in sorghum production. Since 2008, total sorghum consumption in Kenya has increased once again, leveling off at more than 160,000 tons in 2010 to 2013. Furthermore, EABL contracts created a significant increase in sorghum production (MOA, 2010; FAOSTAT, 2013).

2.5 Constraints in Sorghum Production

2.5.1 Limited Access to Quality Seeds and Inputs

Sorghum is termed as the poor man's crop and mainly cultivated by resource poor farmers who have limited access to quality seeds due to low income status. They therefore depend on informal seed supply sources such as on-farm seed savings and sometimes, other farmers may consume all the grains and on planting season they end up borrowing some seeds from their neighbours (Gisselqiuist, 1998; Ochieng *et al*., 2011; Muui *et al*., 2013). Poor storage of on-farm saved seeds has been reported as the main cause of seed borne diseases that are associated with low grain production which is well below the genetic potential of the genotypes used (Abdulsalaam and Shenge, 2011). However, expanded use and higher yields of the sorghum are being realized using hybrids. Resource poor farmers have limited access to inputs such as fertilizers that help to alleviate soil infertility problems thus resulting in poor crops that give yields below optimum potential. In addition, sorghum farmers have not benefited from the subsidized fertilizer scheme operated by the government compared to maize farmers (Riziki and Maina, 2013).

2.5.2 Pests and Diseases

Sorghum midge (*Stenodiplosis sorghicola*), Africa sorghum headbugs (*Eurystylus oldi*) (Henzell *et al*., 1997), sorghum shootfly (*Atherigona soccata*), stem borers (*Buseola fusca*, *Chilo partellus* and *Sessamia calamistis*) (Brink and Belay, 2006) have serious economic impact on sorghum production. Sharma and Teetes (1995) reported that 10-15% of the world sorghum crop is destroyed by sorghum midge, and in Western Kenya nearly 30% of sorghum grain valued at US$ 7 million is destroyed by the pest. Midge is one of the most damaging sorghum pest causing huge losses (Tao *et al*., 2003). Early planting integrated with use of insecticides are effective ways of controlling the pest. Shoot fly larvae attack shoots of seedlings and tillers causing 'dead heart'. Stem borers cause damage in all crop stages. Damage by both shoot fly and stem borers can be reduced by early, non-staggered planting; and seed or soil treatments with appropriate insecticides (Brink and Belay, 2006). In Kenya, shoot fly, birds, ants, aphids and stem borers are major constraints in sorghum production in Eastern Kenya (Muui *et al*., 2013) while birds are the most serious pest of sorghum in Bomet district in Rift Valley province (Ochieng *et al*., 2011).

Common seed and seedling root diseases in sorghum are caused by soil and soil borne *Aspergillus, Fusarium, Pythium, Rhyzoctonia* and *Rhizopus spp*. They are controlled by treatment of the seeds with fungicides (Brink and Belay, 2006). Anthracnose (*Colletotrichum graminicola*) is common in hot and humid parts of Africa (Brink and Belay, 2006). Control measures include the use of resistant cultivars and crop rotation. Downy mildew (*Peronosclerospora sorghi*) may cause serious yield losses which can be avoided through use of resistant cultivars and seed treatment. Smuts (*Sporisorum spp*) are important panicle diseases. Loose and covered kernel smuts are controlled through seed treatment with fungicides while resistant cultivars and cultural practices such as crop rotation and removal of infected panicles effectively controls head smut and long smut. Grain mould is most severe in seasons when rain continues through the grain maturity stage and delay the harvest. Control measures include adjustment of the sowing dates to avoid maturation during wet weather and the use of resistant cultivars.

2.5.3 Drought

Drought is one of the most important abiotic stresses limiting sorghum (*Sorghum bicolor*) production around the world with great significance in the semi-arid tropics, where rainfall is generally low and its distribution erratic (Ejeta *at al.,* 1999). Arid and semi-arid lands (ASALs) cover 80% of Kenyan land mass (MAFAP, 2013) posing a great challenge to crop production in these areas. An effective and sustainable way to alleviate problems of crop production associated with drought is the development of crops that withstand moisture stress (Ribaut and Poland, 2000). There are three types of drought in sorghum; Seedling, pre-flowering and post-flowering drought stress (Rosenow and Clark, 1981; ICRISAT, 1984). Post-flowering drought stress manifests in stalks lodging, charcoal rot (*Macrophomina phaseolina*) disease, reduced seed size, premature plant senescence and death (Rosenow, 1993). Drought affects livelihoods of half a billion people who live in the Semi-Arid Tropics (House, 1996). Soil water deficits were found to be the most important cause of yield loss in Eastern Africa with soil water deficits during crop establishment and during grain fill being major constraints in Ethiopia, while mid-season water deficits were of relatively greater concern in Kenya and Uganda (Wortmann *et al*., 2006).

2.5.4 Soil Fertility Levels

Soil degradation and low fertility are among the most severe specific constraints for sorghum in Sub-Saharan Africa (Waddington *et al*., 2010). Several nutrient deficiencies or problems such as phosphorus deficiency, aluminum toxicity in acid soils, salinity toxicity and iron chlorosis on alkaline soils reduce yields in sorghum (Rooney, 2004). The degradation of land resources, particularly soils, pose a great threat to food production, food security and the conservation of natural resources (Omotayo and Chukwuka, 2009; Ye *et al*., 2010). In Zimbabwe, poor soil fertility is reported as major among the many production constraints (Makanda *et al*., 2009). Soil infertility, including nitrogen deficiency, soil physical degradation and poor fertilizer management are severe and widespread (Waddington, 2010). In Eastern horn of Africa, soil infertility is among the major challenges to sorghum production. In Ethiopia, declining soil fertility is a major constraint on crop production in the semi-arid highlands of Tigray (Corbeels *et al*., 2000). In Uganda, poor soil fertility was listed among the many constraints of low production of sorghum (Nabimba *et al*., 2005). In Kenya, low soil fertility and high cost of inorganic fertilizers are a major constraint to sorghum production in marginal environments (Ashiono *et al*., 2006).

2.6 Economic Importance of Sorghum

Sorghum (*Sorghum bicolor*) is a perennial crop with diverse uses with almost all parts of the crop utilizable in one way or another. However, the crop is mainly grown for its grains which is important for food security purposes. Sorghum is used for human consumption and as feed for animals. Nutritionally, most sorghum grains register 9% protein and low crude protein digestibility due to high percentage of prolamines and tannins (Devries and Toennissen, 2001). It has also been found to be a good source of insoluble fibres which may decrease transit time and prevent gastro-intestinal problems (Ledeer, 2004). In addition, the grains have beta-carotene, a pre-cursor of vitamin A which is important for human growth. In developing countries, the commercial processing of these locally grown grains into value-added food and beverage products is an important driver for economic development (Taylor et al., 2004). The use of sorghum not only provides farmers with a market for their products but also saves foreign exchange, which would otherwise be required to import cereals. It is often recommended as a safe food for coeliac patients, because it lacks the gluten the triticeae tribe cereals wheat, rye and barley (Ciacci *et al*., 2007), being a member of the Panicoideae sub-family which also includes maize and most millets (Shewry, 2002). Sorghum therefore, provides a good basis for gluten-free breads and other baked products like cakes and cookies (biscuits) and snacks and pasta. In addition, the sorghum flour is traditionally used in making "ugali" (thick porridge or gruel). Sorghum grain is used as animal feed in the Americas, China and India. In India, where rainy season sorghum heads are affected by moulds, the grain is used as animal/ poultry feed (Brink and Belay, 2006).

Sorghum grains are also malted and used for brewing beer in Kenya, Ghana, and Nigeria among other countries in the world. Significant research on the utilization of sorghum as malt in brewing industries has been done in South Africa since the mid-20th century and in Nigeria during the 1970s (Palmer, 1992). In Nigeria, industries use about 200,000 tons of sorghum annually (Mohammed *et al.,* 2011). However, not all sorghum varieties are suitable for use in malting and brewing. Sorghum genotypes with high tannin levels are considered unsuitable since tannins bind to proteins making them less digestible yet they are the key source of energy for yeast during fermentation process (Ambula *et al.*, 2003). On the other hand, tannins, which are in high concentration in red-grained sorghum, contain compounds called antioxidants that protect cells against damage, a major cause for disease and aging. Sorghum syrup is concentrated and sterilized to make natural syrup. The syrup is used in confectionary industry as sweetener. The syrup can also be used instead of honey with breakfast foods. The juice can be concentrated to make jiggery as that of sugarcane.

The plant stem and foliage are used for green chop, hay, silage and pasture. In some areas, the stem is used for hut making. The plant remains after the sorghum head are harvested are used as fuel for cooking. The crop residues (stover) are used as fodder for livestock because of its wide adaptation, rapid growth, high green and dry fodder, ratoonability and drought tolerance. Forage sorghum is mostly utilized in North India and in West Africa. Forage sorghums are fed to animals as a green chop or hay (quickly dried sorghum for fodder). Moreover, bio-fuel is produced from sweet sorghum types. The stalks are used for ethanol production which is then blended with petrol to reduce fuel costs.

CHAPTER THREE

EFFECT OF AGRO-ECOLOGICAL ENVIRONMENTS ON YIELD AND YIELD COMPONENTS OF SELECTED SORGHUM [*Sorghum bicolor* (L.) Moench] LINES

Abstract

Sorghum (*Sorghum bicolor* L. Moench) is a drought tolerant crop with a potential for industrial uses. The objective of the study was to determine the effect of growing environments on the yield and yield components of the new sorghum lines for industrial uses. The study was conducted in Busia, Siaya and Kisumu counties of Kenya during the long and short rainy seasons in three different agro-ecological zones. These are Lower Midland (LM) zones in subzones LM 1, LM 2 and LM where agronomic and environmental suitability of nine sorghum lines identified for malting and brewing and for baking were evaluated. The experiment was laid out in randomized complete block design with three replications. Planting was done at the onset of rains in each location. Data on the agronomic traits of interest was collected from the two central rows per plot. All the data were subjected to analysis of variance using SAS version 8.1 and additionally, Genstat® software was used to run a scatter plot using yield data to determine stability in different growing environments. Means were separated according to LSD whenever the genotypic effects were significant ($P \leq 0.05$). There were significant ($P \leq 0.05$) differences among sorghum lines for grain yield in all the sites. There was a genotype x environment effect ($p \leq 0.05$) for the grain yield of the sorghum lines. Significant ($P \leq 0.05$) differences among lines were observed for agronomic parameters, yield components and grain yield. The sorghum line SDSA1 x ICSR43 recorded highest yields in LM 1 in long rainy season which was 88.3, 36.0, 58.4, 73 and 87.2% more than in LM 3 (short rainy season), LM 2 (long rainy season), LM 1 (short rainy season), LM 3 and LM 2 (short rainy season), respectively. The study showed that LM 1 in long rainy season is a stable agro-ecological environment for cultivation of the new sorghum lines. Adoption of these sorghum lines by the farmers and cultivation in the recommended areas will ensure sustainable production of quality grains to meet the increased industrial demand contribute positively towards national development and improvement of the livelihood of small holder farmers through increased food and income.

Keywords: Malting, New sorghum lines, Sorghum yields

3.1 Introduction

Sorghum (*Sorghum bicolor* (L.) Moench) mainly a rainfed crop grown in semi-arid environments of Kenya has a high potential for industrial utilization. However, in Kenya the crop's industrial uses are still at the infant stages due to lack of suitable genotypes. In a recent study by Kiprotich *et al.* (2013), suitable genotypes for use in malting and brewing and in baking were identified in Kenya. The capacity to ensure sustainable quality grain production depends largely on the agro-ecological adaptation of these sorghum lines and cropping calendars to local, seasonal patterns of rainfall which are geographically diverse (AGRHYMET, 1992) and vary across years (Sultan and Janicot, 2003; Sultan *et al*., 2005; Turgut *et al*., 2005). This is because a large diversity of crop germplasm particularly adapted to local climatic patterns has evolved (Traore *et al*., 2000) which has largely due to different levels of photoperiod sensitivity (Craufurd *et al*., 1999; Craufurd and Qi, 2001; Clerget *et al*., 2004). Therefore, understanding the genotype by environment interaction is essential in determination of the stability of a given genotype to a given environment.

The criteria for the selection of suitable genotypes may be yield, or one or more of the yield component characters. However, breeding for high yielding crops require information on the nature and magnitude of variation in the available materials, relationship of yield with other agronomic characters and the degree of environmental influence on the expression of these component characters. Selection based on grain yield character alone is usually not very effective and efficient. However, selection based on its component characters could be more efficient and reliable (Ali *et al*., 2009). Knowledge of association between yield and its component traits and among the component parameters themselves can improve the efficiency of selection in plant breeding.

Kenga *et al*. (2004) reported that over the last 20 years, sorghum production area in Africa has increased yet the average production has not increased. Umadevi *et al*. (2010) indicated that yield is a complex quantitative trait greatly influenced by environmental fluctuations. Sorghum crop exhibits considerable differences in plant traits, panicle and grain characteristics including physiological responses to selection and is highly influenced by environmental factors (Ezeaku and Mohammed, 2006). Thus, the scenario in Africa could be ascribed to less exploitation of high yielding cultivars or where used they are not grown in suitable agro-ecological environments where they can fully express their genetic potential for yield. The objective of the present study was to evaluate the effect of agro-ecological environment on yield and yield components of selected sorghum lines.

3.2 Materials and Methods

3.2.1 Experimental Site

All the experimental sites were in lower midland zone (LM) specifically in subzones 1, 2 and 3. In Siaya County, two sites were used namely Masumbi and Sinyanya. Sinyanya (00^{o} 06’ 68.5’’ S, 034^{o} 08’ 66.0’’E) is located in Bondo sub-county at an altitude of 1168 m above sea level in Lower Midland Zone (LM 3). The experiments were conducted in the first rainy season of 2014 for both Masumbi and Mundika. The predominant soil types in this sub-zone are poorly drained, deep, dark grey to black, humic gleysols and dystric histosols (Jaetzold *et al*., 2005). The rainfall amount is variable and hence reliability is a problem. During the first rainy season, rainfall amount of more than 480 – 600 mm (increasing from South West to North East) is expected in 10 out of 15 seasons and more than 340 mm during the second rainy season. Masumbi (00^{o} 01’ 73.0’’ N, 034^{o} 21’ 87.4’’ E) located in Maranda Division at an altitude of 1370 m above sea level is in Lower Midland (LM 1) zone. Plate 3.1 show photos of experiments conducted in Sinyanya and Masumbi. Dominating soils in this zone are the orthic acrisols and rhodic ferrasols defined by well drained, moderately deep to very deep, dark red to strong brown, friable clay; in many places shallow. The rainfall amount is variable but high and hence reliability is not really a factor of concern. During the first rainy season, more than 750 – 950 mm of rainfall is expected in 10 out of 15 seasons and more than 600 – 800 mm during the second rainy season.

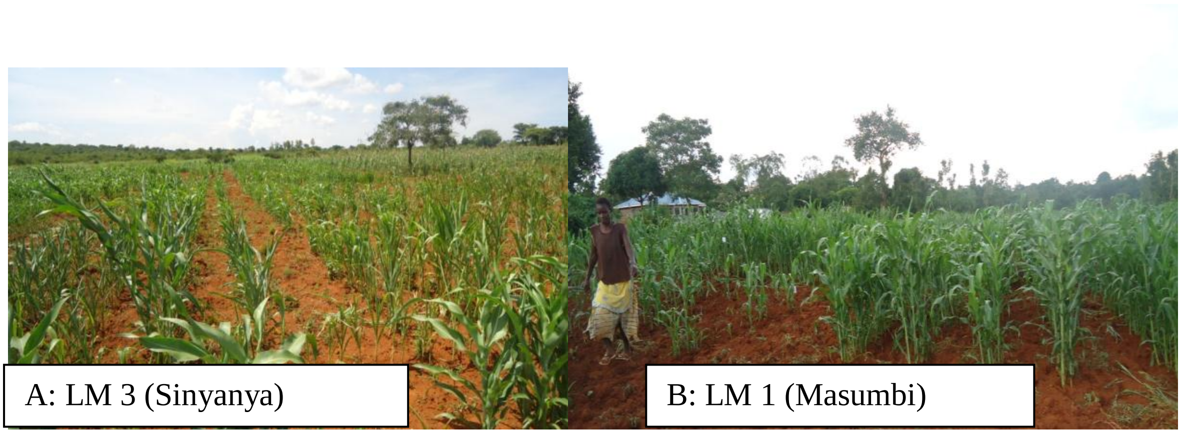

Plate 3.1: Photo A shows the experiment at Sinyanya while B show the experiment at Masumbi

In Busia County, the experiment was carried out in Mundika (00^{o} 24’ 56.6” S, 034^{o} 07’ 93.1” E) during long and short rain seasons in 2014. Plate 3.2 shows sorghums plants for experiment conducted in Munidka during long rains. It is in LM 2 zone characterized by well drained, shallow to moderately deep, yellowish red to dark redish brown, friable, gravely sandy clay to clay soils classified as orthic acrisols with dystric cambisols (Jaetzold *et al*., 2005). The rainfall variability in this subzone is high, and hence the reliability is low. The first rainy season can rely on an amount of at least 800 – 1000 mm in 10 out of 15 seasons and 500 – 700 mm during the second rainy season.

Plate 3.2: Field experiment at Mundika during the long rains season

In Kisumu County, the experiment was laid out in two sites namely Sagam and Nyahera in the second season of 2014. Map of the study areas is shown in figure 3.1. Sagam (0^o 03’20.86” N, 034^o 32’31.06” E) is in LM 1 zone at 1387 m above sea level. dominating soils are phaeozems which are soils that are moderately well drained, moderately deep to deep, (very) dark brown, firm clay; in many places slightly calcareous and/or cracking clay; with a humic topsoil. The zone receives an average annual rainfall of 1450-1650 mm where 60% reliability of the growing periods during the 1st and 2nd rainy seasons is more than 190 and 130 - 150 days, respectively. Annual temperature range is 21.2-22.8 ^{o}C. On the other hand, Nyahera (0^o 02’52.78” S, 034^o 39’03.59” E) lies in LM 3 at 1216 m above sea level. Soils are orthic luvisols and eutric cambisols characterized by well drained, shallow, dark yellowish brown, gravelly clay to clay soil. The area receives an annual rainfall of 1450-1650 mm and annual temperature range of 22-22.7^{o}C.

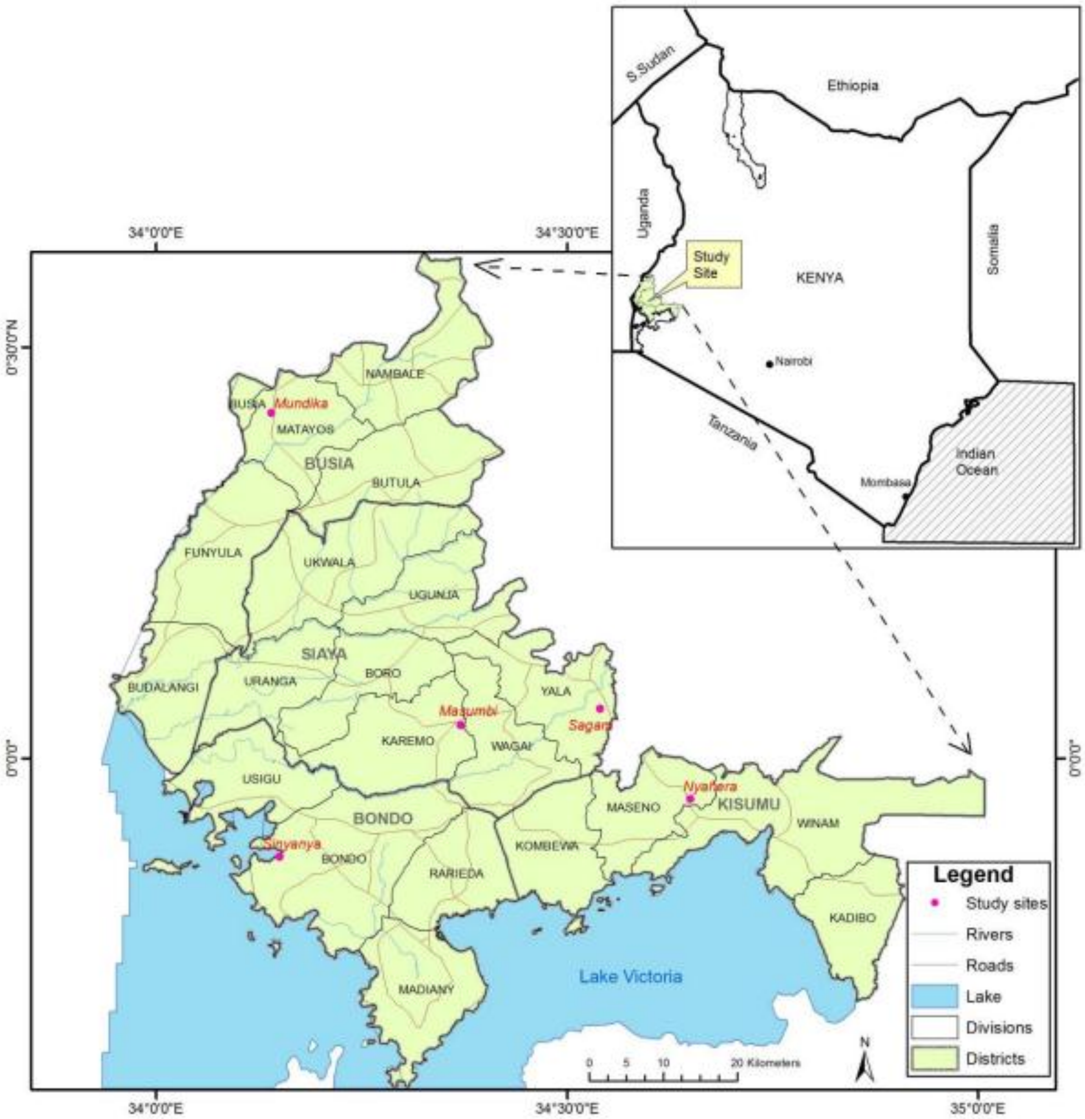

Figure 3.1 : Map of the study area (Source: Kenya Survey)

3.2.2 Treatments

Nine sorghum lines suitable for baking and for malting and brewing were evaluated across selected agro-ecological environments. These lines are SDSA1 X ICSR 43, IS 9203, IS25561, IS 25557, *Sima, Gadam, Serena, Siaya* # 2-3, and *Abaleshya. Sima, Gadam,* and *Serena* were used as the control for the line identified for malting and brewing (SDSA1 X ICSR 43) while *Siaya* #2-3 and *Abaleshya* were the checks for lines identified for baking (IS 9203, IS25561 and IS 25557). *Gadam* grows to a height of 100-130 cm and takes 45-52 days to flower. It matures in 85-95 days after planting and the yields ranges between 1700 and 4500 kg ha^{-1}. In addition, the crop is known for its distinctive characteristic of tolerating pests and drought while the grains have good brewing characteristics. *Serena* on the other hand gives about 1800 to 2300 kg ha^{-1} of grains. It grows to a height of 150-160 cm, takes 69 to 78 days to flower and matures in 110 to 120 days after planting (KARI, 2006). *Abaleshya* grows to a height of 130 to 140 cm and takes 105 to 110 days to flower. Its yield ranges between 1800 kg and 2700 kg per hectare. Siaya #2-3 is a local landrace highly valued by the farmers due to its high grain yield and in addition has compacted head and bitter taste, which is a protective measure against bird damage.

3.2.3 Experimental Design

The experiment was set up in a Randomized Complete Block Design (RCBD) with nine experimental units each measuring 4 m by 2.5 m and replicated three times. A path of 1.5 m separated the replicates. The blocking was based on the gradient of the land. The treatments were the nine sorghum lines evaluated in the selected agro-ecological environments. Each experimental unit had four rows of a specific sorghum line.

3.2.4 Agronomic Management

Land was disc ploughed and harrowed to fine tilth. At the onset of rains, hand sowing at a seed rate of 8 kg ha^{-1} was carried out. The inter row spacing for the drills was 60 cm at a planting depth of 2.5-4 cm. After the first weeding the crop was thinned to a spacing of 60 cm (inter row) by 10 cm (intra row). Due to low nitrogen and phosphorous levels in these soils (Table 3.1), there was a uniform fertilizer application in all the plots. Phosphorous was added at planting through Triple Super Phosphate at a rate of 17.2 P_2O_5 kg ha^{-1}. Nitrogen was applied through Calcium Ammonium Nitrate at the rate of 40 kg ha^{-1} split into two applications of 20 kg Nha^{-1} at planting and top dressed with 20 kg Nha^{-1} three weeks after seedling emergence. Two weeding operations were carried out manually using hoes, with the first weeding being done at 2-3 weeks after seedling emergence. The second weeding was then carried out when the crop was about 45 cm high. Harvesting was done when the crop had reached physiological maturity indicated by black layer formation in grains as shown in plate 3.3.

Plate 3.3: Evaluated sorghum lines ready for harvesting at Mundika (LM 2)

Table 3.1: Soil components of experimental sites

County	site	[**]AEZ	pH	Soil type	Nitrogen (%)	Phosphorous (ppm)
Siaya	Masumbi	[*]LM1	5.8	Clay loam	0.11	9.75
Siaya	Sinyanya	LM3	5.4	Sandy clay loam	0.17	8.8
Busia	Mundika I	LM2	4.4	Sandy clay loam	0.09	6.4
Busia	Mundika II	LM2	4.4	Sandy clay loam	0.09	6.4
Kisumu	Sagam	LM1	4.7	Clay loam	0.12	8.5
Kisumu	Nyahera	LM3	6.0	Sandy clay loam	0.15	5.5

3.2.5 Data Collection

Data were collected from the two (2) inner rows of the four rows in each plot. During crop establishment in the field, the agronomic traits and quality of important consideration included stand count after thinning, plant height at flowering, and days to 50% heading. Stand-count was determined after thinning the crop to a spacing of 10 cm between plants within the rows. A sample of three plants per two interior rows was used on data collection regarding plant height followed by computations of means to determine the measurements per plant. The plant height at flowering was measured from the base of the plant to the collar of the uppermost leaf using a tape measure. Days to 50% heading were recorded when half the plant population per plot had flowered. Total grain yield in tons per hectare was determined through conversion of yields per unit plot (5 m^2) into yields per hectare after standardization to 13% moisture content.

After harvesting and sun drying of the panicles, sample of five heads per plot were taken for panicle characterization. The panicle length from the base of the first spike to the tip of the panicle and spike length from point of attachment to the panicle to its tip was measured using a calibrated 30 cm ruler. Their weights were measured using top pan electronic balance. The number of kernels per panicle and 100 kernels per sorghum line were manually counted and 100 kernel weight determined using a top pan electronic balance.

3.3 Data Analysis

Data were subjected to analysis of variance using SAS version 8.1 (Littel *et al.*, 2002). Means were separated according to least significant difference (LSD) whenever the sorghum line effects were significant ($P \leq 0.05$). The data on yield was also analysed by GxE scatter plot.The statistical model for the data analysis is represented as:

$$Y_{ijkl} = \mu + L_i + R_{j(i)} + V_k + VL_{ij} + \varepsilon_{ijkl}$$

In the equation, Y_{ijkl} is the response variable, μ is population mean, L_i is the i^{th} effect due to location, $R_{j(i)}$ the j^{th} replicate effects on i^{th} location, V_k is the k^{th} effect due to sorghum line, VL_{ik} is the i^{th} effect due to location on k^{th} sorghum line and ε_{ijk} is the random error.

3.4 Results and Discussion

3.4.1 Stand Count

Variation in stand count was noted among the sorghum lines in all the test environments except when the lines were grown at Mundika (LM 2) during the long rainy season (Table 3.2). Sorghum lines for malting and brewing, maintained similar plant density when grown in Masumbi (LM 1) and during the long rainy season in Mundika (LM 2). However, SDSA1 x ICSR43 line had relatively 24.2% higher stand count than *Sima* and *Serena* at Sinyanya (LM 3). When grown at Nyahera (LM 3), SDSA1 x ICSR43 line produced 24.9% more plants than *Sima* and 15.9% fewer plants than *Serena*. Evaluating the lines at Sagam (LM 1), SDSA1 x ICSR43 line recorded 26% fewer plants per unit area than *Gadam*. This is an indication of genetic variability among the sorghum lines in the adaptability to varying environmental conditions.

Table 3.2: Effect of sorghum lines, environment and their interaction on stand count

Lines	Stand count (Plants m^{-2})						
	Sinyanya (LM 3)	Masumbi (LM 1)	Mundika (LM2)	Sagam (LM 1)	Nyahera (LM 3)	Mundika (LM 2)	
	← Long rains →			← Short rains →			$LSD_{0.05}$
SDSA1 x ICSR43	12.00^{a}‡$_{CD}$†	32.67^{a}_{A}	28.33^{a}_{AB}	27.00^{bc}_{AB}	17.33^{b}_{BC}	5.00^{f}_{D}	11.31
Sima	7.33^{bc}_{B}	23.33^{a}_{A}	29.00^{a}_{A}	9.67^{d}_{B}	10.67^{c}_{B}	6.67^{ef}_{B}	12.19
Serena	7.30^{bc}_{C}	17.67^{ab}_{BC}	18.00^{a}_{BC}	33.00^{ab}_{A}	23.67^{a}_{AB}	14.67^{ab}_{BC}	13.77
Gadam	10.00^{ab}_{C}	29.33^{a}_{AB}	16.67^{a}_{BC}	46.00^{a}_{A}	18.00^{ab}_{BC}	9.33^{cde}_{C}	19.00
IS 9203	4.00^{cd}_{C}	7.00^{b}_{C}	17.00^{a}_{A}	15.67^{cd}_{AB}	6.00^{c}_{C}	7.67^{def}_{BC}	8.27
IS 25557	5.00^{cd}_{B}	27.33^{a}_{A}	22.33^{a}_{A}	25.67^{bc}_{A}	8.67^{c}_{B}	10.33^{cde}_{B}	10.15
IS 25561	3.33^{d}_{C}	20.00^{ab}_{A}	23.67^{a}_{A}	20.00^{bcd}_{A}	6.00^{c}_{BC}	12.00^{bc}_{B}	7.51
Siaya #2-3	6.67^{bc}_{B}	28.00^{a}_{A}	28.33^{a}_{A}	25.00^{bc}_{A}	22.33^{ab}_{A}	16.67^{a}_{AB}	14.31
Abaleshya	5.00^{cd}_{B}	21.33^{ab}_{A}	23.33^{a}_{A}	22.33^{bcd}_{A}	5.33^{c}_{B}	11.67^{bcd}_{AB}	12.70
$LSD_{0.05}$	3.95	15.89	15.98	13.61	6.26	4.32	

†Means followed by subscript same upper case ACROSS the row do not significantly differ ($p \leq 0.05$).

‡Means followed by superscript same lower case DOWN the column do not differ significantly ($p \leq 0.05$).

Plate 3.4: Field experiment at Mundika during the long rains season

At Sinyanya (LM 3), Masumbi (LM 1), Mundika (LM 2) during the long rains and Sagam (LM 1), all the lines suitable for baking had similar plant densities indicating the stability of these test lines in low and high rainfall during the crop's growing period. However, in Nyahera (LM 3) and during short rainy season in LM 2, lines IS 25557, IS 25561 and IS 9203 gave fewer plants per unit area than Siaya #2-3 but did not differ with *Abaleshya*. Plate 3.4 is a photo of sorghum plants for experiment conducted in Mundika during long rainy season. In this study, genotype by environment interaction was noted on stand count of the test sorghum lines. Across the test environments, where high rainfall (Figure 3.2) was received (Masumbi, Mundika during long rains and Sagam) high plant density was recorded for the test sorghum lines (Table 3.2) where low amounts of rainfall was received during the crop's growing period as in the case of Sinyanya (LM 3) and Mundika (LM 2, short rains), all the lines recorded low plant population. This signifies the importance of rainfall during the early stages of crop establishment and thus the timing of the cropping season.

3.4.2 Plant Height

Significant variations in plant height were noted among the sorghum lines within agro-ecological environments (Table 3.3). Line SDSA1 x ICSR43 line produced taller plants than *Serena* and *Gadam* when grown at Masumbi (LM 1) and during long rainy season at Mundika (LM 2). In the rest of the environments, the line maintained shorter but statistically similar plant height with the check lines. The difference in plant height can be attributed to variation in genotypes among the sorghum lines (Hussain *et al*., 2011).

All the sorghum lines suitable for baking had similar plant height in Sinyanya (LM 3), Masumbi, Sagam (both LM 1) and Nyahera (LM 3) (Table 3.3). However, in Mundika (LM 2) during the long rains and short rainy season, variation in plant height was noted where IS 255657 line recorded significantly taller plants than the other lines.

Table 3. 3: Effect of sorghum lines, environment and their interaction on plant height

Lines	**Plant height (cm)**						
	Sinyanya (LM 3)	Masumbi (LM 1)	Mundika (LM2)	Sagam (LM 1)	Nyahera (LM 3)	Mundika (LM 2)	
	← Long rains		→	← Short rains		→	$LSD_{0.05}$
SDSA1 x ICSR43	90.5^{bc}‡$_{D}$†	196.50^{ab}_{A}	178.33^{d}_{AB}	161.57^{cd}_{BC}	177.23^{a}_{AB}	132.00^{ef}_{A}	29.73
Sima	95.43^{abc}_{C}	167.00^{bcd}_{AB}	163.17^{e}_{AB}	200.33^{abc}_{A}	160.67^{a}_{B}	156.30^{de}_{B}	39.46
Serena	$85.63b^{c}_{D}$	150.33^{cd}_{ABC}	135.33^{f}_{C}	164.57^{bcd}_{A}	158.63^{a}_{AB}	142.77^{ef}_{BC}	20.56
Gadam	75.10^{c}_{D}	128.5^{d}_{ABC}	104.17^{g}_{C}	143.43^{dA}_{B}	144.97^{a}_{A}	117.43^{f}_{BC}	26.70
IS 9203	102.23^{abc}_{C}	210.30^{ab}_{B}	237.33^{b}_{A}	208.00^{bcd}_{AB}	158.53^{a}_{C}	197.67^{bc}_{B}	13.55
IS 25557	125.70^{a}_{C}	223.80^{a}_{A}	257.83^{a}_{A}	248.97^{a}_{A}	180.20^{a}_{B}	266.20^{a}_{AB}	34.82
IS 25561	112.30^{ab}_{C}	208.67^{ab}_{AB}	209.83^{c}_{A}	213.80^{abc}_{A}	163.87^{a}_{BC}	187.87^{c}_{AB}	14.18
Siaya #2-3	113.67^{ab}_{C}	191.50^{abc}_{AB}	183.17^{d}_{AB}	22.43^{a}_{A}	166.67^{a}_{A}	174.57^{cd}_{A}	42.95
Abaleshya	$87.00b^{c}_{D}$	182.33^{abc}_{BC}	213.83^{c}_{AB}	218.43^{ab}_{A}	172.53^{a}_{C}	217.87^{b}_{A}	34.95
$LSD_{0.05}$	31.43	44.87	13.20	54.19	42.70	26.25	

†Means followed by subscript same upper case ACROSS the row do not significantly differ ($p \leq 0.05$).

‡Means followed by superscript same lower case DOWN the column do not differ significantly ($p \leq 0.05$).

Significant variations in plant height were noted among the lines suitable for malting and brewing as opposed to the lines suitable for baking within the selected agro-ecological zones. This confirmed the results of previous studies of Aljenandro (1982), Abdel-Rahaman (1985), Bakheit (1990), Abdalla (1991), Hassan (2005) and El Naim *et al*. (2012) who found that cultivars of grain sorghum had a significant effect on the plant height. The plant height of the sorghum lines evaluated was highly influenced by the genotype by environment interaction. Generally, taller plants were obtained at Mundika (LM 2) during the long rainy season, at Masumbi (LM 1) and at Sagam (LM 1). When grown in Nyahera (LM 3), the lines grew taller than when grown in Sinyanya (LM 3). Sinyanya (LM 1) received high temperatures (Figure 3.2) and low rainfall (Figure 3.3) during the crop's growing period, which may have had an effect on the height of the plants. Height has considerable effect on yield in sorghum (Abdul, 2009) whereby short plants reduces the risk of lodging especially in fertile and humid conditions and increases responses to nitrogen availability associated with improved light interception and hence higher crop yield (Tripathi 2006). The plant height and the grain yield in the current study did not correlate (Table 3.3) which is contrary to the findings by Henzel (1992) and Jordan *et al.* (2003) who indicated that taller plants gave high grain yield. This is probably due to the influence of environment on the height of the plants as opposed to genetic influence.

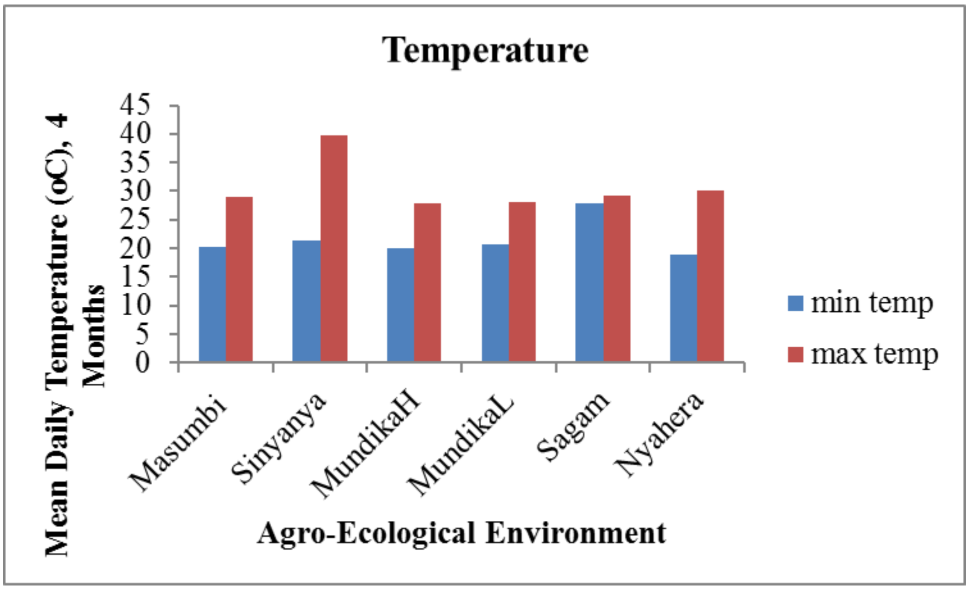

Figure 3.6: Mean maximum and minimum daily temperature during sorghum growing period in selected agro-ecological environments

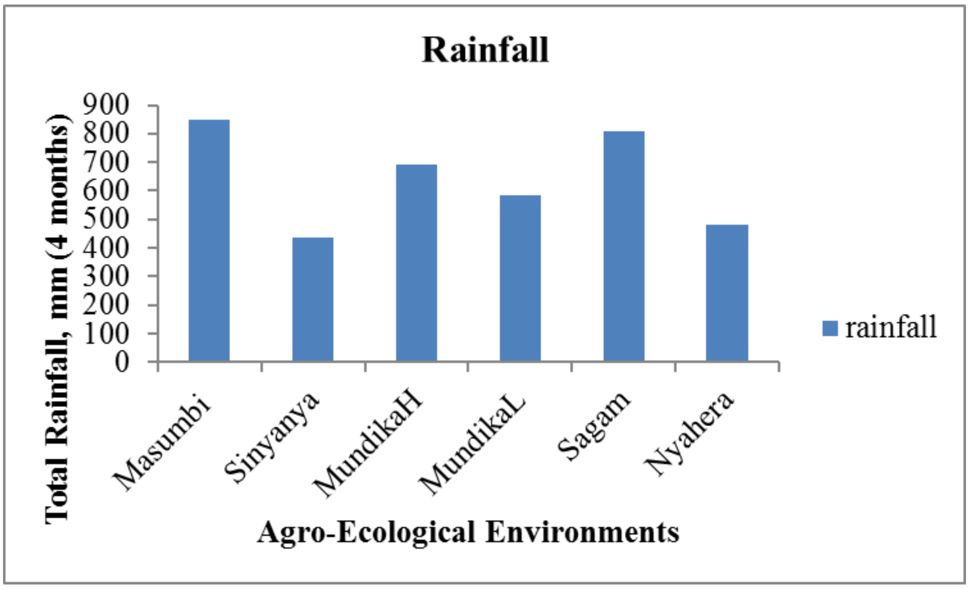

Figure 3.7: Cumulative rainfall during sorghum growing period at the selected agro-ecological environments

3.4.2 Days to 50% Heading

The days taken by the sorghum lines for half the plant population to head ranged between 61 to 89 days (Figure 3.8). This was consistent with the findings by Mosa (2010) who reported a range of 62-89 days in sorghum genotypes evaluated in Sudan. Considering the lines suitable for malting and brewing, SDSA1 x ICSR43 line took longer to reach 50% heading differing significantly ($P \leq 0.05$) with *Gadam*, *Sima* and *Serena* in all the growing environments except in Masumbi (LM 1) where no variation was noted among all the sorghum lines (Figure 3.8).

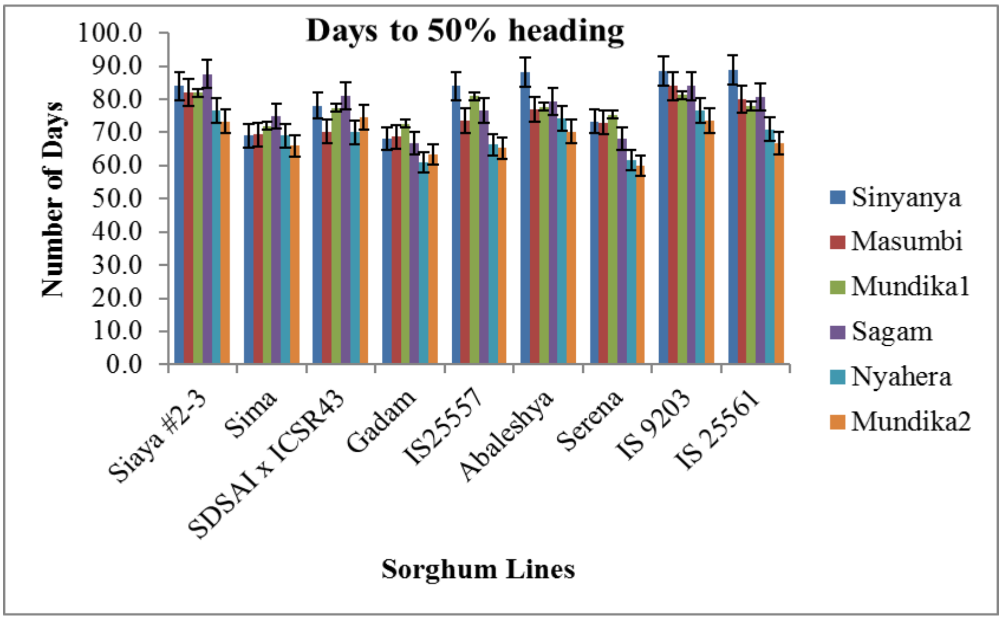

Figure 3.8: Days to 50% heading by selected sorghum in different agro-ecological environments in Kenya

The considerable variation in number of days to 50% heading among sorghum lines across the test agro-ecological environments could be as a consequence of genotypic and environmental differences as reported by El Naim *et al*. (2012).

During the long rains in Mundika (LM 2), all the sorghum lines suitable for baking did not show variation ($P \leq 0.05$) in the number of days taken for half the plant population to flower (Figure 3.8). Growing the lines in Sinyanya (LM 3), IS 25561 and IS 9203 took longest time to flower while IS 25557 took similar days as Siaya # 2-3 and *Abaleshya*. In Masumbi (LM 1), IS 25561 and IS 9203 were comparable ($P \leq 0.05$) to Siaya #2-3 while IS 25557 took about 12 days and 7 days less than Siaya #2-3 and *Abaleshya* respectively. In Sagam (LM 1), lines IS 25561 and IS 25557 were not significantly different ($P \leq 0.05$) from *Abaleshya* while IS 9203 and IS 25557 took 3 and 11 days less than Siaya #2-3 respectively, to reach 50% heading. Cultivating the lines in Nyahera (LM 3), IS 25561 and IS 9203 showed no variation with *Abaleshya* and Siaya #2-3 while IS 25557 took 8 and 10 days less than *Abaleshya* and Siaya #2-3 respectively. During the short rainy season in Mundika (LM 2), line IS 9203 took similar days as Siaya #2-3 to flower while no significant difference was noted among IS 25557, IS 25561 and *Abaleshya*.

Lines SDSA1 x ICSR43 and IS 25557 significantly ($P \leq 0.05$) differed with the checks in the days to 50% heading, which concurred with findings by Hassan's (2005) that cultivars significantly differed in the number of days to 50% flowering. While El Naim *et al*., (2012) reported that days to 50% heading were significantly and positively correlated with 100 grain weight, this study found that 100 grain weight was negatively correlated ($P \leq 0.001$) with the number of days to 50% heading (Table 3.13) which was consistent with the findings by Ouma and Akuja (2013). Sorghum lines that took longer time to flower at a given agro-ecological environment also recorded low yields in that environment thus explain why grain yield in Sinyanya (LM 3) was the lowest relative to the other test environments. This is because flowering at a later date incurs risks of terminal drought which is detrimental to grain filling (Ribaut and Poland, 2000). The differences in days to 50% heading could be attributed to genetic differences and germplasm adaptation to local climatic patterns (Traore *et al*., 2000) largely due to different levels of photoperiod sensitivity (Craufurd *et al*., 1999; Craufurd and Qi, 2001; Clerget *et al*., 2004). Therefore, there is an indication of genotypic differences existing between SDSA1 x ICSR43, IS 25557 and the lines used as the checks.

3.5 Yield Components of Industrial Sorghums Across Agro-ecological Environments

Analysis of variance revealed significant ($P \leq 0.05$) differences for the yield and yield components among the selected sorghum lines.

3.5.1 Panicle Weight

The panicle weight varied among sorghum lines and with the environment in which they were cultivated (Table 3.4). In Sinyanya and Nyahera (LM 3), all the sorghum lines suitable for malting and brewing were not statistically ($P \leq 0.05$) different for panicle weight. In Masumbi (LM 1) and during the short rainy season in Mundika (LM 2), SDSA1 x ICSR43 gave 41.7 and 29.6% heavier panicles than *Gadam*, respectively, but did not differ ($P \leq 0.05$) from *Sima* and *Serena*.

Table 3.4: Effect of sorghum lines, environment and their interaction on panicle weight

Lines	Panicle weight (g)						
	Sinyanya (LM3)	Masumbi (LM1)	Mundika (LM2)	Sagam (LM1)	Nyahera (LM3)	Mundika (LM2)	
	← Long rains →			← Short rains →			$LSD_{0.05}$
SDSA1 x ICSR43	35.77^{ab}‡$_{C}$†	66.20^{a}_{AB}	73.39^{a}_{A}	45.04^{ab}_{BC}	35.57^{ab}_{C}	44.65^{a}_{AB}	23.60
Sima	25.37^{b}_{B}	59.35^{a}_{A}	44.75^{bc}_{AB}	54.11^{a}_{A}	47.56^{ab}_{AB}	35.80^{abc}_{AB}	24.90
Serena	28.87^{ab}_{C}	55.38^{a}_{AB}	76.43^{a}_{A}	38.97^{ab}_{BC}	46.42^{ab}_{BC}	37.63^{ab}_{BC}	21.90
Gadam	16.62^{b}_{A}	27.25^{b}_{A}	19.44^{d}_{A}	20.47^{c}_{A}	22.84^{b}_{A}	24.27^{bc}_{A}	13.51
IS25557	24.91^{b}_{BC}	30.44^{b}_{AB}	29.83^{cd}_{AB}	40.26^{ab}_{A}	10.64^{b}_{C}	20.18^{c}_{BC}	15.04
IS 9203	9.35^{b}_{C}	35.25^{b}_{B}	49.36^{bc}_{A}	40.32^{ab}_{AB}	16.75^{b}_{C}	31.99^{abc}_{B}	13.55
IS 25561	3.26^{b}_{C}	24.03^{b}_{AB}	31.50^{cd}_{A}	31.31^{bc}_{A}	11.13^{b}_{BC}	20.87^{c}_{AB}	14.18
Siaya #2-3	71.31^{a}_{A}	54.40^{a}_{A}	63.34^{ab}_{A}	44.69^{ab}_{A}	98.66^{a}_{A}	37.60^{ab}_{A}	43.35
Abaleshya	13.64^{b}_{CD}	19.61^{b}_{C}	30.17^{cd}_{AB}	34.99^{bc}_{A}	6.61^{b}_{D}	22.31^{bc}_{BC}	9.66
$LSD_{0.05}$	45.43	18.14	21.39	16.16	66.97	15.97	

†Means followed by subscript same upper case ACROSS the row do not significantly differ ($p \leq 0.05$).

‡Means followed by superscript same lower case DOWN the column do not differ significantly ($p \leq 0.05$).

In addition, 24.2 and 57.6% heavier panicles were recorded for SDSA1 x ICSR43 than *Sima* and *Gadam*, respectively, in LM 2 during long rainy season. SDSA1 x ICSR43 had heaviest panicles when grown in Mundika during long rainy season (LM 2). This was 37.5% heavier than for *Gadam* while relative to *Sima* and *Serena*, no significant difference ($P \leq 0.05$) was noted. The weight of the panicle was found to be positively correlated to yield (Table 3.13) which describes why grain yield in Sinyanya and Nyahera (both LM 3) did not differ. In addition, SDSA1 x ICSR43 line had the heaviest panicles in almost all the agro-ecological environments which could have played a key role in the high yields obtained in respective cultivation environments.

When the lines suitable for baking were grown in Mundika (LM 2) during the short rainy season, in Sinyanya (LM 3) and in Masumbi (LM 1), lines IS 9203, IS 25557, IS 25561 had comparable panicle weights with *Abaleshya*. However, the lines had relatively 48.2% and

21.4% lighter panicles than for Siaya #2-3 when grown in Sinyanya (LM 3) and in Masumbi (LM 1) respectively. Taking the lines to Sagam (LM 1) similar panicle weights were obtained. Cultivation at Nyahera (LM 3) resulted in check line Siaya #2-3 yielding upto 70.9% heavier panicles than the rest of the sorghum lines. In Mundika (LM 2) during the long rainy season, lines IS 25557, IS 9203 and *Abaleshya* were not significantly different for panicle weight but gave about 12.4% lighter panicles than Siaya #2-3.

The overall analysis showed environmental and genotypic effect on panicle weight of the sorghum lines evaluated (Table 3.4). The malting and brewing sorghum line had heavy panicles when grown in LM 1 (Masumbi and Sagam) and LM 2 (during the long rainy season). A similar scenario was observed for the lines suitable for baking. In LM 3 where low rainfall was recorded during the crop's growing period, the sorghum lines produced light panicles. This implies that low rainfall received during the crop-growing period could have contributed to low panicle weights. Thus, there is a greater need to understand the environmental effects on the weight of the panicles in order to understand its implication on the yield since the study also showed a significant and positive correlation between panicle weight and grain yield (Table 3.13). Lines SDSA1 x ICSR43, IS 9203, IS 25557 and IS 25561 were not stable for the weight of the panicles across the growing environments. This could be contributing factor to variation in grain yield among the sorghum lines across the environments where they were cultivated.

3.5.2 Panicle Length

Variation in the length of the panicles existed among the sorghum lines suitable for malting and brewing across the test environments (Table 3.5). When evaluated at Sinyanya (LM 3), line SDSA1 x ICSR43 recorded 23.5% longer panicles than *Serena* while about 33.9% longer panicles were observed for SDSA1 x ICSR43 than *Gadam* and *Sima*. Taking the lines to Masumbi (LM 1), *Sima* and *Serena* produced about 30.8% shorter panicles than SDSA1 x ICSR43 which recorded the longest panicles. Line SDSA1 x ICSR43 had 13.6, 27.4 and 33% longer panicles than *Serena*, *Sima* and *Gadam,* respectively, when grown in Mundika (LM 2) during the long rainy season. The length of the panicle was similar ($p \leq 0.05$) among the check lines when cultivated at Sagam (LM 1). However, SDSA1 x ICSR43 recorded the longest panicles giving up to 27.4% longer panicles than the check lines. When the lines were grown in Nyahera (LM 3), SDSA1 x ICSR43 recorded the longest panicles which were about 23.5% longer than for *Sima* and *Gadam* and 12.7% longer than for *Serena*. *Sima* and *Gadam* had about 26.3% and *Serena* 19.1% shorter panicles than SDSA1 x ICSR43 line when evaluated at Mundika (LM 2) during short rainy season.

Table 3.5: Effect of sorghum lines, environment and their interaction on panicle length

Lines	Panicle length (cm)						
	Sinyanya (LM 3)	Masumbi (LM 1)	Mundika (LM 2)	Sagam (LM 1)	Nyahera (LM 3)	Mundika (LM 2)	
	← Long rains		→	← Short rains		→	$LSD_{0.05}$
SDSA1 x ICSR43	30.97^{a}‡$_{A}$†	31.03^{a}_{A}	30.20^{a}_{A}	28.60^{a}_{A}	28.97^{a}_{A}	30.90^{a}_{A}	5.22
Sima	15.30^{d}_{B}	17.63^{d}_{A}	17.20^{de}_{A}	17.57^{e}_{A}	17.93^{d}_{A}	16.93^{e}_{A}	1.07
Serena	19.20^{c}_{B}	22.13^{c}_{AB}	22.97^{bc}_{A}	19.20^{de}_{B}	22.43^{b}_{A}	20.97^{cd}_{AB}	3.04
Gadam	15.37^{d}_{A}	16.43^{d}_{A}	15.70^{e}_{A}	16.30^{e}_{A}	17.40^{d}_{A}	18.03^{de}_{A}	4.09
IS25557	24.47^{b}_{AB}	26.30^{b}_{A}	21.23^{c}_{C}	25.33^{ab}_{A}	21.63^{bc}_{BC}	22.30^{c}_{BC}	2.91
IS 9203	10.37^{cd}_{C}	23.00^{c}_{A}	21.00^{c}_{AB}	22.90^{bc}_{B}	18.53^{cd}_{C}	22.07^{c}_{A}	3.06
IS 25561	17.17^{cd}_{C}	29.47^{a}_{A}	26.50^{b}_{AB}	26.80^{a}_{AB}	23.00^{b}_{B}	27.47^{b}_{AB}	5.40
Siaya #2-3	10.93^{e}_{B}	12.77^{e}_{A}	11.33^{f}_{AB}	12.70^{f}_{A}	11.63^{e}_{AB}	11.03^{f}_{AB}	1.75
Abaleshya	18.00^{cd}_{BC}	21.50^{c}_{AB}	20.70^{cd}_{ABC}	21.53^{cd}_{AB}	16.97^{d}_{C}	22.47^{c}_{A}	4.12
$LSD_{0.05}$	3.17	2.42	3.61	3.40	3.67	3.19	

†Means followed by subscript same upper case ACROSS the row do not significantly differ ($p \leq 0.05$).

‡Means followed by superscript same lower case DOWN the column do not differ significantly ($p \leq 0.05$).

The lines suitable for baking also varied for the length of the panicles across the agro-ecological environments. At Sinyanya (LM 3), lines IS 9203, IS 25561 were similar ($P \leq 0.05$) for the length of their panicles which in addition did not reveal any significant ($P \leq 0.05$) difference with Siaya #2-3 and *Abaleshya.* However, IS 25557 line produced 15.2% and 38.2% longer panicles than *Abaleshya* and Siaya #2-3 respectively. At Masumbi (LM 1), IS 9203 line did not differ from *Abaleshya* in the length of the panicles but gave 28.6 % longer panicles than Siaya #2-3. IS 25561 line recorded the longest panicles which were longer than for lines IS 9203, *Abaleshya*, IS 25557 and Siaya #2-3 by 12.3%, 15.6%, 5.7% and 39.5% respectively. In Mundika during the long rainy season, IS 25561 recorded the longest panicles which were about 11% longer than IS 9203, IS 25557 and *Abaleshya* and about 40.1% longer than Siaya #2-3. At Sagam (LM 1) IS 25561 line had longest panicles which were not significantly ($P \leq 0.05$) different from IS 25557; the two giving upto 10.9 % and 35.7% longer panicles than lines *Abaleshya* and Siaya #2-3 respectively. Line IS 9203 had similar ($P \leq 0.05$) panicle length with *Abaleshya* but 28.7% longer panicles than Siaya #2-3. At Nyahera (LM 3), line IS 25561 produced longest panicles amongst all baking sorghum lines though statistically similar ($P \leq 0.05$) to those of IS 25557 line. However, lines IS 25557, IS 9203 and IS 25561 did not show significant ($P \leq 0.05$) difference for the length of the panicles. Growing the lines in Mundika (LM 2) during the short rains, IS 9203 and IS 25561 showed variation in the length of the panicles where IS 25561 had 10.4% longer panicles than IS 9203.

Considering the effect of agro-ecological zone on the length of the panicles, SDSA1 x ICSR43 line was stable for the length of the panicle across all the agro-ecological environments. The panicle length of baking lines IS 25557, IS 9203 and IS 25561 were influenced by the environment (Table 3.5). Generally, the evaluated sorghum lines had longer panicles at LM 1 and during short rains in LM 2. Growing the same lines in LM 3 and during long rains LM 2, they produced shorter heads. Similar results on substantial variability in panicle length were noted in findings by Subba *et al*. (2004) and Abdul (2009). In all the test environments, SDSA1 x ICSR43 line recorded longest panicles which could have been a factor contributing to high yields obtained for the line.

3.5.3 Spikes Per Panicle

Sorghum lines for malting and brewing were influenced by agro-ecological environment for the number of spikes per panicle (Table 3.6). *Serena* had the highest number of spikes per panicle when grown in Sinyanya (LM 3) whereas SDSA1 x ICSR43 line had 8% fewer spikes per panicle than *Serena* and about 28.3% more than *Gadam* and *Sima* (Table 3.6). There was no noteable difference ($p \leq 0.05$) among SDSA1 x ICSR43, *Gadam* and *Serena* observed for the number of spikes per panicle when evaluated at Masumbi (LM 1). At Sagam (LM 1), SDSA1 x ICSR43 line had 19.4 and 24% more spikes per panicle than *Sima* and *Gadam* respectively, but did not vary from *Serena*. When taken to Nyahera (LM 3), lines SDSA1 x ICSR43 and *Sima* had similar ($P \leq 0.05$) number of spikes per panicle but gave 23.4% more and 12.8% less spikes per panicle than *Gadam* and *Serena* respectively. Lines SDSA1 x ICSR43 and *Serena* were however similar ($P \leq 0.05$) for the parameter when grown in Mundika (LM 2) during short rainy season with SDSA1 x ICSR43 giving approximately 10.8% more spikes than *Sima* and *Gadam*.

When the lines suitable for baking were evaluated at Sinyanya (LM 3), lines IS 9203 and IS 25561 produced about 5.5% and 17.2% lower number of spikes than *Abaleshya* and Siaya #2-3 respectively. On the other hand, line IS 25557 was not significantly different from Siaya # 2-3 but gave 7.9% more spikes per panicle than *Abaleshya*. When planted in

Masumbi (LM 1), lines IS 9203 and IS 25561 were similar ($P \leq 0.05$) to *Abaleshya* for the number of spikes per panicle. However, the two had about 7.3% and 11.4% fewer spikes per panicle than lines IS 2557 and Siaya #2-3 respectively. In addition IS 9203 line showed no variation ($P \leq 0.05$) from Siaya #2-3 for the number of spikes per panicle. At Mundika (LM 2) during the long rainy season, all the sorghum lines were similar ($P \leq 0.05$) for the number of spikes per panicle. At Sagam (LM 1), all the sorghum lines were comparable to *Abaleshya* for the number of spikes per panicle. When taken to Nyahera (LM 3), lines IS 25557, IS 9203 and IS 25561 did not show significant ($P \leq 0.05$) difference for the number of spikes per panicle. During the short rainy season in LM 2, lines IS 2557, IS 9203 and IS 25561 did not vary ($P \leq 0.05$) from *Abaleshya* for the number of spikes per panicle. In addition, IS 9203 line produced similar number of spikes per panicle with Siaya #2-3 whereas IS 25561 line gave 11.2% fewer spikes per panicle than Siaya #2-3.

The number of spikes per panicle varied with the growing environment for most of the sorghum lines evaluated (Table 3.6). The sorghum lines produced highest number of spikes per panicle in LM 2 during the long rainy season relative to the other test environments. The number of spikes per panicle did not vary when the sorghum lines were grown in Sinyanya (LM 3) and LM 1. When the lines were grown in Nyahera (LM 3), they produced the fewest number of spikes per panicle than the other test environments. Number of spikes per panicle represented substantial variability among the lines evaluated. Similar results were reported by Subba (2004) and Abdul (2009).

Table 3.6: Effect of sorghum lines, environment and their interaction on the number of spikes per panicle

Lines	Spikes per panicle						
	Sinyanya (LM 3)	Masumbi (LM 1)	Mundika (LM 2)	Sagam (LM 1)	Nyahera (LM 3)	Mundika (LM 2)	
	← Long rains →			← Short rains →			$LSD_{0.05}$
SDSA1 x ICSR43	51.33^{bc}‡$_{BC}$†	51.00^{ab}_{BC}	65.33^{ab}_{A}	49.33^{ab}_{BC}	46.67^{bc}_{C}	58.33^{ab}_{AB}	11.80
Sima	35.00^{ef}_{B}	39.67^{cd}_{B}	48.33^{d}_{A}	33.33^{c}_{B}	38.33^{cd}_{B}	47.00^{cd}_{A}	6.95
Serena	60.33^{a}_{BC}	54.00^{ab}_{CD}	73.00^{a}_{A}	48.00^{ab}_{BC}	60.33^{a}_{BC}	65.00^{a}_{AB}	10.93
Gadam	28.67^{f}_{C}	31.00^{b}_{BC}	37.00^{e}_{AB}	30.33^{d}_{BC}	29.00^{e}_{BC}	43.00^{d}_{A}	8.22
IS25557	52.33^{b}_{AB}	51.00^{ab}_{AB}	60.33^{bc}_{A}	45.33^{abc}_{B}	33.33^{de}_{C}	52.33^{bc}_{AB}	10.26
IS 9203	40.00^{de}_{C}	44.00^{bc}_{BC}	60.00^{bc}_{A}	46.67^{ab}_{B}	39.67^{cd}_{C}	55.67^{bc}_{A}	6.17
IS 25561	33.67^{ef}_{DE}	39.00^{cd}_{CD}	56.00^{cd}_{A}	41.67^{bc}_{BC}	29.00^{e}_{E}	48.67^{cd}_{B}	7.21
Siaya #2-3	56.67^{ab}_{AB}	55.33^{a}_{AB}	59.00^{bc}_{A}	51.33^{a}_{B}	51.67^{b}_{B}	61.00^{ab}_{A}	7.17
Abaleshya	44.67^{cd}_{BC}	$44.33a^{bc}_{BC}$	62.33^{bc}_{A}	47.00^{ab}_{B}	34.33^{de}_{C}	55.55^{bc}_{AB}	12.14
$LSD_{0.05}$	7.66	11.13	8.87	7.98	8.24	8.94	

†Means followed by subscript same upper case ACROSS the row do not significantly differ ($p \leq 0.05$).

‡Means followed by superscript same lower case DOWN the column do not differ significantly ($p \leq 0.05$).

3.5.4 Spike Weight

Environmental effect on the weight of spikes was evident for all the sorghum lines except for lines Siaya #2-3 and S*erena* (Table 3.7). At Sinyanya (LM 3), *Sima* produced the heaviest spikes among the lines suitable for malting and brewing and was not statistically ($P \leq$ 0.05) different from SDSA1 x ICSR43 line. However, line SDSA1 x ICSR43 did not differ significantly ($P \leq$ 0.05) with G*adam* but had 23.3% heavier spikes than S*erena*. There was no major difference observed ($P \leq$ 0.05) among lines SDSA1 x ICSR43, G*adam* and *Serena* for the spike weight when grown in Masumbi (LM 1) and Nyahera (LM 3). Growing the lines in Mundika (LM 2) during long rainy season, *Gadam* recorded the lightest spikes while lines SDSA1 x ICSR43, *Sima* and *Serena* did not show significant difference ($P \leq$ 0.05) for the parameter. At Sagam (LM 1) and during short rainy season in Mundika (LM 2), no variation ($P \leq 0.05$) in spike weight was observed among the sorghum lines evaluated.

Considering the lines suitable for baking (Table 3.7), lines IS 9203 and IS 25561 did not differ significantly ($P \leq 0.05$) with *Abaleshya* when grown in Sinyanya. However, the two lines had approximately 29.4% lighter spikes than Siaya #2-3 and IS 25557. All the sorghum lines evaluated showed no variation in the spike weight when grown in LM 1 and LM 2. At Nyahera (LM 3), lines IS 25557, IS 9203 and IS 25561 were comparable ($P \leq 0.05$) to *Abaleshya* for the spike weight. Generally, heavier spikes were obtained in LM 1 and during long rainy season in LM 2 possibly because of sufficient rainfall during the crop's growing period thus allowing good grain setting and filling. The rest of the test environments with low rainfall had low and similar weights of the spikes.

Table 3.7: Effect of sorghum lines, environment and their interaction on the spike weight

Lines	**Spike weight (kg/ha)**						
	Sinyanya (LM 3)	Masumbi (LM 1)	Mundika (LM 2)	Sagam (LM 1)	Nyahera (LM 3)	Mundika (LM 2)	
	← Long rains		→	← Short rains		→	$LSD_{0.05}$
SDSA1 x ICSR43	$1.11^{ab\ddagger}_{B\dagger}$	1.86^{b}_{A}	1.84^{a}_{A}	1.24^{ab}_{B}	1.10^{bc}_{B}	0.97^{ab}_{B}	0.54
Sima	1.39^{a}_{B}	4.29^{a}_{A}	1.72^{ab}_{AB}	1.57^{a}_{AB}	1.48^{a}_{AB}	1.01^{a}_{B}	2.85
Serena	0.69^{cde}_{D}	1.37^{b}_{AB}	1.65^{abc}_{A}	1.14^{ab}_{BC}	1.06^{bc}_{BCD}	0.80^{abc}_{CD}	0.45
Gadam	0.87^{bcd}_{AB}	1.26^{b}_{A}	0.61^{d}_{B}	0.93^{b}_{AB}	1.14^{ab}_{AB}	0.78^{abc}_{AB}	0.58
IS25557	0.88^{bc}_{AB}	0.94^{b}_{AB}	0.89^{cd}_{AB}	1.26^{ab}_{A}	0.44^{de}_{C}	0.60^{c}_{BC}	0.39
IS 9203	0.48^{def}_{C}	1.47^{b}_{A}	1.63^{abc}_{A}	1.03^{b}_{BC}	0.58^{de}_{BC}	0.78^{abc}_{B}	0.30
IS 25561	0.13^{f}_{B}	0.94^{b}_{A}	1.04^{abcd}_{A}	1.08^{b}_{A}	0.53^{de}_{AB}	0.69^{abc}_{AB}	0.56
Siaya #2-3	0.88^{bc}_{A}	1.30^{b}_{A}	1.47^{abc}_{A}	1.01^{b}_{A}	0.74^{cd}_{A}	0.63^{bc}_{A}	0.92
Abaleshya	0.48^{ef}_{CD}	3.63^{b}_{ABC}	0.97^{bcd}_{A}	0.84^{b}_{AB}	0.26^{e}_{D}	0.58^{c}_{BCD}	0.35
$LSD_{0.05}$	0.38	2.23	0.82	0.46	0.38	0.36	

†Means followed by subscript same upper case ACROSS the row do not significantly differ ($p \leq 0.05$).

‡Means followed by superscript same lower case DOWN the column do not differ significantly ($p \leq 0.05$).

3.5.5 Spike Length

Growing the lines suitable for malting and brewing at Sinyanya (LM 3), SDSA1 x ICSR43 line, produced the longest spikes which were up to 29.8% longer than for *Gadam, Sima* and *Serena* (Table 3.8). However, lines SDSA1 x ICSR43, *Sima* and *Serena* had no variation ($P \leq 0.05$) in the length of spikes when planted in Masumbi (LM 1) and in Mundika (LM 2) during long rainy season. *Gadam* produced the shortest spikes when planted during short rains in Mundika (LM 2). At Sagam (LM 1), lines SDSA1 x ICSR43 and *Sima* were comparable while *Gadam* and *Serena* recorded approximately 26% shorter spikes than SDSA1 x ICSR43. *Sima* and *Serena* produced 9.3% shorter spikes than SDSA1 x ICSR43 while G*adam* produced 20.1% shorter spikes than SDSA1 x ICSR43 when evaluated at Nyahera. During the short rainy season in Mundika (LM 2), SDSA1 x ICSR43 produced longest spikes, which were about 15.5% longer than for the check lines.

For the baking lines at Sinyanya, IS 9203 and IS 25561 had about 13% and 33.9% shorter spikes than the control and IS 25557 lines respectively. When taken to Masumbi, IS 255561 line produced the longest spike giving about 21.8% longer spikes than the other sorghum lines. During the long rainy season in Mundika (LM 2), all the sorghum lines were similar ($P \leq 0.05$) to *Abaleshya* for the spike length, while in addition, IS 25561 recorded the longest spikes giving about 2.4 % longer spikes than IS 25557 and Siaya #2-3. In Sagam, (LM 1) line IS 25561 gave the longest spikes with no considerable difference from IS 25557 whereas IS 9203 was similar to the check lines. At Nyahera (LM 3), IS 25561 line had longest spikes amongst all baking sorghum lines. Environmental influence on the length of the spikes was not realized on Siaya #2-3, SDSA1 x ICSR43 and G*adam* while the rest of the lines were not stable for the parameter across the test environments (Table 3.8). The spikes were long in all the test environments except in LM 3 although lines in Nyahera showed no significant variation in spike length with lines in LM 2 during the short rainy season.

Table 3.8: Effect of sorghum lines, environment and their interaction on the spike lengths

Lines	Spike length (cm)						
	Sinyanya (LM 3)	**Masumbi (LM 1)**	**Mundika (LM 2)**	**Sagam (LM 1)**	**Nyahera (LM 3)**	**Mundika (LM 2)**	
	← Long rains →			← Short rains →			$LSD_{0.05}$
SDSA1 x ICSR43	8.93^{a}‡$_{A}$†	8.23^{a}_{A}	9.20^{a}_{A}	9.07^{a}_{A}	8.67^{a}_{A}	9.47^{a}_{A}	1.86
Sima	5.70^{bc}_{B}	7.73^{a}_{A}	7.53^{abc}_{A}	7.57^{ab}_{A}	7.20^{b}_{A}	6.93^{bc}_{AB}	1.32
Serena	5.10^{bc}_{C}	7.27^{a}_{AB}	8.2^{ab}_{A}	5.93^{cd}_{BC}	6.30^{bc}_{BC}	5.83^{bc}_{BC}	1.61
Gadam	4.83^{cd}_{A}	5.07^{b}_{A}	5.77^{cde}_{A}	5.33^{cd}_{A}	5.77^{cd}_{A}	6.23^{bc}_{A}	1.62
IS25557	5.87^{b}_{AB}	5.20^{b}_{BC}	4.47^{e}_{C}	6.50^{bc}_{A}	5.13^{de}_{BC}	5.63^{c}_{ABC}	1.28
IS 9203	2.53^{g}_{C}	5.67^{b}_{AB}	5.67^{de}_{AB}	5.70^{cd}_{AB}	4.90^{ed}_{B}	5.97^{bc}_{A}	1.07
IS 25561	2.90^{fg}_{B}	8.83^{a}_{A}	7.37^{bcd}_{A}	7.97^{ab}_{A}	6.80^{b}_{A}	7.13^{b}_{A}	2.45
Siaya #2-3	3.77^{ef}_{A}	4.33^{b}_{A}	4.53^{e}_{A}	4.53^{d}_{A}	3.90^{f}_{A}	3.80^{d}_{A}	1.22
Abaleshya	3.90^{de}_{C}	5.37^{b}_{ABC}	6.07^{cde}_{A}	5.87^{cd}_{AB}	4.30^{ef}_{BC}	5.93^{bc}_{A}	1.57
$LSD_{0.05}$	0.93	1.56	1.81	1.54	0.93	1.46	

†Means followed by subscript same upper case ACROSS the row do not significantly differ ($p \leq 0.05$).

‡Means followed by superscript same lower case DOWN the column do not differ significantly ($p \leq 0.05$).

3.5.6 Number of Grains Per Spike

There was no variation in the number of grains per spike among the malting and brewing check lines grown in Sinyanya (LM 3) (Table 3.9). However, SDSA1 x ICSR43 line had approximately 39.4% more grains per spike than the check lines. *Gadam* produced the lowest number of grains per spike when grown in Masumbi (LM 1) and during long rainy season in Mundika (LM 2) whereas lines SDSA1 x ICSR43, *Sima* and *Serena* had no significant ($P \leq 0.05$) difference.

Table 3.9: Effect of sorghum lines, environment and their interaction on the number of grains per spike

Lines	Number of grains per spike						
	Sinyanya LM3	Masumbi LM1	Mundika LM2	Sagam LM1	Nyahera LM3	Mundika LM2	
	← Long rains →			← Short rains →			$LSD_{0.05}$
SDSA1 x ICSR43	79.67^{a}‡$_{A}$†	62.00^{ab}_{AB}	71.33^{ab}_{AB}	52.00^{bc}_{B}	50.00^{ab}_{B}	52.00^{a}_{B}	23.65
Sima	42.67^{bcd}_{A}	48.67^{bc}_{A}	39.33^{bc}_{A}	55.00^{bc}_{A}	49.33^{ab}_{A}	37.33^{ab}_{A}	22.40
Serena	34.67^{bcd}_{BC}	48.00^{bc}_{AB}	44.00^{abc}_{A}	39.00^{c}_{BC}	43.67^{abc}_{ABC}	31.33^{b}_{C}	13.95
Gadam	37.33^{bcd}_{A}	40.33^{c}_{A}	31.33^{c}_{A}	42.67^{bc}_{A}	43.67^{abc}_{A}	39.67^{ab}_{A}	18.87
IS25557	47.33^{bc}_{AB}	47.67^{bc}_{AB}	39.33^{bc}_{BC}	59.00^{b}_{A}	29.00^{bcd}_{BC}	28.33^{b}_{C}	18.94
IS 9203	22.67^{de}_{CD}	65.33^{ab}_{A}	64.67^{ab}_{A}	51.67^{bc}_{AB}	12.33^{cd}_{D}	38.67^{ab}_{BC}	16.19
IS 25561	6.00^{e}_{C}	50.33^{c}_{AB}	45.33^{bc}_{AB}	57.00^{bc}_{A}	32.00^{bcd}_{B}	35.33^{b}_{AB}	24.75
Siaya #2-3	57.67^{ab}_{A}	71.00^{a}_{A}	85.00^{a}_{A}	77.67^{a}_{A}	56.00^{a}_{A}	53.33^{a}_{A}	53.76
Abaleshya	24.67^{cde}_{BC}	31.33^{b}_{AB}	45.33^{bc}_{A}	44.33^{bc}_{A}	15.33^{d}_{C}	31.67^{b}_{ABC}	18.85
$LSD_{0.05}$	23.17	19.73	32.10	18.65	22.49	16.26	

†Means followed by subscript same upper case ACROSS the row do not significantly differ ($p \leq 0.05$).

‡Means followed by superscript same lower case DOWN the column do not differ significantly ($p \leq 0.05$).

The sorghum lines evaluated in Sagam (LM 1) and Nyahera (LM 3) had similar ($P \leq 0.05$) number of grains per spike. Line SDSA1 x ICSR43 yielded the highest number of grains per spike when grown in Mundika (LM 2) during the short rainy season with no variation from *Sima* and G*adam.* However, relative to S*erena* SDSA1 x ICSR43 line produced 21.9% more grains per spike.

For the baking lines tested in Sinyanya (LM 3), lines IS 9203, IS 25561 and *Abaleshya* were comparable for the number of grains per spike. However, lines IS 9203 and IS 25561 relatively gave about 43.6% and 35.2% fewer grains per spike than Siaya #2-3 and IS 25557 respectively. At Masumbi (LM 1), lines IS 9203, IS 25557 and *Abaleshya* were similar ($P \leq 0.05$) for the number of grains per spike which was about 13% lower and 4.2%

higher than for IS 25561 and Siaya #2-3 respectively. During the short and long rainy season in Mundika (LM 2), lines IS 25557, IS 9203 and IS 25561 were comparable to *Abaleshya*. However, lines IS 25561 and IS 25557 gave about 30.4% fewer grains than Siaya #2-3 while IS 9203 was similar to Siaya # 2-3 during the long rains in LM 2. Growing the lines in Nyahera (LM 3), Siaya #2-3 yielded upto 27.3 % more grains per spike relative to rest of the sorghum lines evaluated. On the other hand, lines IS 25557, IS 9203 and IS 25561 did not show significant difference for the number of grains per spike.

Variations in grain number among the sorghum lines were observed with similar results reported by Lansac *et al*. (1996). Effect of environment on the sorghum lines for the number of grains per spike was evident (Table 3.9) for the lines SDSA1 x ICSR43, IS 25557, IS 25561, IS 9203 and Abaleshya. Highest number of grains per spike was recorded in LM 1 and during long rainy season in LM 2. These environments received more rainfall during the crop-growing period than in LM 3 and during short rains in LM 2. The study showed a positive correlation between the number of grains per spike and the panicle weight and eventually the total grain yield. This suggests that there is a greater need to understand the differences among sorghum lines in dry matter accumulation during anthesis (Gerik *et al*., 2004) which was probably influenced by environmental effect on the genetic expression of the trait by the sorghum lines evaluated.

3.5.7 Kernel Weight

Line SDSA1 x ICSR43, did not vary ($P \leq 0.05$) with S*erena* for 100 kernel weight when evaluated at Sinyanya (LM 3) (Table 3.10). When grown in Masumbi (LM 1), lines SDSA1 x ICSR43, G*adam* and *Serena* were comparable for the 100 kernel weight. However, SDSA1 x ICSR43 produced 16 and 7.9% lighter kernels than *Sima* and S*erena*, respectively in Mundika (LM 2) during long rainy season. In Sagam (LM 1), line *Sima* recorded the heaviest kernels with no variation with *Serena*. In addition, SDSA1 x ICSR43 line was statistically similar ($P \leq 0.05$) to *Gadam* but produced approximately 9.7% lighter kernels than S*ima* and *Serena.* SDSA1 x ICSR43 yielded lighter kernels than G*adam* and *Serena* by approximately 18.4% and *Sima* (29.4%) when grown in Nyahera (LM 3). In LM 2 during short rainy season, lines SDSA1 x ICSR43 and *Gadam* gave kernels of similar weight whereas *Sima* and *Serena* gave approximately 8.6% heavier kernels than SDSA1 x ICSR43.

For the baking lines evaluated in Sinyanya (LM 3), IS 25557 line produced 11.3% heavier kernels than IS 9203 while *Abaleshya* and Siaya #2-3 were comparable. In Masumbi (LM 1), lines IS 9203 and IS 25561 were similar ($P \leq 0.05$) to the check lines for the 100 kernel weight. In addition, lines IS 9203 and IS 25557 were comparable while IS 25561 produced 7.7% lighter grains than IS 25557. During the long rains in Mundika (LM 2), lines IS 25561 and IS 25557 were statistically similar ($P \leq 0.05$) to *Abaleshya* for the 100 kernel weight but produced about 8.9% heavier grains than Siaya #2-3. Line IS 9203 did not differ from *Abaleshya* but yielded 11.8% heavier grains than Siaya #2-3. When grown in Sagam (LM 1), no variation in the 100-kernel weight was observed. At Nyahera (LM 3), lines IS 25557, IS 9203 and IS 25561 showed no variation although IS 9203 had 9.5% heavier grains than *Abaleshya*. During the short rainy season in Mundika (LM 2), lines IS 2557, IS 9203 and IS 25561 did not show major ($P \leq 0.05$) difference with *Abaleshya* for the 100 grain weight. In addition, lines IS 9203 and Siaya #2-3 had grains of similar weights.

The 100 kernel weights of the sorghum lines evaluated were affected by the environment (Table 3.10) Heavier kernels were obtained in Masumbi (LM 1) and in long rainy season in Mundika (LM 2) while in Nyahera (LM 3), Sinyanya (LM 3) and in short rainy season in LM 2 the lines had lighter kernels. The present study has shown that kernel weight differed among the sorghum lines, which is contrary to the findings by Ouma and Akuja (2013) who evaluated sorghum cultivars across two agro-environments in Kenya. This shows the necessity of multi-locational experiments for adequate conclusions. Multi-environment trials (METs) are widely used by plant breeders to evaluate performance of genotype for a target population of environments (Abu *et al*., 2005; Audilakshmi *et al*., 2005).

Table 3.10: Effect of sorghum lines, environment and their interaction on the 100 kernel weight of the selected sorghum lines

Lines	100 grain weight (g)						
	Sinyanya	Masumbi	Mundika	Sagam	Nyahera	Mundika	
	← Long rains →			← Short rains →			$LSD_{0.05}$
Siaya #2-3	2.49^{de**}_{BC*}	2.89^{d}_{A}	2.80^{f}_{AB}	2.50^{d}_{BC}	2.26^{e}_{C}	2.34^{e}_{C}	0.36
Sima	4.36^{a}_{A}	4.31^{a}_{AB}	4.76^{a}_{A}	4.13^{a}_{AB}	4.18^{a}_{AB}	3.61^{a}_{B}	0.73
SDSA1 x ICSR43	2.95^{cd}_{C}	3.88^{ab}_{A}	3.45^{cde}_{AB}	3.07^{c}_{BC}	2.28^{cd}_{C}	2.81^{cd}_{C}	0.45
Gadam	3.65^{b}_{AB}	3.92^{ab}_{A}	3.62^{c}_{AB}	3.27^{bc}_{BC}	3.31^{b}_{BC}	3.14^{bc}_{C}	0.43
IS25557	3.21^{bc}_{B}	3.63^{bc}_{A}	3.19^{e}_{B}	2.97^{cd}_{BC}	2.76^{cd}_{C}	3.10^{bcd}_{B}	0.33
Abaleshya	2.53^{de}_{B}	3.20^{cd}_{A}	3.24^{de}_{A}	3.17^{c}_{A}	2.44^{de}_{B}	2.74^{cde}_{AB}	0.50
Serena	3.23^{bc}_{B}	3.64^{bc}_{AB}	4.04^{b}_{A}	3.73^{ab}_{AB}	3.35^{b}_{B}	3.34^{ab}_{B}	0.51
IS 9203	2.04^{e}_{C}	3.36^{cd}_{A}	3.55^{cd}_{A}	2.83^{cd}_{B}	2.95^{bc}_{B}	2.67^{de}_{B}	0.37
IS 25561	2.56^{d}_{C}	3.11^{d}_{AB}	3.35^{cde}_{A}	3.07^{c}_{AB}	2.81^{cd}_{BC}	2.84^{cd}_{BC}	0.34
$LSD_{0.05}$	0.52	0.51	0.33	0.50	0.42	0.44	

*Means followed by the same upper cases do not differ across each row ($P \leq 0.05$)

**Means followed by the same lower cases do not differ within each column ($P \leq 0.05$)

3.6 Yield

Means comparison for the yield of sorghum lines for malting and brewing across selected agro-ecological environment has been presented in Table 3.11. In Sinyanya (LM 3), no significant ($P \leq 0.05$) difference was noted among the malting lines. In Masumbi (LM 1), SDSA1 x ICSR43 line recorded highest grain yield giving 64.9 and 45.4% higher yields than G*adam* and S*erena*, respectively but performed similarly ($P \leq 0.05$) to S*ima*. During the long rainy season in Mundika (LM 2), the lines yielded differently ($P \leq 0.05$) with SDSA1 x ICSR43 line giving highest grain yield which was 14.1, 38.8 and 88.6% more than S*erena*, *Sima* and G*adam*, respectively. SDSA1 x ICSR43 was comparable to S*ima* and G*adam* when grown in Sagam (LM 1), Nyahera (LM 3) and during short rainy season in LM 2. However, SDSA1 x ICSR43 line produced 27.6, 31.4 and 52.7% less yields than S*erena* in Sagam (LM 1), Nyahera (LM 3) and in Mundika (LM 2) during short rains, respectively.

Considering the lines suitable for baking, growing them in Sinyanya (LM 3), line Siaya #2-3 recorded highest grain yield which was upto 79.4% more than the rest of the baking sorghum lines. Planting the lines at Masumbi (LM 1) and during the long rains in Mundika (LM 2), no variation in grain yield was noted. Lines IS 25557, IS 55561 and IS9203 did not differ ($P \leq 0.05$) with *Abaleshya* and Siaya #2-3 for grain yield when evaluated at Sagam (LM 1). In addition, the lines performed similarly ($P \leq 0.05$) to *Abaleshya* when grown in Nyahera (LM 3) and during the short rainy season in Mundika (LM 2). However, relative to Siaya #2-3 the lines produced approximately 62.4% and 30.1% less yields in Nyahera and Mundika during the short rainy season, respectively.

Table 3.11: Yield (tons ha^{-1}) of nine sorghum lines in the selected agro-ecological environments

Lines	Yield (tons/ha)					
	Sinyanya (LM 3)	Masumbi (LM 1)	Mundika (LM 2)	Sagam (LM 1)	Nyahera (LM 3)	Mundika (LM 2)
	← Long rains		→	← short rains		→
Siaya #2-3	0.96[a]*	3.06[ab]	3.06[ab]	2.39[abc]	1.77[ab]	1.21[ab]
Sima	0.71[abc]	5.51[ab]	1.61[cd]	1.26[c]	1.37[b]	0.73[bc]
SDSA1 x ICSR43	0.48[abcd]	7.76[a]	3.65[a]	2.04[bc]	1.21[bc]	0.53[c]
Gadam	0.56[abcd]	1.65[c]	0.22[e]	1.48[bc]	1.11[bc]	0.68[bc]
IS25557	0.40[cd]	3.08[bc]	1.14[de]	2.74[ab]	0.41[cd]	0.64[c]
Abaleshya	0.27[cd]	1.83[c]	1.17[de]	2.49[abc]	0.18[d]	0.61[c]
Serena	0.79[ab]	2.91[bc]	2.75[abc]	3.62[a]	2.32[a]	1.71[a]
IS 9203	0.11[d]	1.93[c]	1.96[bcd]	1.70[bc]	0.37[cd]	0.65[c]
IS 25561	0.13[d]	1.98[c]	1.49[d]	1.92[bc]	0.33[d]	0.63[c]
$LSD_{0.05}$	0.51	1.98	1.25	1.36	0.78	0.53

*Means followed by the same letters do not differ within each column ($p<0.05$)

The high grain yield of SDSA1 x ICSR43 line relative to the checks could be attributed to its high panicle weight and length, longer spikes and high number of grains per spike. This is because grain yield in the present study was found to be highly correlated ($P \leq 0.001$) to the panicle weight and the number of grains per spike (Table 3.13) which confirmed the findings by Mohammed (1988). Tesfaye *et al*. (2011) reported that higher grain number in general is the most important yield component associated with increase in yield of sorghum.

A genotype by environment effect was observed for the sorghum genotypes for malting and brewing as presented in Table 3.12. SDSA1 x ICSR43 line recorded highest yields in Masumbi (LM 1) which was 88.3, 36, 58.4, 73 and 87.2% more than in Sinyanya (LM 3), Mundika (LM 2) in long rainy season, Sagam (LM 1), Nyahera (LM 3) and during short rains in LM 2, respectively. Yields in LM 3, Sagam (LM 1), and in short rains in LM 2 did not differ significantly with scatter plot confirming that the four environments are average performers for SDSA1 x ICSR43 line (Figure 3.9). *Sima* recorded highest yields in Masumbi (LM 1) while the rest of the environments were not statistically ($P \leq 0.05$) different.

Table 3.12: Genotype by environment interaction on yield (tons ha^{-1}) of sorghum lines evaluated across selected AEZ in Kenya

Lines	Yield (tons ha^{-1})						
	Sinyanya LM 3	Masumbi LM 1	Mundika LM 2	Sagam LM1	Nyahera LM 3	Mundika LM 2	
	← Long rain season →			← Short rain season →			$LSD_{0.05}$
SDSA1 x ICSR43	0.48^{c}*	7.76^{a}	3.65^{b}	2.04^{bc}	1.21^{bc}	0.53^{c}	2.91
Sima	0.71^{b}	5.51^{a}	1.61^{b}	1.26^{b}	1.37^{b}	0.73^{b}	1.44
Serena	0.79^{c}	2.91^{ab}	2.75^{ab}	3.62^{a}	2.32^{ab}	1.71^{bc}	1.36
Gadam	0.56^{bc}	1.65^{a}	0.22^{c}	1.48^{a}	1.11^{ab}	0.68^{b}	0.58
IS25557	0.40^{c}	3.08^{a}	1.14^{bc}	2.74^{ab}	0.41^{c}	0.64^{c}	1.93
IS 9203	0.11^{b}	1.93^{a}	1.96^{a}	1.70^{ab}	0.37^{ab}	0.65^{ab}	1.70
IS 25561	0.13^{c}	1.98^{d}	1.49^{ab}	1.92^{a}	0.33^{c}	0.63^{bc}	0.99
Siaya #2-3	0.96^{d}	6.96^{a}	3.06^{b}	2.39^{bc}	1.77^{cd}	1.21^{cd}	1.22
Abaleshya	0.27^{c}	1.83^{ab}	1.17^{abc}	2.49^{a}	0.18^{c}	0.61^{bc}	1.48

*Means followed by the same letters do not differ across each row

Gadam gave high yields in LM 1 and Nyahera (LM 3) but growing it in Sinyanya (LM 3) and during short rainy season in LM 2 grain yield reduced by about 41.6% while lowest yields were obtained in LM 2 in long rainy season. *Serena* on the other hand had highest yields when grown in Sagam which was not different from yields obtained during long rains in LM 2, Masumbi (LM 1) and Nyahera (LM 3). However, growing in *Serena* in Sinyanya (LM 3) and during short rains in LM 2 similar yields were obtained.

A genotype by environment effect was also observed for the sorghum lines for baking as presented in Table 3.12. Line IS 25557 gave highest yields when grown in LM 1 while the rest of the environments recorded similar yields. This response was similar for *Abaleshya*.

Line IS 9203 gave similar yields in all the test environments except in Sinyanya (LM 3) where 89.4% yield reduction was recorded relative to Mundika (LM 2). Line IS 25561 had high yields in LM 1and during long rain season in LM 2 lower yields were obtained in LM 3 and during short rainy season in LM 2 with the latter environments having comparable ($P \leq$ 0.05) yields. Line Siaya #2-3 produced highest amount of grains when grown in Masumbi (LM 1) with a considerable variation from yields obtained from the rest of the environments. However, yields obtained for Siaya #2-3 when grown in LM 2 during short rainy season, Sagam (LM 1), and Nyahera (LM 3) were similar ($P \leq$ 0.05 while growing it in Sinyanya lowest yields were obtained.

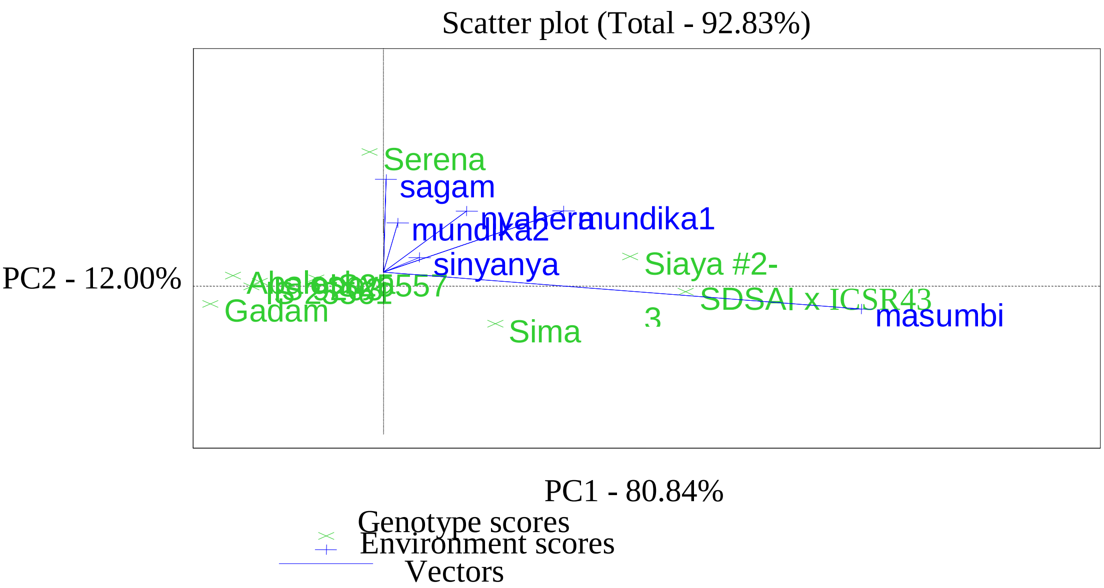

Figure 3.9: A G × E scatter plot for the assessment of the performance of sorghum lines for industrial uses in different agro-ecological environments in Kenya

Genotype by environment interactions can complicate the recommendation of cultivars to different environments, making evaluation across varied agro-ecological environments necessary. The gap between genetic yield potential and the realized yield in sorghum is primarily related to the environment to which the crop is cultivated (Omanya *et al*., 1996). This study showed a significant ($P \leq$ 0.05) sorghum by environment interaction which was an indication of diversity of the lines evaluated and their differences in environmental response (Fig. 3.9). This confirmed the suggestion by Basford and Cooper, (1998) that selection of genotypes cannot be based on the 'best' genotype in one environment for all the target environments. In Masumbi (LM 1) all the lines recorded highest grain yield relative to other sites which could have resulted from favourable growing conditions that allowed the lines to express their genetic potential for grain yield. High yield stability usually refers to a genotype's ability to perform consistently, whether at high or low yield levels, across a wide range of environments (Annicchiarico, 2002).

The scatter plot (Figure 3.9) served to assess relations among environments and between entries and environment. If the sorghum line is traced closer to a given agro-ecological environment, then it is more stable in that growing environment than the lines traced at a distance from the environment of interest. The sorghum lines clustered around the average line are average performers in all the test environments. Therefore, SDSA1 x ICSR43 was the most stable line for Masumbi (LM 1) while in Sagam (LM 1), Nyahera (LM 3) and during long and short rain seasons in Mundika (LM 2) all the sorghum lines performed averagely the same. Serena was found to be the least stable line for cultivation in Masumbi (LM 1) but the best suitable line for Sagam (LM 1).

3.7 Correlation of Agronomic, Yield Components and Yield of Sorghum Lines Across Selected Agro-Ecological Environments

Pearson correlation revealed that stand count was positively correlated with panicle weight and grains per spike at $P<0.01$ and spike weight and grain yield at $P<0.05$ (Table 3.13). Days to 50% heading showed a positive correlation with plant height and panicle length and a negative relationship with 100 kernel weight at $P<0.01$. A greater spike length, spike weight, grains per spike and 100 kernel weight resulted in a higher panicle weight and consequently greater grain yield as indicated by positive correlation of panicle weight with spike length, spike weight, grains per spike, 100 kernel weight and grain yield at ($P<0.01$). Furthermore, a positive relationship was observed between panicle length and spike length and grains per spike and 100 kernel weight at $P<0.05$. Spike weight was positively correlated with grains per spike, 100 kernel weight and grain yield at ($P<0.01$) whereas grains per spike was correlated with 100 kernel weight and grain yield at $P<0.05$. Similarly, Rekar and Biradar (2015) reported a strong correlation of panicle weight, plant height, number of panicle and test weight with grain yield per plant. The agronomic parameters and yield components can therefore be improved to realize a higher grain yields in sorghum (Puspitasari, *et al*., 2012). This study revealed a positive correlation (Table 3.13) between grain number and the total grain yield which is contrary to the findings by Mutava *et al*. (2011) who evaluated 300 sorghum genotypes from different races and found a negative correlation between the number of grains and the total grain yield.

Table 3.13: Correlation of agronomic parameters, yield components and yield of sorghum lines evaluated across selected agro-ecological environments

	SC‡	DH	PH (cm)	PW (g)	PL (cm)	SP	SL (cm)	SW	G_pS	100-KW (g)	GY(tons/ha)
SC	1.00	0.33	0.80	0.92**	0.68	0.14	0.78	0.88*	0.94**	0.79	0.83*
DH		1.00	0.84**	0.18	0.84**	-0.05	-0.24	0.39	0.16	-0.89**	0.22
PH			1.00	0.81*	0.85*	0.28	0.98**	0.58	0.63	0.48	0.60
PW				1.00	0.72	0.48	0.85**	0.87**	0.90**	0.88**	0.75**
PL					1.00	0.28	0.87*	0.69	0.61	0.56	0.78
SP						1.00	0.42	0.16	0.25	0.37	-0.02
SL							1.00	0.59	0.64	0.53	0.59
SW								1.00	0.92**	0.94**	0.95**
G^{-1}S									1.00	0.87*	0.82*
100-KW										1.00	0.83*
GY											1.00

* Significant at $P \leq 0.05$

‡ SC= Stand count, PH= Plant height, DH= Days to 50 % heading, PW=Panicle weight, PL= Panicle length, SP= Spikes per panicle, SL= Spike length, SW= Spike weight, G_pS= Grains per spike, 100-KW=100 Kernel Weight and GY= Grain yield

CHAPTER FOUR

EFFECT OF AGRO-ECOLOGICAL ENVIRONMENTS ON GRAIN QUALITY OF SELECTED SORGHUM LINES

Abstract

Grain sorghum has a great potential for use as food and beverage. However, the effect of the growing environment on the grain quality of sorghum for industrial uses in Kenya, is lacking. The current study aimed at determining the effect of agro-ecological environment on the grain quality of selected sorghum lines for industrial uses. The experiments were conducted at varied locations in Kisumu, Siaya and Busia counties of Kenya in randomized complete block design with three replications. Nine sorghum lines were sown in plots measuring 4 m x 2.5 m and replicated three times, each having four rows of the specific sorghum line. The sorghum plants were monitored until they had reached physiological maturity when panicles were harvested from two central rows of each plot. The panicles were then dried, hand threshed and winnowed to obtain grains that were finely ground and the flour used for proximate analysis. The percent starch, amylose, tannin content and crude protein were determined using Anthrone, Mc Cready, Folin-Denis and Kjeldahl methods, respectively. Analysis of variance was performed using SAS software and means separated using Least Significant Difference test. The crude protein content ranged from 8.9 to 15.4% across environments. LineSDSA1 x ICSR43 recorded the lowest tannin content that ranged from 8.00 – 24.33 mg/100 ml tannic acid equivalents. There were no significant differences among sorghum lines in LM 1 and LM 2 environments in terms of amylose content ranging from 15.2 to 13.4% across environments. Similarly, amylopectin did not vary with genotypes in LM 1 environments and Mundika (LM 2). Highest amylopectin was recorded by Serena (62.6%) in Mundika (LM 2). The amount of starch varied with sorghum lines and environments ranging 29.7-80.2%. The study showed that SDSA1 x ICSR43 line is suitable for cultivation in LM 1 and LM 2 agro-ecological environments where it produces grains that are low in tannins and therefore a good candidate for malting and brewing.

Keywords: Amylose, Sorghum Lines, Starch, Tannins

4.1 Introduction

Grain sorghum has considerable potential for use as a human food and beverage source including lager and stout beer, and baked products. Commercial processing of sorghum grains into value-added food and beverage products is an important driver for economic development in the developing countries (Taylor et al., 2004). In malting and brewing, the quality aspects of sorghum grains that is important are amylose, amylopectin, starch, protein and tannin contents. Each of these quality attributes play a considerable role in the quality of beer obtained after brewing.

Structurally, starch is composed of two high molecular weight homopolysaccharides known as amylose and amylopectin (Dicko *et al.*, 2006a) whose content and quantity, affects the rate of starch digestibility (Tester *et al.*, 2006; Sharma *et al.*, 2008). During the brewing process, starch is the raw material broken down to simple sugars to yield alcohol after fermentation. The conversion efficiency of starch to alcohol decreases as the amylose content of cereal grains increases (Wu *et al.*, 2006). The quantity of protein in sorghum has a significant effect on brewing (FAO, 1995; Beta *et al.*, 1995) since proteins degradation by of proteins by proteolytic enzymes to peptides and amino acids (Jones, 2005a, b) provides energy for the yeasts during fermentation process leading to production of alcohol. Tannins are considered undesirable due to their capacity to bind to proteins, making them less digestible and producing undesirable astringent taste (Ambula *et al.*, 2003). Sorghum accessions naturally have high tannin contents and this poses a challenge when using sorghum as a raw material for malting. However, reduction of the tannins levels is possible through decortication, fermentation, germination and chemical treatment (Drina *et al.*, 1990, Beta *et al*., 1999 and Dicko *et al*., 2005).

Sorghum grain contains no cholesterol and like all other grains it has a fairly good amount of carbohydrates that could meet a good deal of the recommended daily intake (Thompson, 2000). Grain sorghum used as food ingredients or dietary supplement helps to control cholesterol levels in humans (Carr *et al*., 2005), with sorghum bran playing a considerable role in protection against diabetes and insulin resistance (Farrar *et al*., 2008). It is considered safe for people who react to gluten, a protein which is found in wheat, barley and rye (Ciacci *et al*., 2007). The increased consumption of sorghum reduces the risk of certain cancers due to its rich antioxidant properties (Gomez-Cordoves *et al*., 2001; Yang *et al*., 2009). The antioxidants in sorghum grains are higher than those of other grains and fruits (Awika and Rooney, 2004).

The quality of sorghum grain is affected by factors such as genotype, climate, soil type, and fertilizer supply, which can affect its chemical composition and the nutritive value (Ebadi *et al*., 2005). Johnson (2005) working on the influence of corn and sorghum characteristics on wet milling and nixtamalization found that high temperatures and water stress resulted in lower starch concentrations. Dowling *et al*. (2002) reported that the protein content in sorghum grain is higher than that of corn although its nutritional protein quality is lower due to content of tannins that bind to protein making them less digestible in the body. Wallwork *et al.* (1998) indicated that if a short period of high temperature occurs at a certain point in the grain filling period, it may affect one or more components that are being synthesized concurrently and result in a different composition of the mature grain. The high temperatures and the stress of moisture can limit the amount of grain fill operating through the metabolism of starch in the grain. Bleidere and Sterne (2008) working on spring barley reported that hot and dry conditions occurring during cell division period in starchy endosperm resulted in shortening this period thus influencing the accumulation of starch hence low starch and higher protein. It is because the accumulation of starch is more sensitive to high temperatures than to the accumulation of nitrogen, which frequently determines increases in the grain nitrogen proportion and thus results in higher protein content (Schelling *et al.*, 2003).

The release of a new sorghum hybrid suitable for malting and brewing, and for use in baking is of great significance to farmers in Kenya who would wish to venture into sorghum production for commercial purposes. Industrial sorghum has a ready market and is likely to provide farmers with better returns. However, information regarding the effect of the agro-ecological environments on the grain quality attributes of sorghum desirable for malting and brewing and for baking in Kenya, is lacking. The acquisition of good quality grain is fundamental to produce acceptable food and beverage products from sorghum. The study was therefore carried out with the aim of determining the effect of agro-ecological environment on the grain quality of selected sorghum lines for industrial uses to aid in developing proper advice to sorghum farmers for sustainable production of quality grains.

4.2 Materials and Methods

4.2.1 Field Experiment

Nine sorghum lines were grown at Masumbi and Sagam both in lower midland zone (LM) 1 in long and short rainy seasons respectively, and at Mundika (LM 2) in both long and short rainy season. The description of the sites is as described in section 3.2.1 above.

4.2.2 Sorghum Lines

Five sorghum lines suitable for baking and four suitable for malting and brewing were evaluated at the four agro-ecological environments. These lines are SDSA1 X ICSR 43, IS 9203, IS25561, IS 25557, *Sima*, *Gadam*, *Serena*, *Siaya* # 2-3 and *Abaleshya*. *Sima*, *Gadam*, and *Serena* were used as the controls for the line identified for malting and brewing (SDSA1 X ICSR 43) while *Siaya* #2-3 and *Abaleshya* were the checks for lines identified for use in baking (IS 9203, IS25561 and IS 25557).

4.2.3 Experimental Design and Treatments

The experiment was set up in a Randomized Complete Block Design (RCBD) with nine experimental units each measuring 4 m by 2.5 m and replicated three times. A path of 1.5 m separated the replicates. Each experimental unit had four rows of a specific sorghum line. The nine sorghum lines and the agro-ecological environments used in the study are shown in Table 4.1).

4.2.4 Agronomic Management

The agronomic management was done as described in section 3.2.4 in Chapter three above.

4.2.5 Sample Collection

Harvesting was done when the sorghum lines had reached physiological maturity. It involved cutting the panicles at the collar of the top most leaf using secateurs. Samples were put in well-labelled bags. Only the two inner rows of the four rows per plot were harvested. Panicles were then sun dried followed by hand threshing and winnowing to obtain clean grains. The grains were thereafter milled finely using a grinder to pass through a 1 mm sieve. The flour obtained was used for proximate analysis for determination of starch, amylose, amylopectin, protein and tannin contents of the grains.

Table 4.1: Treatment structure for the experiment

Treatment	Description (Targeted use)
Sorghum lines	
Sima	Malting and brewing check
Gadam	Malting and brewing check
Serena	Malting and brewing check
SDSA1 x ICSR43	**Malting and brewing line**
Siaya #2-3	Baking line used as check
Abaleshya	Baking line used as check
IS25557	**Baking line**
IS 9203	**Baking line**
IS 25561	**Baking line**
Agro-Ecological Environment and Season	
Masumbi LR	LM 1, Long rains
Mundika LR	LM 2, Long rains
Mundika SR	LM 2, Short rains
Sagam SR	LM 1, Short rains

4.2.6 Determination of Starch

Percent starch content was estimated by the Anthrone method (Hodge and Hofreiter, 1962) whereby 0.2 g of milled grain sample was homogenized in 80% hot ethanol to remove sugars. The residue was then centrifuged and retained. The residue was dried well over a water bath. To the residue, 5.0 ml of distilled water and 6.5 ml of 52% perchloric acid was added and then extracted at 0 °C for 20 min. The supernatants were centrifuged, pooled and made up to 100 ml. 0.1 ml of the supernatant was pipetted out and made up to the volume to 1 ml with distilled water. The standards were prepared by taking 0.2, 0.4, 0.6, 0.8 and 1 ml of the working standard solution and the volume made up to 1 ml in each tube with water. Four ml of anthrone reagent was then added to each tube and sample heated for 8 min in a boiling water bath. Each sample was cooled rapidly and the intensity of green to dark green colour was read using a spectrophotometer at 630 nm. The glucose content in the sample was determined using the standard calibration graph and then the value was multiplied by a factor of 0.9 to arrive at the starch content.

4.2.7 Determination of Amylose

Amylose was determined using the Mc-Cready method (Mc-Cready *et al*., 1950) where 0.1 g of milled sorghum grain was weighed, and 1 ml of distilled ethanol added followed by 10 ml of 1 N NaOH. The sample was heated for 10 min in a boiling water bath. The volume was made up to 100 ml. The extract taken was 2.5 ml and 20 ml of distilled water was added followed by three drops of 0.1% phenolphthalein. Dropwise, 0.1 N HCl was added until the pink colour just disappeared. One ml iodine reagent was added till the volume was 50 ml and the colour read at 590 nm using a spectrophotometer. Standard amylose solutions of 0.2, 0.4, 0.6, 0.8 and 1 ml were taken and the colour developed as in the case of the test samples. The amount of amylose present in the sample was calculated using the standard graph.

$$\%\ \text{amylose} = \left[\frac{x}{2.5}\right] \times 100\ \text{mg amylose}$$

Where x is the absorbance obtained. The amount of amylopectin content was determined through subtraction of amylose content from the starch content since starch comprise of amylose and amylopectin.

% Starch - % Amylose = % Amylopectin

4.2.8 Determination of Tannin Content

Tannins content was determined through Folin-Denis method (Schanderl, 1970). Powdered flour (0.5 g) was weighed and transferred to a 250 ml conical flask followed by addition of 75 ml of water. The flask was heated gently and boiled for 30 minutes and then centrifuged at 2000 rotations per minute for 20 min. The supernatant was collected in a 100 ml volumetric flask. One mililitre of the sample extract was transferred to a 100 ml volumetric flask containing 75 ml water. Five mililitres of folin regent, 10 ml of 35% sodium carbonate solution were added and then diluted to 100 ml with water. The sample was shaken and the absorbance read at 700 nm after 30 min. A graph was prepared using 0 - 100 mg tannic acid, where 1 ml contained 100 mg tannic acid. The tannin content of the sample was calculated as tannic acid equivalent from the standard curve.

4.2.9 Determination of Crude Protein Content

Total nitrogen and protein was determined using Kjeldahl method (AOAC, 1999). One tenth gram finely milled sorghum grains were weighed and transferred into a digestion tube. Selenium catalyst mixture weighing 1 g was mixed with the samples and 5 ml of 96% sulphuric acid was added into the tube. The tubes were then heated cautiously in the digester at the fume cupboard until the digest was clear. The sample was transferred to a 100 ml volumetric flask, and distilled water was added into 100 ml graduated flask up to the mark. Boric acid indicator solution of 5 ml was then transferred to 100 ml conical flask containing 5 drops of mixed indicator and was placed under the condenser of the distillation apparatus. Ten mililitres of the clear supernatant liquid of the digest was then transferred into the apparatus, and 10 ml of 46% sodium hydroxide added and then rinsed again with distilled water. Distillation then commenced. The distillation process is shown in plate 4.1. After the first distillation, drops reached the boric acid indicator solution, and colour changed from pink to green. A total of 150 ml of the distillate was collected. The solution was titrated with 0.0174 N sulphuric acids until the colour changed from green to pink.

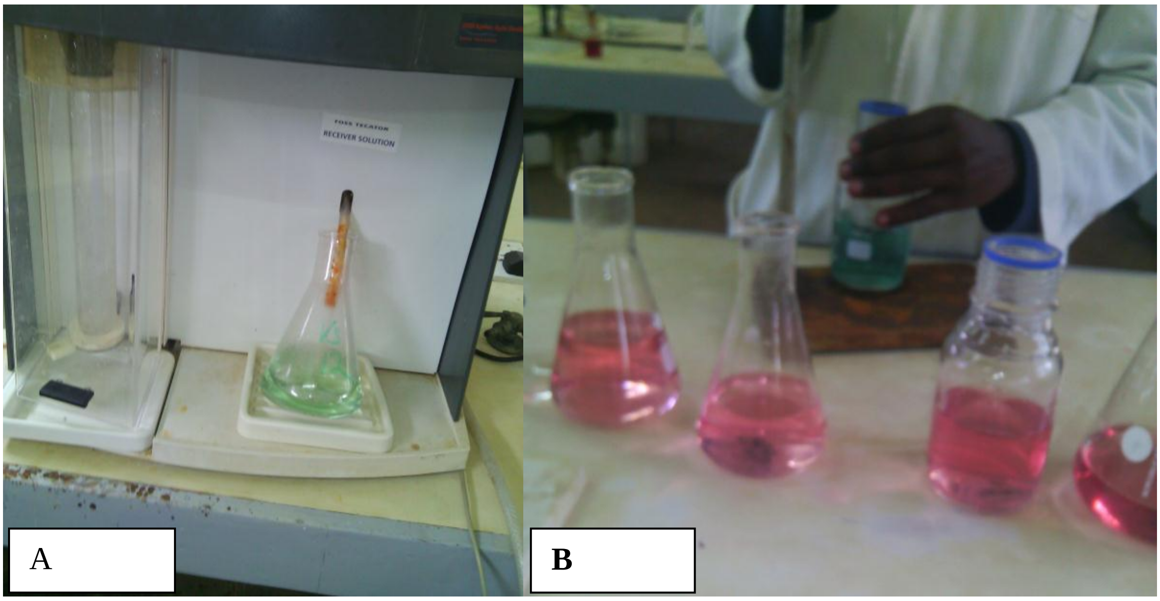

Plate 4.1: Crude protein determination; A shows the distillation process whereas B shows titration of the distillate

$$\%N = \frac{a \; x \; N \; x \; Mw \; x \; 100}{b \; x \; c} \; x \; 100\%$$

Where,

a = ml of sulphuric acid used for titration of the sample,

N = Normality of sulphuric acid (0.0174),

Mw = Molecular weight of N_2 (0.014),

c = ml digest taken for distillation (10 ml),

b = g sample taken for analysis (0.1 g),

% Crude Protein = 6.25 × % N.

4.3 Data Analysis

Data were subjected to analysis of variance using SAS version 8.1 (Littel *et al*., 2002). Means were separated according to Least Significant Difference (LSD) whenever the sorghum line effects were significant ($P \leq 0.05$). The statistical model for the data analysis is represented as:

$$Y_{ijkl} = \mu + L_i + R_{j(i)} + V_k + VL_{ij} + \varepsilon_{ijkl}$$

In the equation, Y_{ijkl} is the response variable, μ is population mean, L_i is the i^{th} effect due to location, $R_{j(i)}$ the j^{th} replicate effects on i^{th} location, V_k is the k^{th} effect due to sorghum line, VL_{ik} is the i^{th} effect due to location on k^{th} sorghum line and ε_{ijk} is the random error.

4.4 Results and Discussion

4.4.1 Crude Proteins

There were significant differences in the crude protein content in the different sorghum lines. Results showed that the protein content of the sorghum lines evaluated ranged from 8.93-13.79, 10.32 – 15.35, 9.08 – 14.64, and 9.36 – 12.38% when grown in long rainy season in Mundika (LM 2) and Masumbi (LM 1) and during short rainy season in LM 2 and Sagam (LM 1) respectively (Table 4.2). Some inbred and hybrid lines of sorghum in Kansas (Hicks *et al.*, 2002) and African sorghum lines (Aba *et al.*, 2005) had similar range of 10.3 - 16.5 % and 10 – 16.45%, respectively.

Table 4.2: Crude protein levels of the nine sorghum lines evaluated at Mundika (LM 2) during long (LR) and short rain (SR) season, Masumbi (LM 1) and Sagam (LM 1)

% Crude Protein across and within Environments					
Sorghum lines	**Mundika (LM 2)**	**Masumbi (LM1)**	**Mundika (LM2)**	**Sagam (LM1)**	
	← Long rains →		← Short rains →		$LSD_{0.05}$
SDSA1 x ICSR43	11.92‡$^{ab}_{A}$†	11.62$^{b}_{A}$	10.32$^{cd}_{A}$	12.06$^{a}_{A}$	6.67
Sima	9.08$^{b}_{AB}$	15.35^{a}A	12.75$^{ab}_{B}$	10.74$^{ab}_{B}$	4.57
Serena	12.60$^{ab}_{AB}$	12.74$^{ab}_{A}$	10.84$^{bcd}_{A}$	9.84$^{bc}_{B}$	2.18
Gadam	13.81$^{ab}_{A}$	13.44$^{ab}_{A}$	12.56$^{abc}_{A}$	8.25$^{c}_{B}$	1.94
IS 9203	14.64$^{a}_{A}$	10.52$^{b}_{A}$	11.37$^{bc}_{A}$	10.74$^{ab}_{A}$	4.37
IS 25561	10.17$^{ab}_{A}$	10.48$^{b}_{A}$	10.62$^{bcd}_{A}$	9.36$^{bc}_{A}$	2.86
IS25557	12.31$^{ab}_{A}$	11.90$^{ab}_{AB}$	13.79$^{a}_{AB}$	9.73$^{bc}_{B}$	3.23
Siaya #2-3	14.59^{a} $_{C}$	10.32$^{b}_{BC}$	8.93$^{d}_{A}$	12.38$^{a}_{B}$	2.75
Abaleshya	13.61$^{ab}_{A}$	11.21$^{b}_{A}$	10.51$^{bcd}_{A}$	11.06$^{ab}_{A}$	4.24
$LSD_{0.05}$	4.82	3.47	2.31	1.99	

†Means followed by subscript same upper case ACROSS the row do not significantly differ ($p \leq 0.05$).

‡Means followed by superscript same lower case DOWN the column do not differ significantly ($p \leq 0.05$).

When grown during long rainy season in LM 2, SDSA1 x ICSR43 line was comparable to *Gadam* and *Serena* in crude protein content but gave 10.53% lower crude protein than *Sima.* SDSA1 x ICSR43 line produced 13.8 % less crude protein than *Sima* when grown in Masumbi (LM 1) but when planted at Sagam (LM 1), SDSA1 x ICSR43 line did not differ from *Sima*. However, SDSA1 x ICSR43 line yielded 18.75% and 10.14% more crude protein than *Gadam* and *Serena* respectively, at Sagam. The differences in crude protein content may be attributed to the genetic variability associated with these accessions (Chavan *et al.*, 2009, Ng'uni *et al.*, 2012).

Genotype by environment interaction was evident for the crude protein content of the evaluated sorghum lines (Table 4.2). Among the lines suitable for malting, SDSA1 x ICSR43 line maintained statistically similar amounts of crude protein in all the test environments whereas *Gadam* and *Serena* showed a drop in crude protein when cultivated in Sagam (LM

1). *Sima* on the other hand yielded high crude protein when grown in Masumbi (LM 1) and in long rainy season in LM 2 while low crude protein content was obtained upon growing the line during short rainy season in LM 2 and in Sagam (LM 1).

Among the lines suitable for baking, lines IS 25557 and Siaya #2-3 were the only two lines that showed interaction with the environment in which they were cultivated in terms of crude protein content (Table 4.2). IS 25557 line had low crude protein when grown in Sagam (LM 1) while Siaya #2-3 yielded high crude protein when cultivated in LM 2 during the short rainy season, moderately high crude protein when grown in Masumbi (LM 1) and lowest amount was obtained when the line was grown in LM 2 during the long rainy season. Protein content and composition vary due to genotype and water availability, temperature, soil fertility and environmental conditions during grain development (Hulse *et al.*, 1980; Ebadi *et al.*, 2005). The protein content of sorghum variety is important if the variety is to be designated as grain sorghum and for brewing purposes. This is because sorghum is a major source of protein and calories in the diet of large segment of the populations of Africa and Asia (Yousif and ElTinay, 2001).

4.4.2 Tannins

In this study, the tannin content of the sorghum lines ranged between 8.00 – 70.00 mg/100 ml tannic acid equivalents (Table 4.3). This is consistent with work by Kiprotich *et al*. (2014) who reported similar ranges of 6.88 -7.89 mg/ 100ml tannic acid among locally grown sorghum genotypes. The lineSDSA1 x ICSR43 had the lowest tannin content which ranged from 8.00 – 24.33 mg/100 ml tannic acid equivalents depending on the growing environment. Relative to the check lines, the tannin content of SDSA1 x ICSR43 line was 45.27% lower than for *Sima* when grown in Mundika (LM 2) during the short rainy season. Growing the lines in Masumbi (LM 1), SDSA1 x ICSR43 line had 39.56%, 46.27% and 54.32% less tannin than *Sima, Gadam* and *Serena* respectively. During long rainy season in LM 2, the lowest amounts of tannins were obtained for SDSA1 x ICSR43 than the check lines while planting these lines in Sagam (LM 1) their tannin content was statistically analogous.

Table 4.3: Tannin levels of the nine sorghum lines evaluated at Mundika (LM 2) during long (LR) and short rain (SR) season, Masumbi (LM 1) and Sagam (LM 1)

Tannin (mg/100ml) across and within Environments					
Sorghum lines	Mundika (LM 2)	Masumbi (LM1)	Mundika (LM2)	Sagam (LM1)	
	← Long rains →		← Short rains →		$LSD_{0.05}$
SDSA1 x ICSR43	9.67‡$^{c}_{B}$†	9.67^{d}_{AB}	8.00^{f}_{B}	24.33^{c}_{A}	19.80
Sima	25.67^{b}_{B}	22.33^{c}_{B}	17.67^{e}_{B}	53.00^{abc}_{A}	12.23
Serena	16.67^{bc}_{A}	32.67^{b}_{A}	29.67^{d}_{A}	31.33^{bc}_{A}	21.36
Gadam	15.67^{bc}_{A}	26.33^{bc}_{A}	18.33^{e}_{A}	41.33^{abc}_{A}	26.84
IS 9203	46.00^{a}_{A}	50.33^{a}_{A}	49.67^{b}_{A}	46.67^{abc}_{A}	11.52
IS 25561	45.00^{a}_{A}	51.00^{a}_{A}	47.33^{b}_{A}	54.33^{abc}_{A}	25.72
IS25557	41.00^{a}_{AB}	32.00^{b}_{C}	46.00^{bc}_{BC}	53.33^{abc}_{A}	11.65
Abaleshya	47.67^{a}_{B}	49.67^{a}_{B}	41.00^{c}_{B}	70.00^{a}_{A}	20.11
Siaya #2-3	25.67^{a}_{A}	52.00^{a}_{A}	58.67^{a}_{A}	60.33^{ab}_{A}	26.09
$LSD_{0.05}$	13.225	9.090	5.833	35.350	

†Means followed by subscript same upper case ACROSS the row do not significantly differ ($p \leq 0.05$)

‡Means followed by superscript same lower case DOWN the column do not differ significantly ($p \leq 0.05$)

The sorghum lines suitable for baking had tannin levels ranging from 41.00 - 70.00 mg/100 ml tannic acid equivalents (Table 4.3). No variation in tannin content was observed among the sorghum lines when grown in LM 2 during the short rainy season and in Sagam (LM 1). However, evaluating the lines during the long rain season in LM 2, Siaya #2-3 recorded the highest amount of tannins while IS 25557 had the lowest amount of tannins relative to other lines when evaluated at Masumbi (LM 1). Low tannin sorghums are desirable in making food products due to their palatability (Awika *et al*., 2004). Good quality breads containing tannin sorghum bran have high antioxidant and dietary fiber levels with a natural dark brown color and excellent whole grain flavor (Gordon, 2001). In addition, healthy bread mixes containing tannin sorghum bran, barley flour, and flax seed have been developed (Rudiger 2003). Only a limited number of studies have addressed the issue of wheat-free loaf breads from sorghum, resembling wheat breads. Unlike composite breads, wheat-free sorghum breads are suitable for coeliacs (Schober *et al*., 2005) and might possibly replace wheat breads in developing countries.

The combined analysis showed that agro-ecological environment was the main source of variation in tannin content of sorghum lines particularly SDSA1 x ICSR43, IS 25557, *Abaleshya* and *Sima* (Table 4.3). High environmental temperature during growing may inhibit tannin biosynthesis in the sorghum grain (Wu *et al*., 2016). Trikoesoemaningtyas *et al*., (2015) reported similar findings on sorghum lines evaluated in Indonesia. Taleon *et al*. (2012) indicated that the total flavonoid content of black sorghum was affected strongly by environment, mainly due to the differential effect of abiotic factors such as light and temperature and also by the differential intensity of fungal infection. Sorghum grains suitable for malting and brewing should not have tannin levels greater than 18.13 mg/100 ml since high tannin levels poses a challenge during brewing process. Tannins inhibit the activity of alpha amylase (Alonso *et al*., 2000) and this lowers hydrolysis of starch which is essential for brewing. This study has shown that growing SDSA1 x ICSR43 in LM 1 (Sagam) during the short rainy season causes a drastic increase in tannin content for the line thus affecting its suitability for use in brewing. Cultivation of SDSA1 x ICSR43 in LM 1 and LM 2 during the long rainy season and LM 2 during the short rainy season produces quality grains for malting and brewing with regard to tannin levels.

4.4.3 Starch

The sorghum lines evaluated had starch content ranging from 29.73- 80.23% (Table 4.4). Generally, the malting and brewing sorghum lines had higher amounts of starch than the lines suitable for baking. This confirms the findings by Almodares and Sepahi (1996) that the cultivar of sorghum affects the levels of sorghum non-structural carbohydrates. SDSA1 x ICSR43 line yielded similar amount of starch as the check lines in all the test environments. On the other hand, environmental effect on starch content was noted on lines SDSA1 x ICSR43, *Sima* and *Serena* while *Gadam* maintained comparable amount of starch in all the test environments. Sorghum grain starch accumulation is subject to environmental factors since it is a quantitively inherited trait (Bing *et al*., 2014). Line SDSA1 x ICSR43 line yielded highest amount of starch when grown in Mundika (LM 2) both in long and short rainy seasons, moderate amount in Masumbi and lowest amount when grown in Sagam. Lines *Sima* and *Serena* when grown in Sagam (LM 1) and Masumbi (LM 1) respectively produced the lowest amount of starch.

Table 4.4: Starch content of the nine sorghum lines evaluated at Mundika (LM 2) during long (LR) and short rain (SR) season, Masumbi (LM 1) and Sagam (LM 1)

% Starch across and within Environments					
Sorghum line	Mundika (SR,LM 2)	Sagam (LM1)	Mundika (LR,LM2)	Masumbi (LM1)	
	← Short rains →		← Long rains →		LSD $_{0.05}$
SDSA1x ICSR43	$71.20‡^{abc}_{A}†$	41.43^{b}_{BC}	79.35^{a}_{AB}	56.43^{abc}_{C}	17.81
Sima	72.77^{abc}_{A}	29.73^{ab}_{AB}	78.80^{a}_{AB}	71.40^{a}_{B}	23.78
SERENA	81.67^{a}_{AB}	49.10^{ab}_{B}	56.77^{ab}_{A}	44.08^{c}_{B}	28.90
GADAM	80.23^{ab}_{A}	60.33^{a}_{A}	62.53^{ab}_{A}	64.63^{ab}_{A}	20.80
IS 9203	55.30^{d}_{A}	56.57^{ab}_{A}	64.93^{ab}_{A}	55.07^{bc}_{A}	24.63
IS 25561	68.33^{abcd}_{B}	41.67^{b}_{B}	51.33^{b}_{A}	52.67^{bc}_{B}	12.40
IS25557	61.50^{dc}_{A}	54.03^{ab}_{A}	69.91^{ab}_{A}	58.10^{abc}_{A}	27.94
Siaya #2-3	64.87^{bcd}_{A}	56.90^{ab}_{A}	58.86^{ab}_{A}	50.13^{bc}_{A}	18.21
Abaleshya	64.93^{bcd}_{A}	51.63^{ab}_{A}	62.17^{ab}_{A}	47.43^{c}_{A}	22.95
LSD$_{0.05}$	15.51	17.39	25.81	15.74	

†Means followed by subscript same upper case ACROSS the row do not significantly differ ($p \leq 0.05$).

‡Means followed by superscript same lower case DOWN the column do not differ significantly ($p \leq 0.05$).

All the lines suitable for baking did not differ in the amount of starch within each growing environment (Table 4.4). In addition, genotype by environment effect was only observed with IS 25561 line whereby in Mundika (LM 2) during short rainy season highest starch content was realized whereas in the other test environments lower amounts of starch was recorded that were statistically similar across the environments. Many researchers have reported the effect of growing environment on the chemical composition of sorghum grain (Beta and Corke 2001; Tester and Karkalas 2001; Kiprotich *et al*., 2014) and Trikoesoemaningtyas *et al*., 2015). However, the current study has shown that variation in starch content among sorghum lines suitable for use in baking was highly based on genotype rather than the growing environment. Similar findings on genetic variations in starch content were reported in triticale (*Triticosecale*) (Burešová *et al*., 2010**)** and in wheat (*Triticum aestivum* L.) (Labuschagne *et al.*, 2007; Massaux *et al.*, 2008).

4.4.4 Amylose

Low amylose content is desirable for food and industrial purposes. This is because lower amylose content increases carbohydrate digestibility (Lichtenwarner *et al.*, 1978) and improve ethanol fermentation (Yan *et al*., 2011). Amylose content of the evaluated sorghum lines ranged from 15.17- 33.37% (Table 4.5). This was within the range of normal sorghum as described by Shelton *et al.* (2004). Considering each growing site, no variation in amylose content was observed when the lines were grown in LM 1 (Masumbi and Sagam) and during short rains in Mundika (LM 2) (Table 4.5). However, growing the lines during the long rains in LM 2 resulted in Siaya #2-3 yielding highest amount of amylose whereas IS 25561 gave the lowest. In Masumbi (LM 1), highest amount of amylose was obtained for IS 25561 while IS 9203 had the lowest percent amylose. This was in line with other research findings where significant inter-varietal differences in the content of amylose among sorghum varieties were noted (Beta and Corke, 2001; Dicko *et al*., 2006b). All the sorghum lines suitable for malting and brewing did not vary in the amount of amylose in all the agro-ecological environments with a similar trend observed for lines suitable for baking except when the lines were evaluated at Mundika (LM 2) during the long rainy season (Table 4.5).

Table 4.5: Amylose content of the nine sorghum lines evaluated at Mundika (LM 2) during long (LR) and short rain (SR) season, Masumbi (LM 1) and Sagam (LM 1)

% Amylose across and within Environments					
Sorghum line	Mundika (SR,LM 2)	Sagam (LM1)	Mundika (LR,LM2)	Masumbi (LM1)	
	← short rains →		← long rains →		$LSD_{0.05}$
SDSA1x ICSR43	20.67^{a}‡$_{A}$†	22.33^{a}_{A}	25.33^{ab}_{A}	27.08^{ab}_{A}	12.20
Sima	16.17^{a}_{A}	25.50^{a}_{A}	20.92^{ab}_{A}	20.00^{ab}_{A}	12.57
SERENA	19.08^{a}_{A}	18.32^{a}_{A}	27.33^{ab}_{A}	23.26^{ab}_{A}	10.41
GADAM	21.58^{a}_{A}	27.50^{a}_{A}	20.08^{ab}_{A}	22.50^{ab}_{A}	17.10
IS 9203	17.50^{a}_{B}	30.08^{a}_{A}	22.77^{ab}_{AB}	23.67^{ab}_{AB}	12.56
IS 25561	22.33^{a}_{A}	28.33^{a}_{A}	33.37^{a}_{A}	29.00^{a}_{A}	16.42
IS25557	15.17^{a}_{A}	28.22^{a}_{A}	20.83^{ab}_{A}	15.28^{b}_{A}	22.70
Siaya #2-3	17.25^{a}_{A}	20.92^{a}_{A}	16.75^{b}_{A}	24.83^{ab}_{A}	18.35
Abaleshya	22.25^{a}_{A}	25.08^{a}_{AB}	28.76^{ab}_{B}	25.83^{ab}_{A}	4.85
$LSD_{0.05}$	11.550	16.561	14.080	12.873	

†Means followed by subscript same upper case ACROSS the row do not significantly differ ($p \leq 0.05$).

‡Means followed by superscript same lower case DOWN the column do not differ significantly ($p \leq 0.05$).

This was possibly due to similarities in minimum and maximum temperature among the growing sites during the crop-growing period. Temperatures have an effect in amylose content of cereal grains. For instance, high temperatures caused a decrease in amylose content in wheat whereas low temperatures had an opposite effect (Kulp and Ponte 2000). Temperature may lead to alterations in sugar transport or metabolism and an altered distribution of soluble sugars over the different pollen tissues and during grain formation (Jain *et al.*, 2007).

4.4.5 Amylopectin

Among malting and brewing sorghum lines within a specific agro-ecological environment, no variation in the amylopectin content was noted in Mundika (LM 2) during the short rain, Masumbi and Sagam (LM 1) (Table 4.6).

Table 4.6: Amylopectin levels of the nine sorghum lines evaluated at Mundika (LM 2) during long (LR) and short rain (SR) season, Masumbi (LM 1) and Sagam (LM 1)

% Amylopectin across and within Environments					
Sorghum line	**Mundika (LM 2)**	**Sagam (LM 1)**	**Mundika (LM 2)**	**Masumbi (LM 1)**	
	← short rains →		← long rains →		LSD $_{0.05}$
SDSA1 x ICSR43	50.33‡$^{abc}_{A}$†	19.10$^{a}_{BC}$	54.02$^{ab}_{AB}$	30.35$^{abc}_{C}$	21.33
Sima	56.60$^{abc}_{A}$	24.27$^{a}_{AB}$	58.89$^{a}_{AB}$	51.40$^{a}_{B}$	32.38
SERENA	62.59$^{a}_{B}$	30.78$^{a}_{B}$	29.43$^{cd}_{A}$	20.83$^{c}_{AB}$	32.04
GADAM	58.65$^{ab}_{AB}$	32.83$^{a}_{AB}$	42.45$^{abc}_{A}$	42.13$^{abc}_{C}$	17.18
IS 9203	37.80$^{c}_{A}$	26.48$^{a}_{A}$	42.16$^{abc}_{A}$	31.40$^{abc}_{A}$	22.72
IS 25561	46.07$^{abc}_{B}$	13.23$^{a}_{B}$	17.96$^{d}_{A}$	23.67$^{bc}_{B}$	20.34
IS25557	46.33$^{abc}_{A}$	25.82$^{a}_{AB}$	49.08$^{abc}_{A}$	42.82$^{ab}_{B}$	19.50
Siaya #2-3	47.62$^{abc}_{A}$	35.98$^{a}_{A}$	42.11$^{abc}_{A}$	25.30$^{bc}_{A}$	23.78
Abaleshya	42.68$^{ab}_{A}$	26.55$^{a}_{A}$	33.41$^{bcd}_{A}$	21.60$^{bc}_{A}$	22.96
LSD$_{0.05}$	19.52	25.58	21.51	21.59	

†Means followed by subscript same upper case ACROSS the row do not significantly differ ($p \leq 0.05$).

‡Means followed by superscript same lower case DOWN the column do not differ significantly ($p \leq 0.05$).

However, amylopectin content of SDSA1 x ICSR43 line was 29.5 % more than for *Serena* when grown in Mundika (LM 2) during the long rainy season. The study showed that variability in the amylopectin content of sorghum lines for malting and brewing was more environmental than genotypic (Table 4.6). The SDSA1 x ICSR43 had the highest amount of amylopectin when cultivated in Mundika (LM 2) during long and short rainy seasons while growing the line at Masumbi (LM 1) moderate amounts were realized. *Sima* and *Gadam* had similar percent amylopectins when grown in Mundika (LM 2) during long and short rainy seasons and Masumbi (LM 1) whereas they produced low amylopectin amounts when grown at Sagam (LM 1). The physical properties and chemical compositions of cereal grains is greatly affected by growing environments (Beta and Corke 2001; Tester and Karkalas 2001).

The baking lines did not show variation in the quantity of amylopectin per the test environments (Table 4.6). However, significant effect of environment on the amylopectin content of lines IS 25557 and IS 25561 was noted. Line IS 25557 had its amylopectin amount reduced by 31.1% when grown in Sagam (LM 1) relative to growing it in Mundika (LM 2). Growing IS 25561 line during the short rainy season in LM 2 resulted in 43.9% increase in the amount of amylopectin than when grown in long rainy season in the same agro-ecological environment. The current study has shown that the growing environment has more effect on the amylopectin content of sorghum grains than the genotype. This is probably because starch, which comprises 70-80% amylopectin, is a quantitively inherited trait and starch accumulation is subject to environmental factors (Bing *et al*., 2014). The variation in temperature during pollination, grain filling and development causes the variation in the amount of sugars that are metabolized and distributed into the sorghum grains (Jain *et al*., 2007).

4.4.6 Correlation of the Quality Parameters

Correlation among characters is of interest to the breeders because it aids in identification of easily measured characters that could be used as indicators of more important, but more complex characters. Correlation is also useful in pointing out the possibilities and limitation of simultaneous improvement of desirable characters. In this study (Table 4.7), starch was found to be significantly and positively correlated to 100 kernel weight and percent amylopectin. Heavier grains had high amounts of starch and amylopectin. This is in line with the expectation since starch forms the largest composition in sorghum grain while amylopectin is the major component of the starch granule contributing approximately 70-80% of the total starch by weight (Dicko *et al*., 2006b). However, starch negatively correlated to the height of the plant and protein content. This may be attributed to the high assimilate partitioning to the growing vegetative part of the plant (plant height) at the expense of grain starch accumulation. Cooler temperatures during the grain filling period are associated with higher accumulation of starch at the expense of nitrogen uptake thus resulting in higher starch and lower protein (Schelling *et al.*, 2003). Amylopectin on the other hand had a positive correlation with the protein content and a negative correlation with amylose. Tannin content positively correlated to the days to 50% heading and the height of the plant.

Taller plants and those that took longer for half the plant population to flower produced grains with high amount of tannins. This may be attributed to the crop's ability to channel the other assimilates to the stems and leaves for a considerable amount of time, leaving the grains with higher concentration of tannins (Rekar and Biradar, 2015).

Table 4.7: Simple correlation matrix for agronomic parameters (plant height, days to 50% heading, 100 grain weight and yield) and grain quality (Tannin, Amylopectin, Amylose, Starch and Crude Protein) of the sorghum lines for industrial uses evaluated at Mundika

	100 GW	50% H	PH	Y	P	S	A.lose	A.pectin	T
100 GW	1.00	0.81*	-0.54	0.01	0.35	0.75*	-0.26	0.65	-0.61
50% H		1.00	0.78	0.02	-0.32	-0.66	0.22	-0.57	0.68*
PH			1.00	-0.25	-0.64	-0.71*	0.44	0.69*	0.71*
Y				1.00	0.06	0.06	-0.48	0.24	-0.35
P					1.00	0.69*	-0.75*	0.81**	-0.26
S						1.00	-0.51	0.94***	-0.64
A.lose							1.00	-0.78*	0.13
A.pectin								1.00	-0.51
T									1.00

* Significant at *P*≤ 0.05, 100 GW= 100 Grain weight, 50 % H= Days to 50 % Heading, PH= Plant height, Y= Yield, P= Protein, S= Starch, A.lose= Amylose, A.pectin= Amylopectin and T= Tannins

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 General discussion

The sorghum lines tested were shown to have potential to grow under adverse climatic conditions with minimum input and can thus be promoted in Kenya to ensure increased production and contribute to increased income and livelihoods of smallholder farmers. The sorghum lines performed better in Lower Midland (LM) 1 agro ecological zones that were characterized by relatively higher amount of rainfall compared to LM 3. Higher grain yields could be attributed to the capacity of sorghum plants to remobilize pre-anthesis assimilates to the grains when the soil has good moisture content (Beheshti, 2010). Drought is a major challenge in production of sorghum as it affects physiological and developmental characteristics that determine grain yield. These yield components are developed by series of metabolic and developmental activities; thus water stress conditions at any stage of development that affect such processes causesg significant yield reduction. For instance, drought stress occurring shortly before booting stage until soft dough stage causes reduction in grain yield of some cultivars of sweet sorghum (Zegada-Lizarazu and Monti, 2012). The low grain yield in low performing environments like Sinyanya (LM 3) is associated with small grain size and decrease in grain number that was possibly due to soil water deficit and high temperature stress during critical stages of crop development.

Sorghum lines evaluated in this study showed variations in a given growing environment in regards to yield and yield components such as panicle weights and lengths, grain number and weights, spike lengths and weights. Furthermore, significant difference in grain yield of the evaluated lines across environments was observed. The results in this study conform to findings by Assefa *et al*. (2010) who reported that good rainfall distribution pattern matches crop water needs thus contributing to yield improvements. The observed significant differences among genotypes with regard to grain yield, yield components and grain quality are attributed to genetic variability of the sorghum lines and response to varying environmental conditions. This provide farmers with opportunity to select suitable sorghum lines with best performing traits for a given agro-ecological environment. These findings are is similar to those by Jordan *et al.* (2012) and emphasize the importance of identifying agro-ecological environments suitable for production of the various sorghum lines.

Similarly, grain qualities were significantly different among sorghum lines in relation to crude proteins, tannins, starch, amylose and amylopectin which are important determinants of suitability of sorghum grains for industrial use. In malting and brewing, starch is hydrolyzed into glucose that yield alcohol during the fermentation process. Kiprotich *et al*. (2014) recommended starch amount of more than 60% if the sorghum grain is to be used in malting and brewing. However, starch comprises of amylose and amylopectin (Dicko *et al.*, 2006a) whose ratio affect digestibility of starch. The hydrolysis process is better when the amylose contents is higher (Kiprotich *et al*., 2014). The fermentation process involves microorganism that require energy that is sourced from biosynthesis of proteins. However, digestibility of proteins is lowered if there are high level of tannins. Tannins levels more that 18mg/100ml tannic acid equivalents are not desirable in malting and brewing owing to its stringent taste and ability to lower digestibility of proteins. However, with increasing health awareness, high tannin sorghums are considered suitable in bakery products such as bread since they are good sources of antioxidants that protect aging of body cells thus reducing the risks of certain cancers (Gomez-Cordoves *et al*., 2001; Yang *et al*., 2009). In this study all the baking sorghums lines recorded high levels of tannin content in all the growing environments.

Significant positive association of grain yield with yield components were reported in this study. Thees correlations provides important information of interrelationship of traits which help in improvement of grain yield. The greater variability among lines for traits associated with grain yield and grain quality for brewing and baking properties provide larger scope for selection based on these traits. Currently, East African Breweries Limited uses *Gadam* for malting and brewing. The industrial demand for sorghum grain far much outweighs the current supply. This study has shown that SDSA1 x ICSR43 line significantly gives higher yields than *Gadam* in the test environments thus adoption of SDSA1 x ICSR43 line by the farmers and the cultivation in the recommended environments will greatly contribute to increased sorghum production in Kenya.

5.2 Conclusions

This study showed a noteworthy sorghum by environment interaction, which was an indication of diversity of the lines evaluated and their differences in environmental response. Differences in yield and yield components of the evaluated sorghum lines were noted across the agro-ecological environments and among the sorghum lines. The combined analysis showed that environment affected the nutritional and anti-nutritional content of sorghum lines with different magnitudes. The variances due to sorghum line were higher for starch content, protein content and amylose content, whereas the variability observed for tannin and amylopectin content were mostly due to the agro-ecological environment. The presence of genotypes x environmental interaction resulted in differential nutritional values of sorghum grains over environments. These results suggest that while conducting yield stability trials, breeders should not only focus on agronomic characters and yield potential but should also consider stability of the quality parameters that define commercial utilization of these sorghum lines.

5.3 Recommendations

For sustainable production of quality grains for industrial uses, this study makes the following recommendations:

1. Long Rain Season

i. Lower midland zone (LM) 1 characterized by Sandy clay loam soils with a pH of 5.8, 846.4 mm of rainfall during the crop growing period and the average minimum and maximum temperature of 20^oC and 28^oC respectively, is ideal for the cultivation of lines SDSA1 x ICSR43 and Siaya #2-3. The zone produce grains of required quality in terms of their usage in baking and in malting and brewing

ii. Lower Midland zone 2 with characteristic sandy loam soils of pH of 4.4, rainfall amounting to 692 mm during the crop-growing period, minimum and maximum temperatures of 20^oC and 26^oC respectively, is an averagely stable environment for cultivation of the sorghum lines evaluated in this study.

iii. Rainfall is the most limiting factor in LM 3 since the soil characteristics are similar to those of LM 1. Thus, this agro-ecological environment could be suitable for the cultivation of industrial sorghum lines if a water requirement by the crop is met.

2. Short Rain Season

i. Lower Midland zone 1 and 3 are averagely stable environments for the cultivation of all sorghum lines studied. LM 1 is characterized by clay loam soils, minimum temperature of 26^oC, maximum temperature of 30^oC and 798 mm of rainfall during the crop growing period. LM 3 is characterized by sandy clay loam soils, 488 mm rainfall during the crop growing period and minimum and maximum temperatures of 20^oC and 32^oC, respectively.

ii. During this season, the amount of tannins in SDSA1 x ICSR43 line exceeded the recommended amounts for suitability in brewing. Therefore, this environment is only suitable for the cultivation of sorghum lines for use in baking

3. Lines IS 9203, IS 25557 and IS 25561 are less stable in their chemical composition and thus recommended for further improvement through crop breeding for stability in these agro-ecological environments.

CHAPTER SIX

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APPENDICES

Appendix 1: Analysis of Variance for grain quality attributes, yield components and yield of Sorghum lines

Table A1: Means squares for Crude Protein (%), Starch (%) and Tannin (Mg/100ml Tannic acid equivalent) of nine Sorghum Lines across Four agro-Ecological Environments

Source of variation	df	Crude protein	Starch	Tannin
Replicate	2	0.39	393.50	81.68
Agro-Ecological Environment(E)	3	21.26**	1810.89***	1517.59
Sorghum lines (SL)	8	3.85	289.36*	1922.59
Interaction(E x SL)	24	9.07**	186.57	143.06
Error	94	3.71	120.46	116.31
CV		16.67	18.21	27.56

*Indicates significance at P<0.05, ** significance at P<0.01, *** significant at P<0.001, df refers to degrees of freedom, CV is the Coefficient of Variation

Table A2: Means squares for the Stand Count, Plant Height (cm), Number of days to 50% Heading, Panicle Weight (g), Panicle Length (cm) and the Number of Spikes per Panicle of the nine sorghum lines evaluated across six agro-ecological environments

Source of variation	Df	Stand count	Plant height	50% Heading	Panicle Weight	Panicle Length	$Spikes^{-1}$ Panicle
Replicates	2	238.96	58.59	1.23	385.49	17.32	32.17
Agro-Ecological Environment(E)	5	1604.69***	34687.57***	628.98***	1634.37**	43.11***	1247.05***
Sorghum lines (SL)	8	289.15***	15007.89***	506.17***	4215.12***	509.69***	1234.63***
Interaction(E x SL)	40	102.33***	1224.04***	33.82***	450.10	10.41***	52.51**
Error	106	46.40	484.32	8.7	446.88	3.94	25.53
R-Square		0.75	0.87	0.90	0.56	0.91	0.87

** Indicates significance at P<0.01,*** Indicates significance at P<0.001, Df refers to degrees of freedom

Table A3: Mean Squares for Spike Length (cm), Spike Weight (g), Number of grains per spike, 100 Kernel Weight (g), and Grain Yield (Tons/ha)

Source of variation	Df	Spike Length	Spike weight	Grain $^{-1}$ spike	100 Kernel Weight	Grain Yield
Replicates	2	1.29	0.32	93.01	0.05	59.35
Agro-Ecological Environment (E)	5	11.42***	3.01	1636.20***	2.12***	1843.04***
Sorghum lines (SL)	8	35.90***	2.66***	2210.02***	4.35***	438.92***
Interaction(E x SL)	40	2.10***	0.51	335.08***	0.16***	145.60***
Error	106	0.70	0.36	184.07	0.07	38.40
R-Square		**0.85**	**0.60**	**0.67**	**0.88**	**0.82**

***Indicates significance at P<0.001, Df refers to degrees of freedom