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# Evaluation of Dual Purpose Sorghum Varieties for Animal Feed in Semi Arid Areas Of Kenya

BY

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## DECLARATION

I declare that this is my original work and has not been presented for an award of a degree in any other University.

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## DEDICATION

To my dear and beloved wife Lucy Njoki for supporting, encouraging and praying with me for the success and excellent work. Much dedication also goes to my Parents Mr and Mrs. Njiru Dionisio for bringing me up and walking with me in abiding love and care. They made immeasurable sacrifices in my initial studies so that I may gain education and learn. Not forgetting the boundless support and fervent encouragement from my brother baba Nyambura and his beloved wife mama Nyambura for accepting me as their son and paying my school fees all through from form one to university level. Thanks and may the Almighty God bless them and expand them greatly.

This thesis is a celebratory and commemorative work to me that heralds an inventory of a phenomenal achievement in my procession towards an academic legacy. I hereby splendidly send it out as a noble and timeless masterpiece with the sincere desire that many persons will find much practical value here, should the Lord Jesus Christ tarry.

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## LIST OF ABBREVIATIONS

ADF - Acid Detergent Fibre

ADL – Acid Detergent Lignin

ADS – Acid Detergent Solution

ANOVA – Analysis of Variance

ASAL – Arid and Semi-Arid Lands

BMR – Brown Midrib

CGIAR – Consultative Group for International Agricultural Research

DAAD – Germany Academic Exchange Service

DMI – Dry Matter Intake

ECARSAM – Eastern and Central Africa Regional Sorghum and Millet Network

FAO – Food and Agriculture Organization

GDP – Gross Domestic Product

GOK – Government of Kenya

ICRISAT – International Crops Research Institute for Semi-Arid Tropics

IFPRI – International Food Policy Research Institute

ILRI – International Livestock Research Institute

IVDMD – In Vitro Dry Matter Digestibility

KARI – Kenya Agricultural Research Institute

ME – Metabolisable Energy

NDF – Neutral Detergent Fibre

NDS – Neutral Detergent Solution

NPN – Non Nitrogen Protein

NRC – National Research Council

SAT – Semi-Arid Tropics

SPSS – Statistical Package for Social Sciences

WUE – Water Use Efficiency

## ABSTRACT

This study was designed to compare ten dual purpose sorghum varieties on the basis of nutritional composition and digestibility with a view to recommend the best suited for arid and semi-arid areas. The materials used in the study were from a trial carried out during 2006/2007 short rain season at three Kenya Agricultural Research Institute (KARI) stations situated in semi-arid parts of Kenya namely; Kambi ya Mawe, Kiboko and Machang'a. The ten varieties from local and international collection were selected on the basis of agronomic criteria which included overall agronomic expression in terms of biomass yield, grain yield, number of leaves, number of tillers, low leaf senescence, plant height among others. At the age of 14 weeks, destructive sampling was conducted to obtain samples for chemical and digestibility evaluation. The samples were separated into panicles, leaves, stems and whole plant. In the laboratory the samples were analyzed for dry matter (DM), crude protein (CP), neutral detergent fibre (NDF), acid detergent fibre (ADF), acid detergent lignin (ADL) and in vitro dry matter digestibility (IVDMD).

The dry matter content of the ten sorghum varieties ranged from 91.2 to 92.57%, while crude protein was in the range of 5.13 - 6.61%. The neutral detergent fibre was highest ($P \leq 0.05$) in NGUUGU (73.79%) and lowest in IESV99006 DL (58.52%). The acid detergent fibre content followed the same pattern with NGUUGU showing the highest ($P \leq 0.05$) value (34.23%) and IESV99006 DL with the lowest value (23.94%). The hemicellulose and Acid detergent lignin contents were similar with values of 33.85 -39.56% and 4.55 - 5.8%, respectively. In case of plant parts, the leaves had higher ($P \leq 0.05$) dry matter content (92.34%) than panicles (91.71%) and stems (91.28%). The panicle showed the highest ($P \leq 0.05$) crude protein content (7.07%) while stem had lowest value (3.92%). The NDF values obtained were highest ($P \leq 0.05$)

(7.07%) while stem had lowest value (3.92%). The NDF values obtained were highest ($P \leq 0.05$) for stems (70.68%) and lowest in panicles (60.25%). The ADF, Hemicellulose and ADL showed higher ($P \leq 0.05$) values in leaves and stems and lower values in panicles. The *in vitro* dry matter digestibility (IVDMD) was highest ($P \leq 0.05$) in Variety IESV99006 DL (67.29%) followed by IESV92165 DL (65.95%) while NGUUGU had the lowest value (55.92%). The plant part on the other hand recorded higher ($P \leq 0.05$) IVDMD values in panicles and whole plant at 66.99 and 66.15% respectively, while stems value was lowest at 53.59%.

A combination of ability to produce relatively higher dry matter digestibility, crude protein and low fibre constituents, in addition to biomass yield led to ranking varieties IESV99006DL, IESV92165DL and SDSL90162-2 highly for dual purpose production. NGUUGU had high fibre component and low dry matter digestibility. Varieties such as Macia and IESV99027 DL displayed characteristics for grain sorghum. NGUUGU with highest DM yield/ha, improving of protein content, digestibility and possibly lowering of fibre content through breeding would produce a good forage sorghum variety. Finally animal feeding trials need to be conducted in order to evaluate these varieties in terms of animal performance.

# CHAPTER ONE

## 1.0 INTRODUCTION

Kenya has a land mass area of 596646 Km² of which over 80% is classified as arid and semi-arid lands (ASALs) (approx. 492,200 $Km^2$), and are home to more than 30 percent of Kenya population and over half its livestock population. The semi- arid accounts for about 60% (324000 Km²) of Kenya's surface area (Malimo, 2004; Makokha *2005*; Benke and Scoones, 1992). These areas are characterized by low, erratic and unreliable rainfall, hot condition, declining soil fertility and frequent drought causing crop failures, low animal productivity, famine and widespread poverty. Though climatically harsh, the Kenyan dry lands are of critical importance to peoples who subsist on their livestock herds.

Achieving food security and eradicating extreme poverty and hunger in Kenya calls for growth in the agricultural sector through research that targets increased productivity (Ashiono *et al.*, 2005). Livestock sub-sector of the Kenyan economy contributes over 12% of the Gross Domestic Product (GDP) (Government of Kenya, 2002). Therefore, Livestock production is a major economic and social activity for the communities that live in the high rainfall areas for dairy production and in the semi-arid regions (ASALs) for beef production (Kiptarus, 2005; Malimo, 2004). However, poor nutrition due to fodder shortages presents serious constraint to increased livestock productivity (Thorne *et al.*, 2002; Romney *et al.*, 2003). The main nutritional constraint to the use of crop residues as animal feed is slow rate of digestion due to high lignin and silica and relatively poor nutrient content (Abdul *et al.*, 2004). Mitaru and Okeyo (2004) reported

that inability to feed animals adequately throughout the year is the most widespread technical constraint in the semi arid areas.

According to Jacob *et al.* (1997) many countries, such as Kenya need dual purpose crops which can be grown in the semi-arid regions to help alleviate feed and food shortage. Extensive work with cow peas (Singh *et al.*, 2003; CGIAR, 2005-2008) sorghum (Ravi *et al.*, 2003; CGIAR, 2005-2008) and pearl millet (Blümmel, *et al.*, 2003; Hall *et al.*, 2004) has shown that differences in fodder value of crop residues can be exploited to increase livestock productivity without necessary detriment to grain yield.

Sorghum [*Sorghum bicolor (L.) Moench*] is adapted to drought prone environments that receive 300-760 mm annual rainfall, and has a great potential for expansion in 75% of the Kenyan semi-arid and arid lands that are characterized by low and unreliable rainfall. Studies by Sally *et al.* (2007), Kangama and Rumei (2005), Noah and Waithaka (2005), Soeranto and Sihono (2006) as well as Mitaru (1995) show that sorghum produces more forage dry matter than maize and thus has a greater potential as a forage crop in dry areas where maize does not do well. It is a multifunctional crop that can successfully grow predominantly in low-rainfall and arid to semi-arid environments as a source of food and fodder (Sally *et al.*, 2007; Amukelani, 2005; Mekbib, 2008; Paterson, 2009; Habyarimana *et al.*, 2004; Craufurd *et al.*, 1999; Corredor *et al.*, 2009). Sorghum biomass may be used for animal feed while the grains is used for human food since it has been reported to have good nutritive values (Soeranto and Sihono, 2006; Avner *et al.*, 2005; Rai *et al.*, 1999; Depkes, 1992).

According to Upadhyaya *et al.* (2009) Sorghum germplasm collection at the International Crops Research Institute for Semi Arid Tropics (ICRISAT) gene banks

exceeds 37,000 accessions. Due to remarkable genetic variability with more than 30000 varieties present in the world of sorghum collection (Irén Léder, 2004) there is an enormous species potential for dual-purpose and forage sorghum (Rai *et al.,* 1999; Blümmel *et al.,* 2003; Miller and Stroup, 2004). Thus, improvement of dual purpose sorghum productivity by breeding obliges focus on traits that affect the yield and nutritive quality of forage and grain (Propheter *et al.,* 2010; de Alencar *et al.,* 2008; Burler and Muir, 2006; Reddy *et al.,* 2004). Improved yield stability and nutritional quality of food/feed produced from sorghum is one of important dimension needed in an integrated effort to better meet the basic needs of some of the world's poorest people in some of the world's most difficult agricultural environments (Paterson, 2009). Thus identification of superior dual-purpose food-plus-feed sorghum varieties best suited for semi arid areas will be an attempt for Kenya to close its livestock feed gaps as well as feed its growing human population.

### 1.1 Problem statement and justification

Livestock production constitutes a major component of the agricultural sector, the mainstay of the Kenya economy. Livestock provide mainly meat and milk, the main proteins of animal origin consumed in the country. Since independence, it has been the policy of the Kenyan government to attain self-sufficiency in food production, and thus the need to produce more milk and meat cannot be over-emphasized (Nyabende, 2003). Kenya, being a developing country faces many constraints in her efforts to improve livestock productivity, amongst which, inadequate feed supply is the most important, especially in dry regions. Livestock productivity is closely linked to the quantity and

quality of available forage, of which a significant proportion may be sourced from sorghum (Desta *et al.,* 2000; Romney *et al.,* 2003; Muhammed *et al.,* 2005) which is considered a multipurpose crop (Monti *et al.,* 2004) suitable for areas that are too dry or too hot for the production of other cereals (Jacob *et al.,* 1997). Sorghum out-performs other cereals under various environmental stresses and thus generally more economical to produce (Kangama and Rumei, 2005). It produces more forage dry matter than maize in semi-arid areas (Mitaru, 1995; Berenguer and Faci, 2001; Noah and Waithaka, 2005; Soeranto and Sihono, 2006; Sally *et al.,* 2007). However, grain yield improvements have continued to receive highest research attention and these has limited the incorporation of fodder improvements. According to Eastern and Central Africa Regional Sorghum and Millet Network (ECARSAM) (2005) over 15 varieties in Eastern Africa have been evaluated for food quality, while only one dual purpose variety (E1291) released in Kenya.

The importance of livestock feed in semi arid areas where 60% of the livestock are concentrated cannot be over emphasized, particularly during the drought period. Sorghums have been shown to have a great potential to provide both feed and food in the semi arid areas. It is therefore important to develop and evaluate more dual purpose sorghum varieties suited for arid and semi arid areas. An attempt in this direction is a study by ICRISAT, designed to screen for dual purpose sorghum varieties from local and international collections. This project is a part of the study and is aimed at providing nutritional evaluation data necessary to rank the selected varieties for animal feed.

## 1.2 Objectives

The main objective of this study was to compare selected ten dual purpose sorghum varieties in terms of chemical composition and dry matter digestibility with a view to recommend the best suited for arid and semi-arid areas.

The Specific objectives were to:

1. To determine the dry matter and protein content of the ten selected sorghum varieties
2. To determine the fibre constituents of the ten selected sorghum varieties
3. To determine the *in vitro* dry matter digestibility of the ten sorghum varieties

# CHAPTER TWO

## 2.0 LITERATURE REVIEW

### 2.1 Overview of livestock and animal feed industries in Kenya

#### 2.1.1 Livestock Industry

Milk and meat are important sources of protein and energy in human diets (Muhammad *et al.,* 2005). Sarwar *et al.* (2002) found that poor availability of nutritious green forage leads to livestock not expressing their full potential in terms of meat and milk. At the global level livestock production is growing faster than any other agricultural sector (Paterson 2009). This is as a result of the dramatic and revolutionary increase in demand for animal products due to rapid urbanization. It is estimated that by 2020, half of the population in the developing countries will live in cities, where consumption of meat is high (Mugenieri and Omiti, 2008). According to FAO (2005) Kenya is a low income economy, with livestock being crucial to the economy of Kenya, where their production contributes over 12% of total Gross Domestic Product (GDP), 30-45% of the Agricultural GDP and employs about 50% of the agricultural labour force (Mugenieri and Omiti, 2008; Kiptarus, 2005; GOK, 2001). The Kenya livestock sector is dominated by small producers, with livestock population being concentrated in the arid and semi-arid lands (ASALs) which is about 75% of the total land surface. In ASALs the livestock sector accounts for 90 percent of employment and more than 95 percent of family income (FAO, 2005).

The overall goal of the government is to eradicate poverty, illiteracy and diseases. Livestock is the mainstay of most rural households and contributes significantly to the livelihoods of the population. According to Kiptarus (2005) dairy production is a major

economic and social activity for the communities that live in the high rainfall areas and so is beef production in the arid and semi-arid areas (ASALs). Therefore, concrete efforts are needed to increase the yield and quality of forage to enhance milk and meat production. The main livestock in semi-arid areas include the small East Africa zebu and Boran cattle, East Africa goats, Galla goats, Red Maasai sheep, the one hump camel and indigenous poultry (GOK, 2006).

#### 2.1.1.1 Dairy Industry

Dairy production, which is a dynamic sub-sector in Kenya, is a primary activity and major source of livelihood for families of about 600,000-800,000 small scale farmers (GOK, 2005). Milk is primarily produced from cattle, camels and dairy goats, their relative shares in the estimated milk output being 84%, 12% and 4% respectively. The figures basically indicate that cattle (cows) are the main source of milk in the country. Kenya has 70% of the dairy herd in Eastern and Southern Africa (GOK, 2006). Dairy industry is the most developed within the livestock sub-sector and is dominated by the small scale producers who accounts for 80% of the output (Kiptarus, 2005).

#### 2.1.1.2 Beef Industry

Beef production in Kenya is practiced primarily in the ASAL areas of the country. Hence, the producers need adequate and consistent supply of quality forage during the dry period in order to maintain high levels of milk and meat production. Zebu cattle dominate the national beef herd, with a significant proportion of beef coming also from dairy bull calves, and cull cows. Kiptarus, (2005) reported that, the increase in beef

consumption is higher than the increase in production and demand is expected to outstrip supply in the near future. Beef is derived from three major livestock production systems; extensive pastoral beef, dairy bull calves and commercial beef production systems. Kenya's beef cattle population stands at over 9 million, mainly kept in rangelands (GOK, 2006).

### 2.1.1.3 Camel Production

According to Kiptarus (2005) camels are potentially the most valuable species of livestock for the ASAL areas of Kenya. At present, camels are reared in 17 districts in the country. Overall, Northern Kenya is the most important camel producing area in the country, keeping over 95% of the national herd estimated at 895,100 animals (Kiptarus, 2005).

### 2.1.1.4 Sheep and Goats

Sheep and goats are mainly found in the arid and semi-arid areas of Kenya (GOK, 1999). The sheep and goat industry contributes about 30% of the total red meat consumed in the country. In addition, the industry produces wool, skins and milk (Kiptarus, 2005). The population of sheep and goats is estimated at about 21.08 million herds, comprising of 7.30 million hair sheep, 0.85 million wool sheep, 11.08 million meat goats and some 0.08 million dairy goats (GOK, 2006).

### 2.1.1.5 Poultry and Pig Industry

A large indigenous chicken population and a smaller but more productive exotic flock characterize the Kenyan poultry population (GOK, 1994). Majority of the birds are chickens with very few of the other species such as turkeys, geese, quails, guinea fowl, pigeons and ducks (GOK, 2005). Indigenous chickens are spread all over the country except in the arid areas, while commercial poultry and pigs are found in the periphery of major towns such as Nairobi, Mombasa, Kisumu, Eldoret, Nakuru among others. According to Kiptarus, (2005) and GOK, (2006) Kenya has an estimated poultry population of over 25 million. Of these 68% are indigenous chicken kept under free range condition, 26% are commercial chicken while 6% are other domesticated poultry (GOK, 2002). The population figure are estimated at 23m, 4.7m, 2.5m and 0.7m for layers, broilers, indigenous chicken and others respectively (GOK, 2005). The government has continued to encourage pig production as it plays a major role in the tourism sector. Small scale production constitutes up to 70% of the total pig farmers. Pig population is estimated at over 415,000 (Kiptarus, 2005).

### 2.1.2 Animal feed industry

Livestock feeds are an important input in the application of improved techniques of production. In commercial livestock production especially grade dairy cows, commercial poultry and pig production, concentrate feeds determine the level of profitability of the enterprise (GOK, 2001). Mbugua (1989) reported ten large scale feed manufactures with installed capacities ranging between 5,000 and 150,000 tonnes per year and a number of small scale millers producing variable amounts of feed. Quinet (2003) showed that Kenya

had thirty-four feed millers. In 2006, there were about 70-80 feed manufacturers with an annual turnover of about Ksh. 7 billion with, the biggest feed company producing about 90,000 tonnes per year (GOK, 2006). The returns received from millers in 2005 was 317,912 metric tonnes of total concentrate feed production compared to the installed capacity of approximately 600,000 and the highest percentage was represented by poultry feeds (56%), followed by cattle feeds (32%), pigs (9%) and other types (3%) (GOK, 2005). Competition for maize, the main energy source, between humans and livestock and inadequate research information on suitable feed ingredients for specific areas is a crucial constraint to the industry (GOK, 2006). Alternative energy sources such have the potential of addressing this constraint.

## 2.2 Sorghum production

### 2.2.1 Sorghum crop

Sorghum [Sorghum bicolor (L.) Moench] is a cultivated tropical cereal grass and has a major economic importance worldwide (House, 1985; Paterson, 2009). Cultivated sorghums include grain sorghum, forage sorghum, dual purpose, sweet sorghum, blooms sorghum, sudangrass, sorghum-sudangrass and sorghum almum among others. Sorghum may have been first domesticated in North Africa, possibly in Ethiopia at around 4000-3000 BC (Sally *et al.,* 2007). Sorghum is a cereal of remarkable genetic diversity with more than 2200 accessions in the world collection. This collection is used by plant breeders to improve the crop. The sorghum genus as currently proscribed consists of 25 species (USDA ARS, 2007) although this varies in different scientific publications confirming the dynamic nature of the classification of cultivated sorghum and its wild

relatives (Sally *et al.*, 2007). Sorghum is therefore difficult to classify due to its wide diversity (Amukelani, 2005). Today, sorghum is cultivated across the world in the warm climatic areas and it out-performs other cereals under various environmental stresses and therefore more economical to produce (Kangama and Rumei, 2005; Paterson, 2009).

Sorghum is grown predominantly in low-rainfall arid to semi arid environments as a source of food and fodder (Sally *et al.*, 2007; Blümmel *et al.*, 2009; Takuji and Baltazar, 2009). The important traits which make to sorghum as a crop for ASALs include ability to tolerate and survive under continuous and intermittent drought conditions (Assefa and Staggenborg, 2010; Takuji and Baltazar, 2009; Tobosa *et al.*, 1999; Younis *et al.*, 2000), ability to utilize water efficiently (Sanchez *et al.*, 2002), ability to accumulate forage with higher DM (Burler and Muir, 2006; Murray *et al.*, 2009; Maarouf and Moataz, 2009), resistance to lodging (Burler and Muir, 2006), ability to perform under low soil fertility (Younis *et al.*, 2000) among others. Sorghum can be grown successfully on a wide range of soil types. It tolerates a range of soil pH from 5.0 - 8.5 (Madibela *et al.*, 2002).

#### 2.2.1.1 Morphology, growth and development

Sorghum belongs to the grass family, Graminea. It is essential that producers know the crop they are cultivating in order to develop the most effective production practices.

**Root system**

According to NRC (1996) sorghum often has very deep penetrating and extensive roots. The roots of the sorghum plant can be divided into a primary and secondary

system. The primary roots are those which appear first from the germinating seed. They provide the seedling with water and nutrients from the soil. The fibrous root system may penetrate 24-38 cm in the soil unless under heavy compaction of the soil (Kimber, 2000). Increased root depth will enhanced total water availability for the plant and this plays an important role in the drought avoidance mechanism (Jordan and Sullivan, 1982). Secondary roots develop from nodes below the soil surface. The permanent root system branches freely, both laterally and downwards into the soil. If no soil impediments occur, roots can reach a lateral distribution of 1 m and a depth of up to 2 m early in the life of the plant. Wright *et al.* (1983) reported that reduction in sorghum growth caused by water deficit had proportionally less effect on root growth. Sorghum plant has twice the amount of secondary roots on each primary root enabling it to absorb moisture more effectively than other cereal crops such as maize (Muhammed *et al.*, 2005).

**Leaves**

Sorghum leaves are typically green, glasslike and flat, and not as broad as maize leaves. Sorghum plants have a leaf area smaller than that of maize. The leaf blade is long, narrow and pointed. The leaf blades of young leaves are upright but the blades tend to bend downwards as leaves mature (Murdy *et al.*, 1994). Stomata occur on both surfaces of the leaf. A unique characteristic of sorghum leaves is the rows of motor cells along the midrib on the upper surface of the leaf. These cells can roll up leaves rapidly during moisture stress (Murdy *et al.*, 1994). According to Jordan and Sullivan (1982) and Amukelani (2005) sorghum conserves moisture by reducing transpiration when stressed by leaf rolling and closing stomata. Leaves are covered by a thin wax layer and develop

opposite one another on either side of the stem. Younis *et al.* (2000) reported the reduction in dry matter production under water stress mainly due to the reduction of leaf area. Environmental conditions determine the number of leaves, which may vary from 8 to 22 leaves per plant.

**Stem**

The stem of the plant is solid and dry, to succulent and sweet. Under favourable conditions more internodes develop, together with leaves, producing a longer stem. The stem consists of internodes and nodes (Murdy *et al.*, 1994). A cross section of the stem appears oval or round. The diameter of the stem varies between 5 and 30 mm. The internodes are covered by a thick waxy layer giving it a blue-white colour. The waxy layer reduces transpiration and increases the drought tolerance of the plants. The root band of nodes below or just above the soil surface develops prop roots. The growth bud develops lateral shoots. Sometimes the growth buds higher up the stem may also develop lateral shoots (Murdy *et al.*, 1994).

**Panicle**

The inflorescence of sorghum, the panicle, may be compact or open. The shape and colour of the panicle varies between cultivars. Panicles are carried on a main stem or peduncle with primary and secondary branches on which the florets are borne (Murdy *et al.*, 1994). The peduncle is usually straight and its length varies from 75 to 500 mm. Each panicle contains from 800 to 3 000 kernels which are usually partly enclosed by glumes. The colour of the glumes may be black, red, brown or tan (Carter *et al.*, 1989). The

flowers of sorghum open during the night or early morning. Those at the top of the panicle open first and it takes approximately 6 to 9 days for the entire panicle to flower (Murdy *et al.,* 1994; Carter *et al.,* 1989).

**Seed**

The ripe seed (grain) of sorghum is usually partially enclosed by glumes, which are removed during threshing and/or harvesting (Murdy *et al.,* 1994). The shape of the seed is oval to round and the colour may be red, white, yellow, brown or shades thereof. If only the pericarp is coloured, the seed is usually yellow or red (Murdy *et al.,* 1994). Pigment in both the pericarp and testa results in a dark-brown or red-brown colour. The sorghum grain consists of the testa, embryo and endosperm. The seed coat consists of the pericarp and testa. Pericarp is the outermost layer of the seed and consists of the epicarp, hypodermis, mesocarp and endocarp (Carter *et al.,* 1989; Murdy *et al.,* 1994).

### 2.2.1.2 Sorghum types

**Forage Sorghum**

Forage sorghums are a group of sorghum species and hybrids which have been bred for forage production and are commonly used as annual forage or hay crops. They are tall (to 3.8 m), leafy, erect, tussock grasses. The stems can grow to 1.5 cm thick in some varieties. The leaves are large, up to 4 cm wide and up to 1 m long. The size and shape of the seed head varies with the variety, as does the colour, shape and size of the seed. With the release of a number of late-flowering types in recent years, forage yields of up to 20 tonnes dry matter per hectare are possible under good moisture and nutrient

conditions (Bean and McCollum, 2007). Forage sorghums are suited to deep, well-drained soils in areas receiving between 900 and 1300 mm annual rainfall and are quite drought resistant (Cameron, 2006).

Forages from sorghum family are widely recognized as important feed resources for ruminants (Mohammad *et al.*, 1994). Sorghum forage yields palatable herbage, suitable for grazing, silage and hay making (Duke, 1983; Lanyasunya *et al.*, 2007). Kallah *et al.* (1999) reported a yield of 8.7 t/ha fresh at 7 weeks after planting and 31.5 t/ha fresh (equivalent of 14.3 tons DM $ha^{-1}$) at hard dough stage. Gohl (1981) reported crude protein of 11.7 and 7.8% at age of 4 and 8 weeks respectively. Like most crops, forage sorghum responds well to good silage management practices. Thus, harvesting drier sorghum can reduce the energy and protein value of the silage material. Forage sorghum is particularly well suited to some classes of livestock, such as dairy heifers and dry cows. These animals have lower energy requirements than lactating animals or those on a finishing ration. (Roth, 1995).

**Grain and Dual Purpose Sorghum**

Grain sorghum is globally cultivated, and is a major crop grown in the semi-arid and arid regions of Africa and Asia where grain is used as staple food. Grain sorghum is short (2-5 ft tall) compared to forage sorghum and has a high ability to withstand drought, growing in low rainfall areas. Soil water deficit during grain fill have been estimated to reduce sorghum grain production (Tewodros *et al.*, 2010). Throughout the tropics, farm animals are usually underweight and underproductive due to lack of feed. This constraint is stopping some 600 million poor farmers from meeting a fast-rising global demand for

milk and meat. The single most important ruminant feed resource on many of the small crop-livestock farms of Asia and Africa is not grass but rather the stalks, leaves and other remains of crop plants after harvesting. In India, for example, 44% of the feed annually sustaining all the country's cattle, buffalo, goats, sheep and camel populations is made up of such crop 'wastes'. Whereas most sorghum cultivars are grown for either forage/silage or grain dual purpose is used for both. Dual purpose sorghum producing grain for human consumption and stover for livestock feed should be given priority in the semi-arid tropics (Bramel-cox *et al.,* 1995) where moisture scarcity limits growth duration and total biomass available for livestock feed (Rattunde, 1998, Rattunde *et al.,* 2001). The grain yields are high and have high value as a livestock feed and human food. Dual purpose varieties of sorghum have the potential of producing substantial quantities of feed in areas where they are adapted. Yields of 26 to 33 metric tonnes of dry matter per hectare can be obtained when cut twice.

**Sweet Sorghum**

Sweet sorghum is any sorghum variety which has high sugar content in the stem (Murray *et al,* 2009), thus it is a potential for biofuel (Wortmann *et al.,* 2010). With increasing costs of fossil fuels, new methods of generating renewable fuels need to be researched and developed (Miller and Ottman, 2010). Study by Propheter *et al.* (2010) indicated that the highest biomass and estimated ethanol yields for renewable fuel production can be achieved from sweet sorghum. It thrives under drier and warmer conditions than many other crops and is grown primarily for forage, silage, and sugar production (Blümmel *et al.,* 2009, Dogget, 1988). The sweet sorghum type is used mainly

as livestock fodder: its high rate of photosynthesis produces leafy stalks up to 5 metres tall that make excellent silage. The stalks are rich in sugars, mainly in sucrose that amounts up to 55% of dry matter and in glucose (3.2% of dry matter). They also contain cellulose (12.4%) and hemicelluloses (10.2%) (Billa *et al.,* 1997) and the biomass is rich in readily fermentable sugars (Antonopoulou *et al.*, 2007).

Researchers have shown that this crop can yield up to 45 tonnes of biomass per hectare in 110 days. One tonne of sweet sorghum stalks has potential to yield 74 litres of 200 proof alcohol (Anonymous, 1996). Overall, out of the many "new crops" that have been investigated as potential raw materials for energy and industry, sweet sorghum seems to be the most promising (Propheter *et al.,* 2010; Blümmel *et al.,* 2009; Antonopoulou *et al.,* 2007; Dalianis *et al.,* 1996; Gosse, 1996). Unlike sugarcane, which is a tropical plant, sweet sorghum can be cultivated in nearly all temperate and tropical climatic areas (Paterson, 2009; Rajvanshi and Nimbkar 2008). According to Claassen *et al.* (2004), sweet sorghum can produce fresh biomass yield of 126t/ha. Stalk weight accounts for 82% of total crop weight while leaves and panicles account for 17% and 1% respectively.

### 2.2.2 Global and Regional Sorghum Production

Sorghum is an important and widely adapted crop grown between 40° N and 40°S of equator (Dogget, 1988). It is the fifth most important cereal crop worldwide in both planted areas and metric tons harvested after wheat, maize, rice and barley (FAO of United Nations, 2003). It is grown on more than 42 million hectares (107 million acres) in 99 countries. Worldwide annual production of sorghum is about 60 million tonnes less

than that of other major cereal crop such as maize and wheat (Takuji and Baltazar, 2009). It is nonetheless a staple for both humans and livestock, and is also a potential source of biofuel (Takuji and Baltazar, 2009). In the past 50 years the area under sorghum worldwide has increased by 60% and the yield by 244%. Forty four million hectare were reported by FAO, 2005 to be under grain sorghum producing 60 million tonnes. Worldwide sorghum is used for three distinct purposes, human food, animal feed and others, estimated at 42%, 48% and 10% respectively. Livestock feed is the most important market for surplus sorghum, as it competes effectively with other grain products in terms of price and quality. Thus, the demand for sorghum for feed purposes has been the main driving force in raising global production and international trade since the early 1960s.

The demand is concentrated in the developed countries where animal feed accounts for about 97% of the total use, and in some higher income developing countries, especially in Latin America where 80% of all sorghum is utilized as animal feed. In the United State of America, Australia and South America sorghum is mainly grown for animal feed (Adebiyia *et al.,* 2005). Sorghum is cultivated for grain and as a major food crop in much of South Asia, Africa and Central America. In addition to these uses of the grain, sorghum crop residues and green plants also provide sources of animal feed, building materials and fuel for cooking, particularly in dry land areas. According to Taylor (2004) in terms of tonnage sorghum is Africa's second most important cereal. The continent produces about 20 million tonnes of sorghum per annum, about one-third of the world crop (FAO, 2003). It is the only viable food grain for many of the worlds' most food insecure people thus, it will continue to be important food and feed/forage crop

(Paterson, 2009; Mekbib, 2008; Smith and Frederiksen, 2000). Sorghum is an important component in poultry feed and good progress has been made in the manufacturing of dog food, as well as pigeon and ostrich food.

### 2.2.3. Sorghum Sub Sector in Kenya

Sorghum is an important crop in many parts of Kenya occupying a wide diversity of habitats from 0-2500m above seal level (De Wit *et al.,* 1984). In Kenya, the crop is predominantly traditionally grown principally in the often drought-prone marginal agricultural areas of Eastern, Nyanza, Western, Coast and some parts of Rift Valley provinces (Noah and Waithaka, 2005). According to Mitaru (1995) the potential land suitable for sorghum production in Kenya is about 301,000 ha although this is not fully put into use. Table 1 shows some statistic for sorghum production in Kenya. The crop performs well in areas between 500 and 1700 metres above sea level, with seasonal rainfall of 300 mm and above (Noah and Waithaka, 2005). Generally sorghum productivity is influenced by rainfall, since it is primarily grown in poor areas subjected to low rainfall and drought where other grains are unsuitable for production unless irrigation is available.

As an indigenous crop, it provides food security and is a suitable alternative in many places for both human and animal consumption where maize does not thrive (Mitaru, 1995; Noah and Waithaka, 2005). In Kenya sorghum is used in beer brewing as malt, making *uji*, *ugali* and as animal feed (Kute *et al.,* 2000). The importance of this crop is enhanced due to its stover, which is an important source of dry fodder for

livestock's (Mburu, 1986; Kelley *et al.,* 1993; Hall and Yoganand 2000; Parthasarathy *et al.,* 2006).

**Table 1:** Sorghum Production in Kenya

| Parameter | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 |
|---|---|---|---|---|---|---|---|
| Area Harvested (ha) | 122492 | 136078 | 144294 | 148985 | 123135 | 122368 | 163865 |
| Yield (Kg/ha) | 665.64 | 856.91 | 801.03 | 853.88 | 564.39 | 1223.0 | 800.59 |
| Production Quantity | 81536 | 116607 | 115584 | 127215 | 69508 | 149656 | 131188 |

Source: FAO Statistic Division 2007.

**2.3 Sorghum biomass yield and its components**

The biomass yield is mainly composed of whole plant (panicle, leaves and stalks) excluding the root. Ability of some variety to produce more biomass yield is a positive factor for forage production. Biomass yield is an attribute of several agronomic components such as plant height, grain yield, number of leaves per plant, leaf length and width, leaf senescence, stem length and thickness, tillering ability among others. Nabi *et al.* (2006) in his investigation demonstrated biomass/dry matter yield to be attributed by the above components. It is expected that taller plants especially if accompanied by thick stem and tillers contain more biomass yield. Reddy *et al.* (2007) working on sorghum demonstrated this, when he found that varieties which were taller had high biomass yield than short varieties. Dingkuhn *et al.* (1999) showed tillering ability as major determinants of vegetative vigour. Leaf length, width and leaf number which enhances large surface area for water absorption in water stressed soil, also contribute to biomass yield which further enhances vital processes such as photosynthesis, transpiration, translocation

among others. Studies by Rebetzke *et al.* (2003) showed greater biomass and leaf area arising primarily from longer leaves and number of leaves at harvest. Chantiratikul *et al.* (2006) reported that number of leaves per plant contribute towards biomass yield. Chaudhry *et al.* (1990) and Chaudhry and Hussan (1984) demonstrated similar results.

Dalianis (1996) and Almodares *et al.* (1997) working on sweet sorghum reported a total above ground fresh biomass yield of 22 to 140 t/ha with total dry biomass yield of 12 to 45 t/ha. Sorghum requires less moisture for growth than many other cereal crops (Amukelani, 2005). Studies done in Indonesia showed that sorghum requires 332 kg of water per kg of accumulated dry matter, while maize requires 368 kg of water, barley 434 kg and wheat 514 kg (Rana and Rao, 2000). It is a known fact that if water is not available either from soil reserve, rainfall or irrigation the crop will wilt, with consequent reduction in yield and eventual death of plants. According to Arkel (1979) biomass yields are directly correlated to rainfall. This probably explains why same varieties perform differently in different environments. More efficient use of this soil water early in the season should increase total biomass and grain yield (Reberzke *et al.,* 2003). Studies shows water stress causes a decrease in dry matter and total biomass yield (Habyarimana *et al.,* 2002). McMkenzie *et al.* (2001) reported that enhanced vegetative growth in early stage of crop growth followed by moisture stress could reduce yields due to depletion of available water. Habyarimana *et al.* (2004) also reported that tropical sorghum landraces can achieve high yield (35-51 t $ha^{-1}$ under irrigation and 20-29 t $ha^{-1}$ under rainfed conditions) of total aboveground biomass. Burler and Muir (2003) have shown the ability of sorghum to accumulate forage with higher dry matter compared to maize in situation of water scarcity, while Younis *et al.* (2000) reported the ability of sorghum to perform

under low soil fertility. Study by Lanyasunya *et al.* (2007) demonstrated that application of manure and fertilizer improved yield of sorghum. Ashiono *et al.* (2005) also showed that fertilizers could enhance the production of sorghum in the dry highlands of Kenya. Therefore soil fertilization could be used as a strategy to enhance biomass yield and also to increase crude protein content incase of nitrogen fertilizers.

Studies by Balole and Legwaila (2005) reported an average sorghum grain yields on farmers field in Africa are as low as 0.5 - 0.9 t/ha because sorghum is often grown in marginal areas under traditional farming practices while under favourable conditions sorghum can produce grain yields up to 13 t/ha. Studies done in Rift Valley also shown sorghum grain yields to range between 0.5 – 0.8 t/ha in the North Rift Valley Province (MALD Report 1985 – 1994). Yield performance trials conducted at Kodich (LM4 AEZ) in West Pokot district, which is a semi-arid zone showed that sorghum variety KARI Mtama-1 could give up to 3.4 t/ha of grain yield compared to variety 1576 which yielded 1.5 t/ha, while trials with an improved sorghum variety KAT369 have reported a grain yield of 4.1 t/ha in comparison to 3.2 t/ha of maize (ICRISAT, 1994). Other experiments done in Kenya at Chobosta and Matunda between 1995 and 1998 showed that the two dual purpose sorghums (E1291 and E6518) could yield between 0.4 – 6.5 t/ha. Variety E1291 yield ranged from 2.6 – 6.5 t/ha while E6518 ranged from 0.4 – 2.8 t/ha. In the same experiment Livonywa variety and local check gave yield of more than 2 t/ha while the early maturing varieties Serena, Seredo, E525 yielded less than 1t/ha. Studies have also shown that forage sorghum are typically taller, more leafy, late maturing and produce very high dry matter and biomass yield per hectare.

## 2.4 Chemical composition and Nutritive Value

Sorghum is similar in chemical composition to maize (*Zea may*). According to Matlebyane *et al.* (2009) and Abate *et al.* (1985) the feed value of forage for ruminant livestock depends on the balance between nutritive components of the plants, the digestibility of such nutrients and the quality of the nutrients ingested by the animal. On the other hand the nutritive value of sorghum as forage depends on several crop factors, including the cultivar, plant maturity and ensiling. Teferedegne (2000), Valante *et al.*, (2000), and Matlebyane *et al.*, (2009) in their studies reported that environmental differences could influence chemical composition and digestibility of forage grown in different areas and harvested at the same age of maturity. Cultivars with stalk carbohydrates are generally more palatable and more digestible than those with low sugar content. Treatment of stalks with chemicals such as urea and sodium hydroxide improves their digestibility (Saidi *et al.*, 1982).

### 2.4.1 Carbohydrates

The majority of the carbohydrates in sorghum are starch, while soluble sugar, pentosans, cellulose and hemicellulose are low. According to Waniska and Rooney (2002) carbohydrates are a major component in grain and are composed of starch, soluble sugars and fiber. Irén Léder (2004) showed sorghum to be a good source of fibre, mainly insoluble (86.2%) fibre. The insoluble dietary fibre of sorghum may decrease transit time and prevent gastrointestinal problems.

#### 2.4.1.1 Starch

Like other cereals, sorghum is predominantly starch. The average starch content of sorghum grain ranges from 56 to 73% and 32 to 79% of its weight is starch. Starches exist in a highly organized manner in which amylose and amylopectin molecules are held together by the hydrogen bonds and are arranged radically in spherical granules, with most of the starch being in form of amylopectin (70-80%) (Waniska and Rooney, 2002). Regular endosperm sorghum types contain 23 to 30% amylose, but waxy varieties contain less than 5% amylose (Irén Léder, 2004). Amylose consists of linear chains averaging 1500 units. Hydrated amylose forms a helix that can interact with iodide to form a blue or purple colour. Amylopectin is a much larger, branched polymer, composed of about 3000 chains averaging 15 to 20 units (Subramanian *et al.,* 1982). Amylopectin interacts with iodide to form a brown colour. In its properties, sorghum starch resembles maize starch and the two can be used interchangeably in many industrial and feed applications.

#### 2.4.1.2 Soluble sugars

According to Murty *et al.* (1985) soluble sugar content of the caryopsis in grain changes during development but the maximum can be 5.2%. At maturity, the average soluble sugar content ranges from 0.8 to 4.2% with sucrose being 75% of the sugars (Subramanian *et al.,* 1982). Mature caryopsis contains 2.2 to 3.8% soluble sugars, 0.9 to 2.5% free reducing sugars, and 1.3 to 1.4% non-reducing sugars. Glucose ranges from 0.6 to 1.8% and fructose from 0.3 to 0.7%. High lysine and sugary cultivars contain more soluble sugars than normal sorghums.

### 2.4.1.3 Fiber

Cereal grains are a rich source of fiber. Dietary fiber is plant material that resists digestion by enzymes in the monogastric stomach and upper gastrointestinal tract (Amukelani, 2005). According to Waniska and Rooney (2002) the major components of fiber are cellulose, hemicellulose, lignin, and pectin, which are located primarily in the pericarp and endosperm wall. Dietary fibers have unique physiochemical and functional properties, and it can be divided into two broad categories: water-soluble and water-insoluble fiber. Bach-Knudsen *et al.* (1985) found that sorghum contains 6.5 to 7.9% insoluble fiber and 1.1 to 1.23% per kernel soluble fiber. Most of the fiber in sorghum is insoluble, approximately 86.2%, and is located in the pericarp (Iren Leder, 2004). Fibers in the pericarp provide structural and protective functions. Sorghum dietary fiber contains more associated proteins than other cereals. Insoluble dietary fiber increases during food processing due to increased levels of bound protein, mainly kafirins, and enzyme resistant starch (Amukelani, 2005).

**Hemicellulose and Cellulose**

The structural carbohydrate, hemicellulose and cellulose describe those forage components that have low solubility in a specific solvent system and are relatively less digestible than starch and sugars (Valante *et al.,* 2000; Yahya, 1996). According to Åman (1993) and Vogler *et al.* (2009) the value of a crop plant as a forage is determined primarily by the degradability of the vegetative tissues, which in turn is affected by the property of its cell wall structure. Cellulose is a principal constituent of the cell wall of plant, however ruminants such as cattle, goat, sheep, and horses digest cellulose fairly

effectively. Cellulose and Hemicellulose in the cell wall provide a major energy source for ruminant animals when they can be degraded into oligo- and mono-saccharide (Moore and Harfield, 1994; Vogler *et al.,* 2009). The availability of cellulose and hemicellulose as a source of energy however, depends on the overall structural properties of the cell wall, which often varies between species, genotypes, and tissues and the interaction between these three factors. Studies done by (Valante *et al.,* 2000; Van Soest, 1995; Jung and Allen, 1995) showed cellulose and hemicellulose to correlate negatively to voluntary DM intake for forages and consequently high contents reduce digestibility of forages. Studies have also shown these two constituents of fibre to increase as plant matures (Nabi *et al.,* 2006; Allen, 2000; Beck *et al.,* 2007; Muir, 2002; Thapa *et al.,* 1997; Matlebyane *et al.,* 2009; Valante *et al.,* 2000; Teferedegne 2000).

**Lignin**

According to Wedig *et al.* (1987) lignin is an integral component of all plant and it adds rigidity to cell walls. Lignin, found in plant cells, is the second most abundant polymer in nature after cellulose and while being beneficial to plants, the complex linkages in lignin are detrimental to the digestibility of plant cell walls by livestock (Hamphreys and Chapple, 2002). It is of interest to ruminant nutritionists because it is considered essentially indigestible and interferes with digestion of plant cell wall carbohydrates. The cell polymer lignin is thought to impede access of hydrolytic enzymes to the cell wall polysaccharides. For example, Lundvall *et al.* (1994) showed the cell wall digestibility of sorghum to be affected by lignin content. Hence poorly digested forages are associated with high lignin content (Wedig *et al.,* 1987; Lusk *et al.,* 1984). As plant

matures, lignin a polymer complex of 3-phenyl propanoid alcohol, is deposited in the cell walls in increasing quantities (Yahya 1996; Holmes 1992). Chemical and genetic approaches have been employed to improve fibre digestibility by reducing the amount of lignin or the extent of lignin cross linking with cell wall carbohydrates.

### 2.4.2 Protein

Crude Protein levels in feed are a major concern, particularly when young growing animals are a part of the livestock herd. According to NRC (1984) the minimum requirement for maintaining cattle is 7 to 9.5% for pregnant cows depending upon age and weight, while lactating cows, growing calves and yearling requires a higher percentage for maintenance and growth. The protein content of sorghum is nearly equal and is comparable to that of maize and wheat, with its content and composition varying due to genotype and environmental conditions (water availability, soil fertility, temperature and environmental conditions) during grain development (Dendy, 1995). Studies have shown one of the limitations of sorghum is its low protein level and low amounts of essential amino acids. According to Taylor (2004) the protein of sorghum is deficient in the essential amino acid lysine and has low digestibility.

The protein content of sorghum grain is usually 11-13% (Dendy, 1995) with lower values in stems, leaf and whole plant (Phillip *et al.*, 1999; Beck *et al.*, 2007; Chantiratikul *et al.*, 2006 and 2009). Research has also been undertaken to determine the fundamental reasons for the reduced protein digestibility in sorghum upon cooking. These seem to be multifactorial, involving changes in the structure of the sorghum prolamin proteins as well as binding of the proteins with other chemical components in the sorghum grain.

Nabi *et al.* (2006) working with five sorghum varieties showed a decrease in crude protein contents as plant matures with higher content at early blooming stage. He also showed sorghum to contain as much protein as mature alfalfa, but only if harvested at the vegetative stage for forage. Fulagar *et al.,* 1985; Chaudhry *et al.,* 1990; Yahya *et al.*, 1995; Mendhe *et al.,* 1995; Phillips *et al.,* 1999; Wong and Vijasegaran 2001; Chantiratikul *et al.,* 2006 and 2009, also demonstrated decrease in CP with maturity. In general, as CP increases in a forage, livestock perform better (i.e. gain more weight, produce more milk extra). Thus, there is a reasonably good relationship between forage quality and CP content. However, there are several problems with CP as a predictor of animal performance. The first is the concept of first limiting nutrient. Put simply, if an animal is deficient in energy; any amount of protein in excess requirements will do little to increase performance. The issue of low protein levels in sorghum is best addressed by the appropriate use of fertilizer. This has a two fold effect of both increasing protein level of sorghum and the yield per hectare.

**2.4.3 Vitamins and Minerals**

Sorghum is an important source of B vitamins except B 12, and good source of tocopherols. The B vitamins and minerals are concentrated in the aleurone layer and germ. Removal of these tissues by decortication produces a refined sorghum product which has lost part of these important nutrients.

Sorghum is considered a good source of potassium and is practically devoid of sodium. Whole grains are good sources of magnesium, iron, zinc, and copper. The bioavailability of iron in sorghum is negatively affected by the presence of polyphenols

and phytates, but Derman *et al.* (1980) reported that iron absorption was more than 12 times greater from sorghum beer than from gruel. Germination, decortication and/or malting and fermentation enhance the nutritional value of sorghum causing significant changes in chemical composition and elimination of anti-nutritional factors (Irén Léder, 2004)

**2.4.4 Anti-nutritional factors**

Anti nutritional compounds (e.g. protease inhibitors, galacto-oligosaccharides, lectins, ureases, phytates, tannins, phenolics and saponins etc.) are plant constituents which play an important role in biological functions of plants. The effect of these compounds on human and animal organisms is partly negative because they can reduce the digestibility of nutrients and the absorption of minerals (Irén Léder, 2004). They may also inhibit growth as a result of their negative influence on the function of pancreases and the thyroid gland, and can cause pathological alterations in the liver. According to published data some anti-nutritional compounds can inhibit the formation and growth of several types of tumors. In sorghum these anti-nutritional compounds are tannins, phytic acid and cyanogenic glycosides (Subramanium and Metta, 2000; Awika and Rooney, 2004).

Studies have shown that the tannin content of seeds inhibits the activity of some enzymes and therefore adversely influence protein digestibility and cellulose breakdown (Jose *et al.*, 2003; Garcia *et al.*, 2004). In consequence nitrogen retention and use of amino acids are reduced due to the reduction in protein digestibility (Mitaru *et al.*, 1984). Animal tests have proved that tannin inhibits protein absorption, decreases utilization of

minerals and results in some decrease of growth. Feeding pigs with fodder containing 4.21% tannin decreased protein digestibility by 5.6% (Irén Léder, 2004). Rooney (2006) found that tannin sorghums decrease feed efficiency by about 10% when fed to livestock, while Hagerman and Butler (1994) showed tannins in sorghum to reduce digestibility and efficiency of utilization of absorbed nutrients from 3 to 15%. The high tannin sorghums have excellent antioxidant activities and may be very important source of nutraceuticals (Kaufman *et al.,* 2006). Reconstitution (high moisture storage) of the high tannin sorghum grain de-activates tannins and improves the nutritive value of these sorghums for non-ruminants (Mitaru, 1983). Other simple and practical methods of de-activating sorghum grain tannins include the use of wood ash (Mitaru and Munene, 1994).

Phytic acid and/or phytates complex with essential dietary minerals such as calcium, zinc, iron, and magnesium to make them biologically unavailable for absorption (Lasztity and Lasztity, 1990; Irén Léder, 2004). The primary role of phytates may be to store phosphorus and inositol, which are gradually utilized during germination. Removal of the pericarp and aleurone layer by abrasive decortication reduces the phytate content (Doherty *et al.,* 1982) while Irén Léder (2004) showed sorghum bran to contain higher levels of phytates and 40-50% of phytate and total phosphorus can be removed by abrasive dehulling. Cyanogenic glycosides occur in most sorghum varieties. The main cyanogenic glycoside, dhurrin, which is found mainly in the leaves and germinating seeds of sorghum, can amount to 3-4% of the total dry seedling weight. In the course of processing germinating seeds, cyanide may be released—a very toxic material. In the traditional food processing techniques (e.g. drying, malting) the cyanide can be lowered to zero or to well below the level considered toxic (Irén Léder, 2004).

## 2.5 Forage quality

Forage quality has a direct effect on animal performance, forage value, and ultimately on profits. Many factors influence forage quality. The most important are forage species, stage of maturity at harvest and (for stored forages) harvesting and storage methods. Secondary factors include variety, soil fertility and fertilization and temperature during forage growth. Feed quality can be envisaged either as digestibility of the forage or its nutrients content. Crude protein and the more easily digestible carbohydrates decrease while cellulose and lignin increase as plants mature. These changes cause corresponding changes in forage quality. Digestibility of forage is affected by plant species, phonological stage and forage nutrient content. Digestibility decreases as the plant matures due to cumulative increase in lignin (Johnson, 1974; Osolo, 1998).

Digestibility provides the best biological evaluation of feed quality for grazing animal's diet because it indicates the portion that can be used by the animal's body (Holechek *et al.,* 1982). The digestibility of tropical forage species ranges from 40 to 70% (Kariuki, 1998). Crude protein (CP) and total cell wall fibre, also called neutral detergent fibre (NDF) are the major indicators of the potential value of a given feed material (Johnson and DeOliveria, 1989). The CP content of a feed is useful as a general indicator of its potential contribution to the protein needs of the animal. Johnson and DeOliveria (1989) noted however, that some of the protein in the feeds is unavailable to the animal because it is bound by tannins on to the cell wall fibre.

The quality of feed available for animals can be improved by manipulating factors such as forage species, supplementation and stage of harvesting. Improving soil fertility, moisture availability and weed control also affect quality of forage. It is also important to

note that increased N intake drops digestibility though as the feed passes faster in the gut. Most herbivores instinctively choose the type of vegetation best likely to meet their protein requirements. Work by Ramirez *et al.* (1995) showed that lambs selected diets that were never lower than 10% CP and a variable NDF during the year. The high cell wall levels in forage consumed by ruminants may be a limiting factor reducing animal intake and digestibility by microbes in the rumen (Ramirez *et al.*, 1995) and may depress the animal's performance.

# CHAPTER THREE

# 3.0 COMPARISON OF CHEMICAL COMPONENTS AND DRY MATTER DIGESTIBILITY OF TEN SELECTED DUAL PURPOSE SORGHUM VARIETIES GROWN IN THE ARID AND SEMI-ARID AREAS OF KENYA

## 3.1 STUDY BACKGROUND

In a study to screen for dual purpose sorghum varieties best suited for semi arid areas, International Crops Research Institute for Semi Arid Tropics (ICRISAT) conducted on-station forage sorghum trials in the semi arid areas of Kenya. This project is a part of above bigger project and is aimed at providing nutritional evaluation data necessary to rank the selected varieties for animal feed. The trials were conducted in three sites, at Kenya Agricultural Research Institute (KARI) namely; Machang'a, Kiboko and Kampi ya Mawe during short rain season of the year 2006/2007. According to Jaetzold and Schmidt (1983) the three stations are found in ecological zone IV and V (Semi-arid) areas in Eastern Province (appendix 1), at altitude of 1005m, 993m 1250m above sea level for Machang'a, Kiboko and Kampi ya Mawe respectively. These areas have low unreliable rainfall ranging from 610-829, 548-800 and 500-600mm for Machang'a, Kiboko and Kampi ya Mawe respectively (GOK, 2001). The general pattern of rainfall in these areas is bimodal with long-rain from February to May and short-rain from October to December, with April and and November experiencing the heaviest rainfall (GOK, 2001). The rainfall is however, not very reliable and most parts receives less than 550mm of rainfall per year, giving these areas a marginal status. The mean annual temperature for Machang'a is 24°c while Kiboko and Kampi ya Mawe is 23°c.

The latitude and climate, coupled with the differences of the underlying geology, have given rise to varying soil types, which in turn influence land use patterns (GOK, 2001). In Machang'a the soil are generally sandy, loamy, blackish grey or reddish brown while Kiboko and Kampi ya Mawe these are regosols and ferrosols according to FAO/UNESCO classification.

The screening trial by ICRISAT started with twenty five (25) varieties from local and international collections. On the basis of agronomic performance scores on traits such as grain yield, length, width and number of leaves, stem width, plant height, number of tillers, date to 50% flowering and low leaf senescence among others, with greater emphasis on biomass production. The variety were reduced to ten (10). The ten selected varieties described in section 3.1.1 were subjected to nutritional evaluation as part of the study to screen for the dual purpose sorghums.

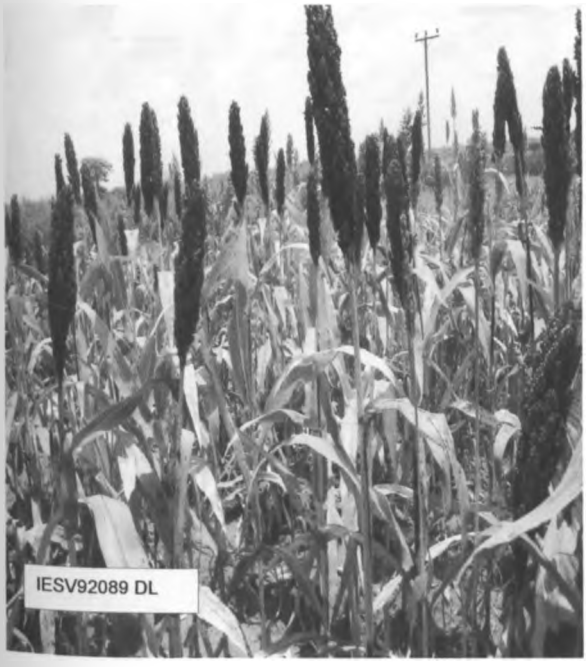
### 3.1.1 Description of the ten sorghum varieties


**BTX 623**

It is a short variety which grows to an average height of 132.7cm. The leaves average at 71.5cm in length, 7.8cm width with about 11 leaves per plant at hard dough stage and have a low degree of senescence. The stem diameter is about 6.9cm with low tillering ability. It attain 50% flowering within 71-74 days. The biomass and grain yield average at about 22.5t/ha and 2.2t/ha respectively and has white grains.


**IESV91131 DL**

It was the shortest among the selected varieties with an average plant height average of 125.2cm. It is about 80.3 cm in Leaf length and 9.4cm in leaf width, with about 10 leaves at hard dough stage and low leaf senescence. The stem diameter is about 7.4cm with low tillering ability. It attain 50% flowering within 71 -74 days. The biomass and grain yield averaged at about 17.1t/ha and 3.2t/ha respectively And has red grains.

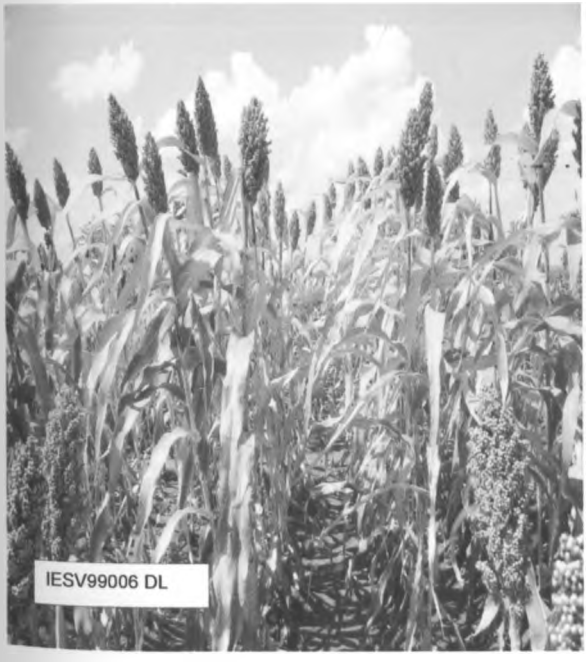



**IESV92089 DL**

The plant height average at around 150.4cm It has short leaves, about 68.6cm in length and 7.5cm in width, with about 9 leaves at hard dough stage with high degree of leaf senescence. The stem diameter is about 5.9cm with low tillering ability. It attain 50% flowering within 68-72 days. The biomass and grain yield averaged at about 23.9t/ha and 2.2t/ha respectively and has red grains.

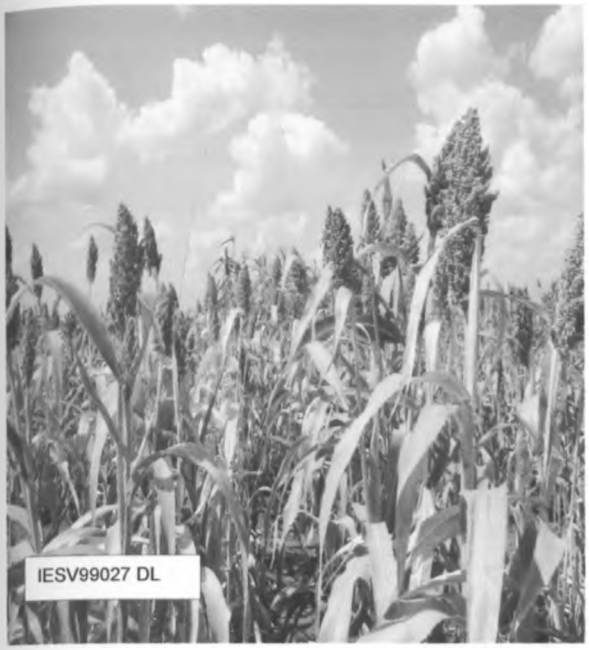

**IESV92165 DL**

It grows to an average height of around 172cm. The leaves average at 72.2 cm in Length, 7.4cm width with about 9 leaves per plant at hard dough stage which have low degree of senescence. The stem diameter is about 5.5cm with low tillering ability. It attain 50% flowering within 67 days. Has a biomass yield of 28.3t/ha and grain yield of 3.2t/ha and has red grains.




**IESV99006 DL**

It grows to an average height of around 176.7cm. The leaves averages at 80.1cm in length, 7.7cm width with about 9 leaves per plant at hard dough stage which have low degree of senescence. The stem diameter is about 5.9cm with low tillering ability. It attain 50% flowering within 66 days. The biomass and grain yield average at about 29.7t/ha and 3.0t/ha respectively and has white grains.




**IESV99027 DL**

It grows to an average height of around 162.7cm. The leaves average at 71.9cm in length, 7.5cm width with about 9 leaves per plant at hard dough stage which have low degree of senescence. The stem diameter is about 5.5cm with low tillering ability. It attain 50% flowering within 66-71 days. The biomass and grain yield average at about 27.0t/ha and 2.8t/ha respectively and has white grains.


**IESV99095 DL**

It grows to an average height of around 144.5cm. The leaves average at 77.1cm in length, 7.7cm width with about 10 leaves per plant at hard dough stage which have low degree of senescence. The stem diameter is about 5.6cm with low tillering ability. It attain 50% flowering within 72 days. The biomass and grain yield average at about 22.0t/ha and 2.6t/ha respectively and has white grains.


## MACIA

It grows to an average height of around 133.4cm. The leaves average at 66.7cm in length, 8.6cm width with about 10 leaves per plant at hard dough stage which have low degree of senescence. The stem diameter is about 6.9cm with low tillering ability. It attain 50% flowering within 72-74 days. The biomass and grain yield average at about 22.0t/ha and 2.9t/ha respectively and has white grains.


## NGUUGU

Has a characteristic of tall variety with an average height of around 282.1cm. The leaves average at 83.8cm in length, 6.5cm width with about 12 leaves per plant at hard dough stage which have low degree of senescence. The stem diameter is about 6.0cm with moderate tillering ability. It take longer to 50% flowering which is attained at about 80 - 72 days, a characteristic of late maturing variety. Has high biomass production capacity (44.2t/ha) but on the other hand it is a low grain yielder (0.8t/ha) which are red in colour.


## SDSL90162-2

It grows to an average height of around 177.9cm. The leaves average at 82.4cm in length, 7.6cm width with about 10 leaves per plant at hard dough stage which have low degree of senescence. The stem diameter is about 5.9cm with slight tillering ability. It attains 50% flowering within 76-78 days. The biomass and grain yield averages at about 36.1t/ha and 2.8t/ha respectively with white grains.

### 3.1.2 Sample collection procedure

The trial had each variety randomly replicated three times at every location. At the age of 14 weeks when the crop was mature (fully developed grain), destructive sampling was conducted for nutritional and digestibility analysis. Samples were picked randomly from plots with the ten varieties selected on the basis of scoring criteria described in 3.1. In every plot with these varieties two plants were cut randomly. From the two, one plant was cut whole into piece and put in one polythene bag. The second plant was separated into three distinct parts; leaves, stems and panicle and each component placed in a separate polythene bag. This sampling process was conducted in the three replications. To minimize the cost of laboratory analysis samples from the same location were pooled. Therefore samples of the same varieties from the three replications were pooled together

in one polythene bag according to different parts so as to have the samples per station as follows;

| Sample | Kambi Ya Mawe | Machang'a | Kiboko |
|---|---|---|---|
| Whole plant | 10 | 10 | 10 |
| Leaves alone | 10 | 10 | 10 |
| Stem alone | 10 | 10 | 10 |
| Head (Panicle) | 10 | 10 | 10 |

The bags were then sealed to prevent moisture loss and then taken to Upper Kabete Campus, Animal Production Nutrition Laboratory for chemical composition and digestibility evaluation.

The sample preparation, grinding and laboratory analysis were conducted using the research and laboratory facilities in the Department of Animal Production, Kabete, University of Nairobi. In the preparation chamber all samples were weighed for wet weight and then subjected to oven drying (60°c) for five days after which the dry weights were taken for dry matter as fed basis determination. Weighing was done using analytical balance which was placed on a heavy table. The dried samples were then subjected to a grinding machine (Wiley Mill) so as to pass through a 2 mm screen. The ground samples were then transferred into sample bottles, labeled and then sealed to prevent samples from gaining moisture during storage and analysis process.

## 3.2 DRY MATTER AND CRUDE PROTEIN CONTENTS OF THE TEN SORGHUM VARIETIES

### 3.2.1 Introduction

The dry matter content is known to be highly correlated with dry matter intake, with high moisture content resulting to reduction in dry matter intake. According to Sonon *et al.* (1991) the concentration of dry matter increases with plant maturity. Since average yields of nutrients increase so dramatically during maturation, changes in nutrient content of the dry matter are considered of little practical importance. On the other hand forage meets the protein needs of animals to varying degree depending upon the type of forages. Various studies cited in the literature review have shown one of the limitations of sorghum is it's low protein level and low amounts of essential amino acids. However, when examined per individual tissues, grains of some varieties have been found to contain 9-13% CP with low level being recorded in stovers. Crude protein levels in feed are a major concern, particularly when young growing animals are part of livestock herd. Various studies have cited restriction in intake when crude protein levels fall below 7%. In general as crude protein increases in a forage, livestock perform is better i.e. gain more weight and produce more milk thus, there is a good relationship between forage quality and protein quality. Therefore it would be beneficial to investigate the crude protein level of these sorghum varieties so as to know the likely effect when they are grown for forage.

### 3.2.2 Objective

To determine the dry matter and crude protein content of the ten dual purpose sorghum varieties

### 3.2.3 Procedure

The ground samples were subjected to proximate analysis in the laboratory to determine dry matter and crude protein content. Samples were analyzed in duplicate according to procedures approved by AOAC (1998).

#### 3.2.3.1 Dry matter determination

Moisture was determined by heating the sample in an oven to remove its water. Air dry moisture content was determined at 60°C, while moisture free sample was dried at 105°C. In the laboratory Moisture dishes were cleaned and dried at 105°C oven for at least one hour upon which they were removed and placed in a dessicator until cooled to room temperature. The dishes were removed each at a time, weighed accurately on an analytical balance and weight recorded. Immediately 2.0000 grams of samples were weighed into each dish, placed in an oven set at 105°C for an overnight upon which dishes were removed and placed in desiccator until cooled to room temperature. The dishes were then removed from desiccator one at a time, weighed quickly and recorded. The moisture % was calculated by difference in weight of sample, before and after heat treatment. The dry matter was calculated by subtracting the moisture % from 100%.

### 3.2.3.2 Crude protein determination

A 0.5g of ground sample was weighed in duplicate and each placed in a Kjeldahl tube. The third tube was a blank i.e. no sample was added but reagents and procedures were exactly like for the tubes with sample. The samples were digested with boiling concentrated Sulphuric acid (5 ml) and a catalyst (Selenium). Digestion was continued until all samples were clear with a blue / green solution, for 30 to 60 minutes depending on the sample. After digestion the acid sample solution were cooled, then diluted with water and made strongly basic with sodium hydroxide. The ammonia released was collected into a boric acid solution. The boric acid solution was titrated with standardized hydrochloric acid until the blue / green end point was achieved. From the titration the amount of nitrogen was determined. The crude protein was obtained by multiplying the amount of nitrogen obtained with a conversion factor 6.25 (AOAC, 1998).

**Calculation of the results**

$$\%N = \frac{(T - B) * N * 14.007 * 100}{\text{Weight of the sample}}$$

$\%Protein = \%N * F$

Where %N is nitrogen

N = Normality of acid  T = Titration volume for sample (ml)

B = Titration Volume for blank  F = Conversion factor for nitrogen to protein (6.25).

### 3.2.4 Statistical Analysis

The data obtained were subjected to Analysis of Variance (ANOVA) using GENSTAT statistical program (Genstat, 2007) 9th Edition. Whenever a treatment effect

was significant, means were separated by Fisher's least significant difference (LSD) procedure at 5% level of significance (Steel and Torrie, 1987).

### 3.2.5 Results and Discussion

#### 3.2.5.1 Dry Matter contents of the ten sorghum varieties

Analysis of variance showed no differences ($P \geq 0.05$) between varieties and locations, respectively. However, there were differences ($P \leq 0.05$) between plant parts. There was no significant ($P \geq 0.05$) interaction between the varieties x location hence means for the three locations were pooled.

**Table 2:** Dry matter contents of the ten sorghum varieties (panicles, leaves, stems, and whole plant) at 105°c*.

| | PLANT PARTS | | | | |
|---|---|---|---|---|---|
| VARIETIES | PANICLES | LEAVES | STEMS | WHOLE PLANT | MEAN |
| BTX 623 | 92.07 | 91.99 | 92.9 | 91.26 | 92.05 |
| IESV91131 DL | 91.78 | 92.81 | 92.11 | 92.05 | 92.19 |
| IESV92089 DL | 91.6 | 92.1 | 91.13 | 91.92 | 91.69 |
| IESV92165 DL | 91.12 | 92.32 | 90.5 | 92.63 | 91.64 |
| IESV99006 DL | 93.08 | 91.53 | 89.89 | 91.57 | 91.52 |
| IESV99027 DL | 90.76 | 92.14 | 90.21 | 91.86 | 91.24 |
| IESV99095 DL | 91.54 | 92.36 | 92.19 | 92.19 | 92.07 |
| MACIA | 91.18 | 92.28 | 89.7 | 91.65 | 91.2 |
| NGUUGU | 91.51 | 92.58 | 92.25 | 91.84 | 92.05 |
| SDSL90162-2 | 91.51 | 93.27 | 91.94 | 92.57 | 92.57 |
| MEAN | $91.71^{c}$ | $92.34^{a}$ | $91.28^{c}$ | $91.95^{ab}$ | 91.82 |
| LSD Plant Part | | 0.6 | | | |
| CV% | | 1.3 | | | |

*Values followed by the same superscript letter (a, b,c) in a row are not significantly different ($P \geq 0.05$).

**Analysis of Variance (ANOVA)**

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| VARIETIES | 9 | 20.741 | 2.305 | 1.70 | 0.100 |
| LOCATION | 2 | 6.523 | 3.262 | 2.41 | 0.096 |
| PLANT PARTS | 3 | 17.583 | 5.861 | 4.34 | 0.007 |
| VARIETIESXLOCATIONS | 18 | 26.964 | 1.498 | 1.11 | 0.359 |
| Residual | 87 | 117.617 | 1.352 | | |
| Total | 119 | 189.429 | | | |

As shown in Table 2, no differences ($P \geq 0.05$) were shown between the ten sorghum varieties. The DM content between varieties ranged from 91.2% to 92.57%. The plant parts demonstrated appreciable differences ($P \leq 0.05$), where the DM value ranged from 90.76 to 93.08%, 91.53 to 93.27%, 89.7 to 92.9% and 91.26 to 92.62% for panicles, leaves, stems and whole plant respectively. The leaves had a higher ($P \leq 0.05$) DM content (92.34%), though not different ($P \geq 0.05$) from that of the whole plant at 91.95%. The panicles and stems were similar at 91.71%, and 91.28%, respectively (Table 2).

The values obtained in the current study were within range reported by other researchers. Ashiono *et al.* (2005), working with six sorghum varieties in Kenya found DM range of 85.2 to 89.9% while Hakki *et al.* (2005) reported a range of 89.80 to 94.05%. Tauqir *et al.* (2009) reported average DM of 85%. Fadel *et al.* (2007) working with five sorghum varieties showed the DM to range from 87.4 to 90.9% and 90.4 to 95.2% for leaves and stems respectively. According to Hakki *et al.* (2005) and Sonon *et al* (1991) the concentration of DM increases with increasing maturity and thus the reason for the high values reported in the present study since the sample were collected at maturity stage. The non-significant differences in DM may imply minor differences in the microclimate between the locations.

### 3.2.5.2 Crude protein contents of the ten sorghum varieties

Analysis of variance showed no differences ($P \geq 0.05$) between varieties and locations, respectvely. However there were differences ($P \leq 0.05$) between plant parts. The

interaction between the varieties x location was not significant (P≥0.05) hence the means for the three locations were pooled.

**Table 3:** Crude protein (%DM) contents of the ten sorghum varieties (panicles, leaves, stems, and whole plant)*.

| | PLANT PARTS | | | | |
|---|---|---|---|---|---|
| VARIETIES | PANICLES | LEAVES | STEMS | WHOLE PLANT | MEAN |
| BTX 623 | 6.93 | 5.39 | 3.50 | 6.21 | 5.52 |
| IESV91131 DL | 7.59 | 5.82 | 4.26 | 5.97 | 5.91 |
| IESV92089 DL | 7.46 | 5.26 | 3.76 | 6.22 | 5.68 |
| IESV92165 DL | 7.98 | 6.13 | 5.11 | 7.23 | 6.61 |
| IESV99006 DL | 7.89 | 6.04 | 4.33 | 6.91 | 6.29 |
| IESV99027 DL | 6.33 | 5.51 | 3.32 | 5.36 | 5.13 |
| IESV99095 DL | 7.33 | 5.39 | 3.82 | 6.75 | 5.82 |
| MACIA | 6.42 | 5.93 | 4.08 | 6.13 | 5.64 |
| NGUUGU | 5.57 | 5.97 | 4.02 | 6.13 | 5.42 |
| SDSL90162-2 | 7.21 | 5.20 | 2.96 | 5.20 | 5.14 |
| MEAN | 7.07[a] | 5.66[b] | 3.92[c] | 6.21[b] | 5.72 |
| LSD Plant part | | 0.57 | | | |
| CV% | | 19.2 | | | |

*Values followed by the same superscript letter (a, b, c) in a row are not significantly different (P≥0.05).

Analysis of Variance (ANOVA)

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| VARIETIES | 9 | 9.7512 | 1.0835 | 1.18 | 0.320 |
| LOCATIONS | 2 | 1.8042 | 0.9021 | 0.98 | 0.379 |
| PLANT PARTS | 3 | 136.8553 | 45.6184 | 49.56 | <.001 |
| VARIETIESXLOCATIONS | 18 | 21.2127 | 1.1785 | 1.28 | 0.221 |
| Residual | 87 | 80.0832 | 0.9205 | | |
| Total | 119 | 249.7065 | | | |

The crude protein (CP) levels of the ten sorghum varieties were similar (P>0.05) and the means ranged from 5.13 to 6.61%. In terms of plant parts on average, the panicles had highest crude protein values (7.07%) while the stems had the lowest (3.92%). The Leaves and whole plant had similar CP content with values of 5.66% and 6.21%, respectively.

Generally CP levels recorded in this study were low in all the ten sorghum varieties which ranged from 5.13 - 6.6% from expected 10% and above. Soil type, low soil fertility, temperature and environmental condition during growth and development and genotype are among other factors which may have contributed to the low CP content in

these sorghum varieties. Similarly to the results of this study, Ashiono *et al.* (2005) working on six cold tolerant sorghum varieties across different ecological zone of Kenya reported CP to range from 3.1 - 9.4%, with average of 5.5 – 7.7%, while José *et al.* (2003) working on 18 sorghum varieties reported an average CP of 6.7% and Snyman and Joubert (1995) showed CP to vary between 5.8 – 6.5% on total plant residues. Nabi *et al.* (2006) reported similar values working with five varieties of sorghum at milk stage but higher values of CP at early blooming and full blooming. Others who have reported CP in the same range on sorghum forage and stover include; Pedersen *et al.* (2000), and Beck *et al.* (2007). Contrary to the CP values obtained in the present study, other researchers working on sorghum have reported higher value depending on stage of growth. Yahya (1996) working on different sorghum varieties reported CP average of 10.68 ± 3.07% while Gohl (1981) reported crude protein of 11.7% and 7.8% at the age of 4 and 8 weeks respectively, compared to the current study where samples were cut at the age of 14 weeks. Elsewhere in India, Grassi *et al.* (2004) reported crude protein of 8 – 13%.

The plant parts had significant differences ($P \leq 0.05$) in CP content. The trend in the current study for the four tested parts i.e. panicles, leaves, stems and whole plant is in agreement with other researchers such as; Madibela *et al.*, 2002; Fadel *et al.*, 2007; Chantiratikul *et al.*, 2009 who found crude protein level to be highest in panicles, followed by whole plant, leaves and lowest in stems. Many sorghum varieties have shown panicle CP content to average between 6 – 13% (Mohammed and Mohamed, 2009; Tauquir *et al.*, 2009, Hakki *et al.*, 2005) among others. Crude protein values of more than 10% have been reported and also less than 5% especially with stems. The CP

reported in the present study (6.42 - 7.98%, 5.20 - 6.13%, 2.96 - 5.11% and 5.20 - 7.23% for panicles, leaves, stems and whole plant respectively) is lower than that reported by Grassi *et al.* (2004), Yahya (1996), Pedersen *et al.* (1983), Gohl (1981) among others. In agreement with the present study Chantiratikul *et al.* (2009) showed the CP content to be lowest in stems compared to panicles and leaves. Most varieties in the current study recorded higher values of CP content in leaves and stems in comparison to data obtained elsewhere by Fadel *et al.* (2007) who reported a CP content of 2.7 – 5.3 and 3.2 – 4.9 for leaves and stems respectively. Pizarro *et al.* (1984), showed the CP content of the whole plant to stabilize at 3 - 5%, stems 2 - 5% while that of leaves at 5 - 9%.

Chantiratikul *et al.* (2009) reported a significant decrease in CP content of sorghum whole plant, leaf and stem with maturity. Others who observed a similar trend include; Kuhlman and Owen (1988), Snyman and Joubert (1996), Osolo (1998), Philips *et al.* (1999), Wong and Vijasegaran (2001), Pedersen and Kenneth (2003) and Chantiratikul *et al.* (2009 and 2006). As plant matures there is reduction in CP content due to fibre accumulation and ligninification in the plant cell with greater proportion taking place in the stems. Previous unpublished work by ICRISAT Scientists showed variety IESV92165 DL and IESV99006 DL to have high production in terms of grain yield (appendix 3). Hence, this might have attributed to the higher CP contents for both the panicles and whole plant compared to other varieties in this study. On the other hand it is also noted that NGUUGU contrary to other varieties recorded high CP content in whole plant followed by leaves rather than high values in panicles. This can be explained by the result obtained in another part of the study which showed that NGUUGU was tall and late

maturing, thus at the time of sample collection the panicles had not fully developed to contain the desired concentration of the grain content.

Protein content and composition vary due to environmental conditions (water availability, soil fertility, temperature and environmental condition during growth and development) and genotype (Thapa *et al.*, 1997; Amukelani, 2005; Matlebyane *et al.*, 2009). One of the limitations of sorghum is its low protein level and low amounts of essential amino acids. The issue of low protein level in sorghum is best addressed by the appropriate use of fertilizer. This has a two fold effect of both increasing the protein level of sorghum and the yield of sorghum per hectare. Ashiono *et al.* (2005) working on dual-purpose sorghum noted an increase of crude protein in grain from 9.38% to 11.56% when nitrogen and phosphorus fertilizers were applied.

Crude protein levels in feed are major concern, particularly when used as feed for young growing animals are a part of livestock herd. The CP among the ten varieties in the current study was not significantly different. The CP content did not meet the minimum requirement for maintaining cattle. Pregnant cows require from 7 to 9.5% CP, depending upon age and weight, while lactating cows, growing calves and yearlings require a higher percentage for maintenance, lactation and growth (NRC, 1984). In general, as CP increases in forage, livestock performance gets better i.e. gain more weight, produce more milk thus, there is a reasonably good relationship between forage quality and protein quality. The low CP levels shown by varieties in the current study would therefore pose a major limitation on CP intake by the ruminants unless supplementation with legumes and other high protein supplements is considered. In arid and semi-arid, however the main constraint is forage quantity hence the ruminants would be constrained

to accept and feed on poor quality forage especially during the dry period. Low CP intake would imply protein deficiency and low productivity. However, ruminants are known to be able to elevate the amino acid nitrogen entering the intestines through an efficient adaptive urea recycling in the rumen (Louca *et al.,* 1982). The recycled urea contributes to the digestion of poor quality roughage thereby improving the overall forage utilization. Therefore it is probable that the ruminants in the arid and semi-arid regions fed on these varieties would still manage to meet their physiological nitrogen requirements despite the low CP content in their diet during the dry season.

## 3.3 CHEMICAL COMPOSITION OF THE CELL WALL CONSTITUENTS OF THE TEN SORGHUM VARIETIES

### 3.3.1 Introduction

The value of a crop plant as forage is determined primarily by the degradability of the vegetative tissue, which in turn is affected by the property of its cell wall structure (Åman, 1993; Vogler *et al.*, 2009). Cellulose and hemicellulose in the cell wall provide a major energy source for ruminant animals, when they are degraded into oligo- and mono-saccharides (Moore and Hatfield, 1994). The availability of cellulose and hemicellulose as sources of energy, however, depends on the overall structural properties of the cell wall, which often varies between species, genotypes, and tissue, and the interaction between these three factors. For example, the presence of the cell wall polymer lignin has been thought to impede access of hydrolytic enzymes to the cell wall polysaccharides (Lundvall *et al.*, 1994; Oba and Allen, 1999; Fontaine *et al.*, 2003).

Cell wall carbohydrates can be quantified by determination of neutral detergent fibre (NDF), which includes cellulose, hemicellulose and lignin as the major components (Van Soest *et al.*, 1991). Due to the variability of NDF in rumen degradation and its influence on animal performance, the knowledge of NDF digestibility in forage is critical for effective ruminant feeding (Oba and Allen, 1999). Forage digestibility in ruminants is constrained by the extent of cell wall digestion (Van Soest, 1994). Incomplete degradation of cell walls is a major factor limiting the value of forages and straws for animals (Ahmad and Wilman, 2001). Grenet and Besle (1991) and Nagadi *et al.* (2000) postulated that the cell wall carbohydrates are little degraded in the rumen due to a high

extent of lignification. Lignin is generally accepted as the primary component responsible for limiting the digestion of forages (Van Soest, 1994; Traxler *et al.*, 1998; Agbagla-Dohnani *et al.*, 2001; Jančík *et al.*, 2008). Studies have cited most sorghum varieties to contain high fibre content with its effect translating to low energy value and low digestibility (Vogler *et al.*, 2009; Madibela *et al.*, 2002; Ashiono *et al.*, 2005; Buxton and Daren 1997; Yahya, 1996). Feeds with less than 45% neutral detergent are considered excellent sources of energy. High values of acid detergent fibre (ADF) imply a limitation on nutrient availability to the animals due to reduction in dry matter digestibility leading to insufficient supply of energy.

From the result of proximate analysis it was found that all the ten sorghum varieties had low CP content in all the parts tested. Generally, most laboratories use NDF and ADF along with CP content to predict the overall quality of forage samples. Hence further analyses were conducted to determine the content of fibre so as to interrelate their effect. Besides, knowing the fibre composition will enhance decision on any improvement measures toward increasing digestibility.

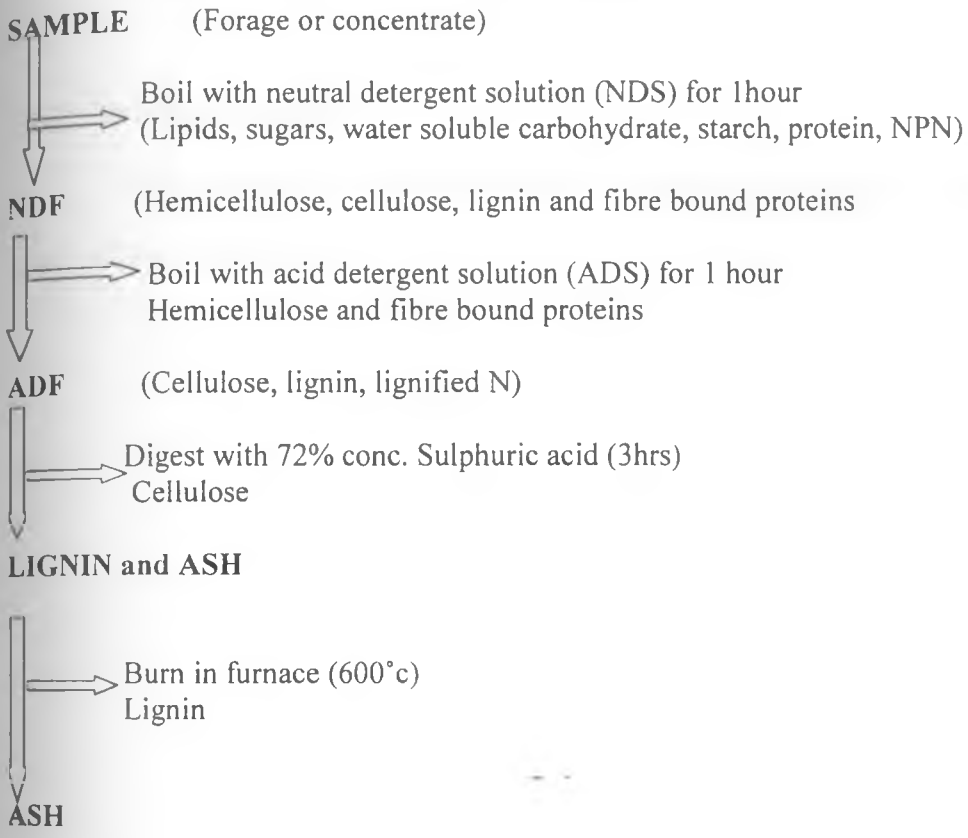
### 3.3.2 Objective

To determine the fibre constituents of the ten selected sorghum varieties.

### 3.3.3 Procedure

Plant cell wall constituents (CWC) were analyzed by determining the NDF, ADF, hemicellulose and ADL according to methods by Van Soest *et al.* (1991). As shown in section, 3.1.3 the samples analyzed were of whole plants (excluding roots) and of

individual tissues; panicles, leaves and stems. For each sample, a pool representing three plants from every location was analyzed in duplicates. The samples were analyzed sequentially for NDF, ADF and ADL as shown schematically below.




Hemicellulose was calculated as the loss of NDF residue upon subsequent extraction with ADS.

$$\text{NDF} = \frac{\text{Weight of oven dry crucible including fibre} - \text{Weight of empty crucible} \times 100}{\text{Weight of sample} * \text{DM content of sample}}$$

$$\text{ADF} = \frac{\text{Weight of oven dry crucible including fibre} - \text{Weight of empty crucible} \times 100}{\text{Weight of sample} * \text{DM content of sample}}$$

$$ADL = \frac{L * 100}{S * DM\ content}$$

Where L = loss upon ignition after 72% Sulphuric acid treatment

S = air dry sample weight

DM content = dry matter content of sample

### 3.3.4 Statistical Analysis

The Analysis of Variance (ANOVA) and separation of means were carried out as described in section 3.2.4

### 3.3.5 Results and Discussion

#### 3.3.5.1 Neutral detergent fibre contents of the ten sorghum varieties

There was a significant ($P \leq 0.05$) variation in varieties, location and plant parts, respectively. However, there was no significant ($P > 0.05$) interaction between location and varieties hence the variety means for the locations were pooled.

**Table 4:** Neutral detergent fibre (%DM) contents of the ten sorghum varieties (panicles, leaves, stems, and whole plant)*.

| | PLANT PARTS | | | | |
|---|---|---|---|---|---|
| VARIETIES | PANICLES | LEAVES | STEMS | WHOLE PLANT | MEAN |
| BTX 623 | 6o.29 | 65.57 | 66.04 | 64.6 | 64 13$^{bc}$ |
| IESV91131 DL | 58.31 | 67.64 | 71.37 | 58.35 | 63.92$^{bc}$ |
| IESV92089 DL | 60.51 | 66.68 | 67.99 | 60.91 | 64.02$^{bc}$ |
| IESV92165 DL | 57.06 | 65.13 | 63.69 | 58.01 | 60.97$^{cd}$ |
| IESV99006 DL | 52.99 | 63.61 | 61 45 | 56.02 | 58.52$^{d}$ |
| IESV99027 DL | 58.39 | 70.33 | 77.02 | 59.72 | 66.36$^{b}$ |
| IESV99095 DL | 61.18 | 68.77 | 71.54 | 65.26 | 66.69$^{b}$ |
| MACIA | 58.22 | 65.97 | 76.41 | 63.16 | 65.94$^{b}$ |
| NGUUGU | 71.56 | 74.3 | 82.86 | 66.42 | 73.79$^{a}$ |
| SDSL90162-2 | 58.74 | 70.72 | 68.44 | 62.88 | 65.2$^{b}$ |
| MEAN | 60.25$_z$ | 67.87$_y$ | 70.68$_x$ | 60.94$_z$ | 64.94 |
| LSD Variety | | 4.06 | | | |
| LSD Plant part | | 2.57 | | | |
| CV% | | 7.7 | | | |

*Values followed by the same superscript letter (a, b, c, d) in a column and subscript letter (x, y, z) in a row are not significantly ($P \geq 0.05$) different.

**Analysis of Variance (ANOVA)**

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| VARIETIES | 9 | 1353.62 | 150.40 | 4.87 | <.001 |
| LOCATIONS | 2 | 1989.48 | 994.74 | 32.21 | <.001 |
| PLANT_PARTS | 3 | 2378.98 | 792.99 | 25.68 | <.001 |
| VARIETIESXLOCATIONS | 18 | 321.76 | 17.88 | 0.58 | 0.906 |
| Residual | 87 | 2686.93 | 30.88 | | |
| Total | 119 | 8730.77 | | | |

The NDF levels of the ten sorghum varieties are shown in Table 4. NGUUGU had the highest ($P \leq 0.05$) value (73.79%) while IESV99006 DL ($P \leq 0.05$) had the lowest value of 58.52%. However, IESV99006 DL and IESV92165 DL had similar values. The values for IESV92165 DL and the other seven varieties were similar ($P \leq 0.05$) and ranged from 60.97% to 66.69% on average. This probably might be attributed to genetic make-up. On

the other hand in term of plant parts the stem had higher ($P \leq 0.05$) NDF content (70.68%) followed by leaves (67.15%) while panicle (61.06%) and whole plant (60.2%) were similar. NGUUGU recorded highest ($P \leq 0.05$) NDF values in all the parts (panicles, leaves, stems and whole plant) while IESV99006 DL followed by IESV92165 DL recorded lower ($P \leq 0.05$) values across all the tested parts.

Neutral detergent fibre is partially digestible, ranging from 20 to 80% depending upon forage species and stage of maturity. The neutral detergent fibre contents obtained in this study were similar to those reported by several authors (Tauquir *et al.*, 2009; Colombo *et al.*, 2007; Fadel *et al.*, 2007; Ashiono *et al.*, 2005; Hakki *et al.*, 2005; Oliver *et al.*, 2004; NRC, 2001; Buxton and Daren, 1997; Yahya, 1996; Snyman and Joubert, 1996). Studies on sorghum in US have reported NDF content of as low as 39.8% (Bean and McCollum, 2007) which is by far better in term of nutrient availability compared to the result of this study. Mohammed and Mohamed, (2009) working with seven sorghum varieties found NDF to range from 45 – 61.4% while, Yahya (1996) found NDF content of various sorghum varieties to range from 56-73%. Ashiono *et al.* (2005) working on six sorghum varieties across agro-ecological zones in Kenya reported NDF to range from 58.9-71.6%. The results of the ten sorghum varieties (58.52-73.79%) obtained in this study were in the same range as those reported by above researchers.

The plant part NDF trend obtained in this study for the panicles, leaves, stems and whole plant of most varieties was in agreement with many other studies (Oliver *et al.*, 2004; Tauquir *et al.*, 2009; Fadel *et al.*, 2007). However, whole plant NDF values for varieties such as BTX 623, IESV99095 DL, MACIA, and NGUUGU were lower than corresponding panicle values, though not significant ($P \geq 0.05$). In some varieties such as

NGUUGU, panicles (the grain) were not well developed at the time of taking the sample hence high NDF. This may be the reason for high NDF values in panicles compared to whole plant. However, there are other researchers, who have demonstrated similar trend. Vogler *et al.* (2009) and Ricca and Combellas, (1993) working with sorghums obtained lower NDF content in whole plant compared to panicles.

Fadel *et al.* (2007) working with five sorghum varieties obtained NDF values ranging from 58.7 to 78% and 63.5 to 71.3% for stems and leaves respectively. These values are within the range of NDF levels obtained in the current study. Stems of most plant species have greater fibre concentration than leaves and other parts (Buxton and Daren, 1997). Fibre concentration also increases as plant mature, which is the most important factor affecting dry matter digestibility. In addition to fibre concentration increasing within stems and most leaves with plant maturity, fibre concentration also increases in total forage because leaf:stem ratio decreases as the plant matures. Albrecht *et al.* (1987) reported that leaf:stem ratio of alfalfa decreased from 1.5 at early vegetative stage to 0.5 by the flowering stage. Buxton and Daren (1997) working on sorghum demonstrated fibre to be concentrated more in stems and leaves which agrees with the results of the present study. The stem had greater NDF than other parts; this is probably due to the amount of fibre and lignin it contains. Higher fibre concentrations in stems occur in part because stems contain more structural conducting tissues. The higher values of NDF in this study may be also attributed to the late stage of maturity at which the samples were collected for analysis. Studies by Muir (2002) showed NDF content of whole plant, leaves and stem to increase with stages of maturity, with environmental factors, particularly rainfall and temperature playing an important role.

### 3.3.5.2 Acid detergent fibre contents of the ten sorghum varieties

Significant ($P \leq 0.05$) variation in acid detergent fibre composition was observed among the varieties, locations, and plant parts, respectively. However, the location x variety interaction was not significant ($P > 0.05$) hence variety means from the three locations were pooled (Table 5).

**Table 5:** Acid detergent fibre (%DM) contents of the ten sorghum varieties (panicles, leaves, stems, and whole plant)*.

| | PLANT PARTS | | | | |
|---|---|---|---|---|---|
| VARIETIES | PANICLES | LEAVES | STEMS | WHOLE PLANT | MEAN |
| BTX 623 | 14.5 | 31.35 | 39.04 | 24.75 | $27.41^{cd}$ |
| IESV91131 DL | 15.08 | 31.58 | 38.19 | 27.17 | $28.01^{bc}$ |
| IESV92089 DL | 16.81 | 35.83 | 36.24 | 25.98 | $28.72^{bc}$ |
| IESV92165 DL | 11.69 | 29.48 | 34.28 | 24.25 | $24.93^{de}$ |
| IESV99006 DL | 11.1 | 28.27 | 32.95 | 23.54 | $23.94^{e}$ |
| IESV99027 DL | 13.65 | 34.27 | 35.33 | 26.18 | $27.35^{cd}$ |
| IESV99095 DL | 14.76 | 40.93 | 41.21 | 25.36 | $30.57^{b}$ |
| MACIA | 14.69 | 35.1 | 38.49 | 24.89 | $28.29^{bc}$ |
| NGUUGU | 19.35 | 41.57 | 43.2 | 32.79 | $34.23^{a}$ |
| SDSL90162-2 | 12.33 | 33.55 | 35.12 | 27.14 | $27.04^{cd}$ |
| MEAN | $14.4_z$ | $34.19_x$ | $37.41_w$ | $26.21_y$ | 28.05 |
| LSD Variety | | 3.08 | | | |
| LSD Plant part | | 1.95 | | | |
| CV% | | 13.5 | | | |

*Values followed by the same superscript letter (a, b, c, d, e) in a column and subscript letter (w, x, y, z) in a row are not significantly ($P \geq 0.05$) different.

**Analysis of Variance (ANOVA)**

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| VARIETIES | 9 | 678.67 | 75.41 | 4.81 | <.001 |
| LOCATIONS | 2 | 213.81 | 106.91 | 6.81 | 0.001 |
| PLANT_PARTS | 3 | 9364.92 | 3121.64 | 198.98 | <.002 |
| VARIETIESXLOCATIONS | 18 | 288.91 | 16.05 | 1.02 | 0.443 |
| Residual | 87 | 1364.88 | 15.69 | | |
| Total | 119 | 11911.19 | | | |

The ADF levels of the ten sorghum varieties are shown in Table 5. The percentage ADF across all the varieties were higher ($P \leq 0.05$) in NGUUGU (34.23%), followed by IESV99095 DL (30.57%), though not significantly ($P > 0.05$) different from IESV92089 DL (28.72%), MACIA (28.29%) and IESV91131 DL (28.01%). On the other hand

IESV99006 DL (23.94%) had lowest ($P \geq 0.05$) ADF content though not significantly ($P \geq 0.05$) different from IESV92165 DL (24.93%). Stems showed higher ($P \leq 0.05$) ADF content (37.41%); followed by leaves (34.19%), whole plant (26.21%) while panicles (14.4%) had lowest values. This trend is consistent with report of other studies on forages and cereal straws (Fadel *et al.,* 2007; Madibela *et al.,* 2002; Tolera and Sundstol, 1999; Tan *et al.,* 1995). The results showed clearly that across all the tested parts (panicles, leaves, stems and whole plant) NGUUGU recorded highest ($P \leq 0.05$) values while IESV99006 DL had the lowest values.

Acid detergent fibre measures the least digestible fraction of the fibre (lignin and cellulose). It represents the fibrous portion of the feed which is resistant to hydrolysis (Bean and McCollum, 2007) of which only lignin is not degradable. The range of ADF reported in this study was lower compared to many other studies. High value of ADF implies a limitation on nutrient availability to the animal. The results obtained in the current study also compared with many other studies done elsewhere on sorghum. Thus, the ADF content of these varieties was within the range found by other researcher such as Tauquir *et al.* (2009), Bean and McCollum, (2007), Beck *et al.* (2007), Nabi *et al.* (2006), Hakki *et al.* (2005), Lusk *et al.* (1984) among others who reported ADF within range of 25-39% in leaves, stems and whole plant. The ADF content in the study agreed with results by Bean and McCollum (2007) working on conventional sorghum, who reported ADF range of 24.6% - 36.5%. These varieties also showed lower ADF content than other varieties tried in Kenya such as E6518, Lan – 1, E1291, Ikinyaruka, BJ128, whose values ranged between 43.4 and 46.4% as reported by Ashiono *et al.* (2005). The current study also recorded lower values of ADF compared to values above 37% reported by Colombo

*et al.* (2007), Fadel *et al.* (2007) and Mohammed and Mohamed, (2009). Studies by José *et al.* (2003) reported an average ADF of 31.6% for 18 sorghum varieties, while Yahya (1996) reported 30.14 – 38.93% on whole plant. Vogler *et al.* (2009), working on several sorghum varieties reported an average ADF content of 37.3%, 36.8%, 31.8% and 31.8% in stems, leaves, panicles and whole plant respectively which are similar with this study. Fadel *et al.* 2007 working with five sorghum varieties obtained ADF value of 46.7 – 59.5% and 38.0 – 50.9% for stems and leaves respectively which are higher to the value obtained in the present study for the corresponding parts.

As plants mature they become more fibrous and lignified with most concentration in stems and leaves hence this explains the higher content of ADF in stems and leaves. The panicles recorded lower value of ADF and this may be explained by the higher content of hemicellulose (Table 6), an indication that cellulose and lignin content was low for panicles. The more ADF content (cellulose, bound protein and lignin) the lower is the digestibility and vice versa. The high temperature and amount of rainfall during the growing season probably might have increased the amount of cell wall and lignin content in the present study. The effect of temperature and rainfall has been reported by Muir (2002). According to Madibela *et al.* (2002), the limitation imposed by higher fibre content is the reduction in dry matter digestibility leading to insufficient supply of energy.

### 3.3.5.3 Hemicellulose contents of the ten sorghum varieties

There was no significant ($P>0.05$) variation in the varieties and the location, respectively. However, significant ($P\leq0.05$) variation in hemicellulose (HC) was

observed among the plant parts. There was no significant (P≥0.05) interaction between the varieties and location hence the means for the three locations were pooled.

**Table 6:** Hemicellulose (%) of the ten sorghum varieties (panicles, leaves, stems, and whole plant)*.

| | PLANT PARTS | | | | |
|---|---|---|---|---|---|
| VARIETIES | PANICLES | LEAVES | STEMS | WHOLE PLANT | MEAN |
| BTX 623 | 46.63 | 26.54 | 39.79 | 35.54 | 37.13 |
| IESV91131 DL | 47.68 | 29.44 | 37.44 | 31.18 | 36.44 |
| IESV92089 DL | 42.54 | 30.45 | 27.49 | 34.93 | 33.85 |
| IESV92165 DL | 50.11 | 33.55 | 28.96 | 31.77 | 36.10 |
| IESV99006 DL | 50.32 | 28.28 | 30.61 | 33.52 | 35.69 |
| IESV99027 DL | 54.13 | 37.38 | 33.34 | 33.50 | 39.59 |
| IESV99095 DL | 50.80 | 27.56 | 24.90 | 35.82 | 34.77 |
| MACIA | 58.36 | 30.87 | 28.37 | 33.33 | 37.73 |
| NGUUGU | 59.05 | 31.11 | 34.45 | 33.63 | 39.56 |
| SDSL90162-2 | 45.76 | 36.44 | 33.13 | 35.74 | 37.77 |
| MEAN | 50.54[a] | 31.16[b] | 31.85[b] | 33.90[b] | 36.86 |
| LSD Plant Part | | 4.26 | | | |
| CV% | | 22.5 | | | |

*Values followed by the same superscript letter (a, b, c) in a row are not significantly (P≥0.05) different.

Analysis of Variance (ANOVA)

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| VARIETIES | 9 | 383.42 | 42.60 | 0.62 | 0.775 |
| LOCATIONS | 2 | 3527.13 | 1763.56 | 25.74 | 0.100 |
| PLANT_PARTS | 3 | 7604.03 | 2534.68 | 37.00 | <.001 |
| VARIETIESXLOCATIONS | 27 | 1396.33 | 51.72 | 0.75 | 0.792 |
| Residual | 78 | 5343.81 | 68.51 | | |
| Total | 119 | 18254.72 | | | |

Table 6, shows the hemicellulose level for the ten sorghum varieties. Though no difference (P>0.05) was observed among the varieties. On average NGUUGU (39.56%) and IESV92089 DL (33.85) had the highest and the lowest hemicellulose levels, respectively. The highest (P≤0.05) HC levels were showed in panicles (50.54%). The whole plant (33.90%) followed by stems (31.85%) and leaves (31.16%) though the levels were not significantly (P>0.05) different. This is consistent with Vogler *et al.* 2009 who found panicle to contain significantly higher levels of HC compared to stems, leaves and whole plant.

The difference between the NDF and ADF shows the proportion of the cell wall constituent that is easily brokendown by ruminants (hemi-cellulose). Ruminants will breakdown hemicellulose and cellulose and only lignin is not broken down in the rumen. The levels of hemi-cellulose recorded in this study were lower in leaves and stems and higher in panicle. This implies cellulose, bound protein and lignin were also present in greater proportion in leaves and stems compared to panicles and whole plant as shown in Tables 5 and 7. From NDF values NGUUGU recorded highest values across all the plant parts, however, in terms of hemicellulose it compared fairly with other varieties thus, indicating the higher proportion of NDF recorded is digested as hemicellulose. The values obtained in the present studies were lower for all parts than those obtained (38-59.5% ) by Vogler *et al.* (2009) and Fadel *et al.* (2007) working on sorghum.

**3.3.5.4 Acid detergent lignin contents of the ten sorghum varieties**

There was no significant ($P>0.05$) variation shown in varieties and the locations, respectively, but significant ($P\leq0.05$) variation was observed among the plant parts. The interaction between the varieties and location was not significant ($P\geq0.05$) hence the means for the three locations were pooled.

**Table 7:** Acid detergent lignin (%DM) contents of the ten sorghum varieties (panicles, leaves, stems, and whole plant)*.

| | PLANT PARTS | | | | |
|---|---|---|---|---|---|
| VARIETIES | PANICLES | LEAVES | STEMS | WHOLE PLANT | MEAN |
| BTX 623 | 3.54 | 4.94 | 6.56 | 4.99 | 5.01 |
| IESV91131 DL | 3.48 | 7.18 | 5.4 | 4.53 | 5.15 |
| IESV92089 DL | 4.52 | 5.28 | 5.57 | 4.07 | 4.86 |
| IESV92165 DL | 4.78 | 4.52 | 5.33 | 3.71 | 4.59 |
| IESV99006 DL | 4.66 | 4.59 | 5.9 | 4.51 | 4.92 |
| IESV99027 DL | 5.02 | 4.76 | 5.67 | 4.91 | 5.09 |
| IESV99095 DL | 2.22 | 5.95 | 6.42 | 4.25 | 4.72 |
| MACIA | 4.47 | 5.08 | 5.98 | 4.63 | 5.04 |
| NGUUGU | 4.95 | 5.86 | 5.9 | 6.48 | 5.8 |
| SDSL90162-2 | 2.22 | 5.92 | 5.49 | 4.57 | 4.55 |
| MEAN | 3.99[c] | 5.41[a] | 5.82[a] | 4.8[b] | 4.97 |
| LSD Plant part | | 0.55 | | | |
| CV% | | 21.7 | | | |

*Values followed by the same superscript letter (a, b, c) in a row are not significantly (P≥0.05) different.

**Analysis of Variance (ANOVA)**

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| VARIETIES | 9 | 13.757 | 1.529 | 1.07 | 0.395 |
| LOCATIONS | 2 | 3.179 | 1.589 | 1.11 | 0.334 |
| PLANT_PARTS | 3 | 59.358 | 19.786 | 13.81 | <.001 |
| VARIETIESXLOCATIONS | 18 | 20.917 | 1.162 | 0.81 | 0.682 |
| Residual | 87 | 124.640 | 1.433 | | |
| Total | 119 | 221.850 | | | |

As shown in Table 7, no significant (P≥0.05) differences were observed among the varieties. The average ADL content ranged from 4.55 to 5.15 % with Variety IESV91131 DL and SDSL90162-2 recording highest and lowest values, respectively. Percentage ADL were higher (P≤0.05) in stems (5.82%) and leaves (5.41%), then whole plant (4.8%) and lowest in panicles (3.99%). This trend is in agreement with study by Madibela *et al.* (2002).

According to this study the levels of ADL content were found to be low, indicating greater portion of the forage is digestible by the ruminant animals such as cattle, sheep and goats. The range obtained in this study agrees with report by Vogler *et al.* (2009) for panicles, leaves, stems and whole plant. Studies have demonstrated an increase in the rate of lignification with maturity and greater accumulation in stems and leaves. Thus owing

to the fact that the samples were collected at hard dough stage explains the reason why this study stems and leaves had more lignin content in comparison to panicles and whole plant where grain concentration contributed to lower lignin content. Yahya (1996) and Colombo *et al.* (2007) working on various sorghum varieties reported slightly higher values of ADL ranging from 5.5 to 8.42%, while Vogler *et al.* (2009) reported ADL of 3.9 to 5.8%, compared to 4.55 to 5.15% in the current study. Tauquir *et al.* (2009), Oliver *et al.* (2004, 2005), Pedersen *et al.* (2000) also working on sorghum reported similar values of ADL as those of the ten sorghum varieties in the current study. Fadel *et al.* (2007) working on plant parts obtained ADL values of 11.3 – 17.3% and 7.3 – 14.0% for stems and leaves respectively, which are far higher than values reported in the present study for the same tissue (Table 7).

The degree of reduction in lignin content is paralleled with an increase in cellulose and hemicellulose content. The increase in cellulose and hemicellulose contents may reflect the existence of a mechanism that compensates for the reduction in lignin content. All the varieties in the current studies had high hemicellulose content in the panicles, translating to a low proportion of cellulose and lignin in panicles compared to other parts with low hemicellulose content (Table 6).

Lignin represents the portion of fibre which is not digested by ruminants. Fibrous carbohydrates have low degradability in rumen when compared to nonfibrous carbohydrates (Van Soest, 1994). The lower the lignin of particular forage the higher the quality or energy value. This is because the reduction in lignin content may make the polysaccharide fractions more susceptible to chemical or enzymatic degradation, which could account for an increased release of sugars. On the other hand lignin is necessary to

provide mechanical support for stems and leaf blades and to impart strength and rigidity to plant walls. Also, much evidence shows that lignin and lignin-like compounds along with other cell wall constituents provide resistance to disease, insects, cold temperatures, and other biotic and abiotic stresses. Thus, practical limits as to how much lignin and other cell-wall constituents can be reduced in forages through breeding to improve digestibility without adversely affecting the ability of forages to grow and survive in the field environments.

## 3.4 THE *IN VITRO* DRY MATTER DIGESTIBILITY OF THE TEN SORGHUM VARIETIES

### 3.4.1 Introduction

The *in vitro* dry matter disappearance is an indication of digestibility of forage samples. Digestibility provides a measure of feed quality because it indicates the portion that can actually be used by the animal body. The value of a crop plant as forage is thus, determined primarily by the degradability of the vegetative tissues, which in turn is affected by the property of its cell wall structure. The crude protein content also plays a major role for rumen microbes to effectively digest the feed, thus *in vitro* dry matter digestibility (IVDMD) is positively correlated to CP. From literature review cattle in tropics need a feed supply of 45% dry matter digestibility to maintain weight and 55% to gain o.5 to 0.6 kg a day. The fodder quality of sorghum (Sorghum bicolor) stover is variable with digestibility as low as 34% and as high as 61%. Improvement in, *in vitro* dry matter digestibility is now a major objective in many breeding programs. Thus determination of the extent to which these varieties are degradable is an indication of usefulness to the livestock. Hence it was worthwhile to determine *in vitro* dry matter digestibility.

### 3.4.2 Objective

To determine the *in vitro* dry matter digestibility of the ten selected sorghum varieties.

### 3.4.3 Procedure

As shown in section, 3.1.3 analyses were performed on whole plants (excluding roots) and on individual parts; panicles, leaves and stems. For each sample, a pool representing three plants from every location was analyzed in duplicates following the procedure adapted from Tilley and Terry (1963). *In vitro* techniques were conducted outside of the animal system but simulated the digestion process. Rumen liquor was collected from a fistulated steer at the Department of Animal Production, Upper Kabete Campus of the Univeraity of Nairobi. A sample of 0.5 gram was placed in numbered centrifuge tube. Blanks tubes were also provided. The rumen fluid was strained through 4 layers of cheesecloth, fluid collected in an insulated jug / flask. Artificial saliva was prepared from buffer solution (distilled water, Ammonium bicarbonate, Sodium carbonate) and micro mineral solutions (sodium phosphate, potassium phosphate, magnesium phosphate, calcium chloride, manganese chloride, cobalt chloride and iron chloride).

After preparation of the above reagents, rumen fluid and artificial saliva were mixed in a ratio of 1:4 respectively. Carbon dioxide was added to the mixture. Fifty ml of innoculum was added to each tube and immediately tubes were placed in a water bath (39°C). After 48 hours stoppers were removed and any particle clinging on the stopper washed into the tube with minimum distilled water. Five ml of 20% HCL and two ml pepsin was added and the mixture incubated for a further 48 hours at (39°C) water bath. After 48 hours of pepsin digestion, contents of centrifuge tubes were transferred to weight tared crucibles. The contents of the crucible were washed with hot water and

crucibles rinsed 3 times with hot distilled water. Crucibles were then dried in oven (105°C) cooled in a dessicator and weighed so as to calculate DM disappearance.

### 3.4.4 Statistical Analysis

The Analysis of Variance (ANOVA) and separation of means were carried out as described in section 3.2.4

### 3.4.5 Results and Discussion

#### 3.4.5.1 *In vitro* dry matter digestibility (IVDMD) of the ten sorghum varieties

According to analysis of variance significant ($P \leq 0.05$) variations in *in vitro* dry matter digestibility (IVDMD) were observed among the varieties, location and plant parts, respectively. However, there was no significant ($P > 0.05$) location x variety interaction; hence the means from the three locations were pooled together (Table 8).

**Table 8:** *In vitro* dry matter digestibility (%DM) of the ten sorghum varieties (panicles, leaves, stems, and whole plant)*.

| | PLANT PARTS | | | | |
|---|---|---|---|---|---|
| VARIETIES | PANICLES | LEAVES | STEMS | WHOLE PLANT | MEAN |
| BTX 623 | 65.78 | 61.44 | 50.38 | 68.64 | $61.56^{c}$ |
| IESV91131 DL | 63.7 | 61.24 | 54.27 | 64.61 | $60.96^{c}$ |
| IESV92089 DL | 65.59 | 58.39 | 53.23 | 64.55 | $60.44^{c}$ |
| IESV92165 DL | 71.75 | 64.59 | 56.43 | 70.49 | $65.82^{ab}$ |
| IESV99006 DL | 72.33 | 64.75 | 59.7 | 72.94 | $67.43^{a}$ |
| IESV99027 DL | 69.44 | 61.82 | 54.72 | 60.88 | 61 $72^{bc}$ |
| IESV99095 DL | 65.84 | 58.84 | 51.22 | 63.83 | $59.93^{c}$ |
| MACIA | 67.83 | 59.78 | 51.95 | 65.55 | $61.28^{c}$ |
| NGUUGU | 57.56 | 56.18 | 48.99 | 60.14 | $55.72^{d}$ |
| SDSL90162-2 | 69.87 | 62.66 | 54.83 | 69.65 | $64.25^{ab}$ |
| MEAN | $66.97_{x}$ | 60 $97_{y}$ | $53.57_{z}$ | $66.13_{x}$ | 61.93 |
| LSD Variety | | 4 17 | | | |
| LSD Plant parts | | 2.64 | | | |
| CV% | | 8.3 | | | |

*Values followed by the same superscript letter (a, b, c, d) in a column and subscript letter (x, y, z) in a row are not significantly ($P \geq 0.05$) different.

Analysis of Variance (ANOVA)

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| VARIETIES | 9 | 901.93 | 100.21 | 4.28 | <.001 |
| LOCATIONS | 2 | 1438.59 | 719.29 | 30.73 | <.001 |
| PLANT_PARTS | 3 | 3414.21 | 1138.07 | 48.61 | <.001 |
| VARIETIESxLOCATIONS | 18 | 538.04 | 29.89 | 1.28 | 0.223 |
| Residual | 87 | 2036.72 | 23.41 | | |
| Total | 119 | 8329.49 | | | |

The IVDMD of the ten sorghum varieties are shown in Table 8. There was significant ($P \leq 0.05$) difference in IVDMD among the ten varieties. As indicated in Table 8, on average the IVDMD of the ten sorghum varieties ranged from 55.72 to 67.43%.

Variety IESV99006 DL at 67.43% recorded highest ($P \leq 0.05$) value though not different ($P \leq 0.05$) from IESV92165 DL, SDSL90162-2 at 65.82% and 64.25% respectively. On the other hand percentage IVDMD among the varieties, was significantly ($P \leq 0.05$) lower in NGUUGU at 55.72%, followed by IESV99095 DL at 59.93% which was not significantly ($P \leq 0.05$) different from the rest five varieties. The plant parts also had remarkable significant ($P \leq 0.05$) differences. The panicles stood superior in terms of IVDMD (66.97%) though not significantly ($P \leq 0.05$) different from whole plant at 66.13%. The leaves had average value of 60.99% while the IVDMD of the stem was significantly ($P \leq 0.05$) lower at 53.57% (Table 8).

Johnson (1974) reported that digestibility decreases as plant mature due to cumulative increase in fibre content. Therefore since the samples used in this study were collected at hard dough stage, probably is the reason for the low digestibility due to accumulation of fibre content on these varieties especially on stems and leaves. Stems decline in digestibility more rapidly with increasing plant maturation than leaves and other parts, which is the trend demonstrated in the present study. According to Pizarro *et al.* (1984) the digestibility of crop decreased linearly with time at the rate of 0.13%/day. Studies have shown stems and leaves to contain high amount of fibre and lignin. This explains why the digestibility was low in stems and leaves compared to panicles and whole plant. This similar trend was observed by Bolsen and White (1989), though the present study had lower values of IVDMD in panicles. On the other hand leaves develop a lignified midrib to provide mechanical support, which contributes to a high fibre concentration of leaves and may explain why leaves were also low in digestibility. The

grain contributed to higher digestibility of panicles and whole plant due to high grain:stem ratio which increases as plant matures.

Several chemical and structural features have been identified that may limit digestibility. Of these, lignin is most prominently mentioned (Jung and Deetz, 1993). Lignin is thought to interfere with microbial degradation of fibre polysaccharides by acting as a physical barrier. Recently the importance of cross-linking to polysaccharides by ferulate bridges has been implicated as an additional factor inhibiting digestion of grass fibre (Jung and Allen, 1995). However, in the present study all the varieties recorded higher IVDMD than 45% reported by Younguist *et al.* (1990) and McDowell (1972) to be acceptable level to maintain weight and 55% dry matter digestibility to gain 0.5 to 0.6 kg a day for cattle in the tropics, but lower than 72.5 and 73.3% reported by Felix and Funso (1994) working with sheep. Snyman and Joubert (1996) working on sorghum also reported IVDMD of 53.9% whole plant residues and 52.3% for leaves, while Blümmel et al. (2009) working with eighteen hybrids and 16 varieties of sweet sorghum found IVDMD to range of 43 -54.8%

Faster digestion allows more forage (and thus more nutrients) to be consumed and the more mature and fibrous (low in quality) forage, the longer it takes to be digested and the less an animal will consume (Ball *et al.,* 2001). Generally NDF and ADF fractions are lower in grain-type sorghums because the stover is diluted by the higher grain-to-stover ratio common to grain-type varieties. In addition grain-type sorghums are frequently more digestible because the proportion of grain in these plants is larger than forage types. This may explain why variety NGUUGU which seem more suitable as forage-type (as reflected in agronomic traits) had high NDF and ADF content but low digestibility

compared to varieties such as IESV99006DL, IESV92165DL and SDSL90162-2, which produced a substantial amount of grain and biomass yield, a characteristic of good dual purpose sorghum. The lower concentration of NDF, ADF and ADL in variety IESV99006 DL and IESV92165 DL (Table 4, 5 and 7) could explain their higher dry matter digestibility.

Other studies have demonstrated that the higher the fibre fraction in forage the lower digestibility (Buxton and Daren, 1997; Zerbini and Thomas, 2003; Tauquir *et al.*, 2009). The current study is in agreement with other researchers (Tauquir *et al.*, 2009; Nabi *et al.*, 2006; Ashiono *et al.*, 2005; Madibela *et al.*, 2002) who have shown this as demonstrated by plant varieties and plant parts trend in fibre composition (Table 4, 5, 6, 7) and in vitro dry matter digestibility (Table 8). According to Tauquir *et al.* (2009) digestibility of the cell wall is variable among various forage sources and is an inverse function of lignification. In the present investigation, varieties with high fibre content such as NGUUGU had low DM digestibility. The low CP contents in these varieties may be below the level required for optimal microbial action in the rumen fluid used in the IVDMD procedure and, therefore may also have contributed to the low IVDMD values observed in the current study. Improvement in *in vitro* dry matter digestibility is now a major objective in many forage breeding programs. Digestibility has been shown to depend on chemical composition of the cell wall (Lundvall *et al.*, 1994; Fontaine *et al.*, 2003; Dann *et al.*, 2008), though the exact relationship is quite complex. Reducing the amount of fibre in stems and leaves of these varieties should be one of the most straightforward methods of improving their digestibility. Additionally, improving the rate

of fibre digestion will potentially have greater impact because more of the total digestible energy which is in the fibre will be available.

### 3.4.5.2 Correlation coefficients between *in vitro* dry matter digestibility and chemical components

Correlations coefficient were run to show the relationship between chemical composition parameters (crude protein, neutral detergent fibre, acid detergent fibre, acid detergent lignin and hemicellulose) and the in vitro dry matter digestibility (Table 9).

**Table 9:** Correlation between *in vitro* dry matter digestibility and chemical components

| Variables | Correlation | P - value | R - Squared |
|---|---|---|---|
| Crude Protein | 0.513 | 0.129 | 0.263 |
| Neutral Detergent Fibre | -0.9** | 0.001 | 0.81 |
| Acid Detergent Fibre | -0.94** | 0.001 | 0.884 |
| Acid Detergent Lignin | -0.706* | 0.022 | 0.499 |
| Hemicellulose | -0.285 | 0.426 | 0.081 |

* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).

According to Table 9, in vitro dry matter digestibility (IVDMD) was positively correlated to crude protein ($r = 0.513$, $R^2 = 0.263$), though the correlation was not significant. In vitro dry matter digestibility was however, negatively correlated to NDF ($r = -0.90$, $R^2 = 0.81$, $P<0.001$), ADF ($r = -0.94$, $R^2 = 0.884$, $P<0.001$), ADL ($r = -0.706$, $R^2 = 0.499$, $P<0.05$), Hemicelluloses ($r = -0.285$, $R^2 = 0.081$, $P>0.05$). With exception of hemicelluloses the other fibre components (NDF, ADF, and ADL) had high and significant negative correlation with IVDMD.

A positive correlation between in vitro dry matter digestibility and crude protein indicate that as the crude protein increases, there was an improvement in dry matter digestibility. The crude protein in the present study was low, thus, the positive association with IVDMD was not significant. Fibre constituents (NDF, ADF and ADL) have negative effect on energy content of forages and this was consistent with a highly negatively correlation observed between NDF, ADF and ADL with IVDMD in the current study. Blümmel and Belum (2006), demonstrated a significant negatively association between the fibre constituents with IVDMD. Gregorio *et al.* (2000) working with sorghum showed climatic factors to affect the relationships between neutral detergent fibre, acid detergent fibre and acid detergent lignin with in vitro dry matter digestibility. This may as well have influenced the results in this study, resulting to a highly negative significant correlation.

According to Madibela *et al.* (2002) the limitation imposed by higher fibre content is the reduction in dry matter digestibility leading to insufficient supply of energy. Correlation analysis provides a measure of the degree of association between variables. In the present study, correlation analyses were used to establish relationships between chemical composition parameters and *in vitro* dry matter digestibility of the ten sorghum varieties. The results of the current study indicate that dry matter, hemicellulose, crude protein content have poor capacity to predict in vitro dry matter digestibility of these sorghum varieties. However, neutral detergent fibre and acid detergent fibre could be used to predict the in vitro dry matter digestibility, since they were highly negatively correlated with IVDMD. Van Soest (1995) has showed that ADF and NDF are negatively and significantly correlated to intake and digestibility of forages. This observation is

similar to the results of the present study. The explanation is that NDF and ADF are analytical products having nutritional characteristics that describe forage components that have low solubility in specific systems and are relatively less digestible than starch. Similarly Linn and Kuehn (1993) found that high ADF and NDF content reduced digestibility of plants and could be used to predict net energy content.

# CHAPTER FOUR

## 4.0 GENERAL DISCUSSION

The purpose of this study was to determine the nutritional composition and digestibility of the ten dual purpose sorghum varieties with a view to recommend the best suitable for dry areas. This section endeavours to link up the results obtained with respect to objectives and expound on the relevant implication on animal performance in semi-arid areas.

Livestock are a major contributor to the farm economy in many semi-arid regions. During the dry season, livestock depend on crop residues for feed, because grass pastures are often overgrazed. Maximizing grain crops stover yields for use as forage without reducing grain yield could help meet the forage needs of the small farmer. Many traits such as DM, CP, NDF, ADF, hemicellulose, cellulose ADL, and IVDMD, in their interaction can be used to estimate quality in both freshly harvested sorghum forage and silage. Digestibility has been shown to depend on chemical composition of the cell wall (Dann *et al.,* 2008; Fontaine *et al.,* 2003; Lundvall *et al.,* 1994). According to Åman (1993) the value of a crop plant as forage is determined primarily by the degradability of the vegetative tissue, which in turn is affected by the property of its cell structure. The plant cell wall is a complex of hemicellulose, cellulose, pectin, protein and aromatic compounds such as lignin and hydroxycinnamic acids. The ADF fraction is closely related to digestibility of the forage simply because it contains cellulose and lignin, Plant cell walls are the major source of dietary fibre for animals. Polysaccharides in the cell wall cannot be degraded by mammalian enzymes. Instead animals depend on microbial fermentation, and ruminants are especially well adapted to use plant fibre for energy. The

association of cellulose with lignin in plant cell structure is the predominant factor which complicates cellulose availability. Fibre measured as neutral detergent fibre usually accounts for 30-80% of organic matter in forage crops. The remaining organic matter, cell solubles, is almost completely digestible. The nutritional availability of fibre to livestock, however, varies greatly, depending on its composition and structure. Lignin has been identified as primarily responsible for limiting digestibility of fibre, but fibre utilization is also limited by physical constraints at the cellular organization level. The cell wall digestibility has been shown to be affected by lignin content (Lundvall *et al.*, 1994) and lignin composition (Oba and Allen 1999; Fontaine *et al.*, 2003).

According to Madibela *et al.* (2002) Sorghum provide viable energy resource for ruminants due to high IVDMD. Dry matter digestibility and fibre content have been shown to be negatively correlated (Bunting, 1982; Allen *et al.*, 1980). This is demonstrated in the present study where IVDMD was shown to be negatively correlated to NDF, ADF and ADL (Table 9) while NDF, ADF, and ADL exhibited a strong positive relationship. Significant variation in cell wall composition was observed among the varieties. In all plant parts examined in the current study, percentage NDF, ADF and ADL across the varieties were significantly higher in stem tissue followed by leaves and lowest in panicles (Table 4, 5 and 7). Stem digestibility decline more rapidly with increasing plant maturation than leaf and panicle. In addition to fibre concentration increasing within stems and most leaves with plant maturity, fibre concentration also is increased in total forage because leaf:stem ratio decreases as the plant matures. The major factor lowering digestibility of forages as they mature is their high fibre and low cell-soluble concentrations. Depending on maturity, ruminants digest 40-50% of NDF in

legumes, and 60-70% in C4 grass (Buxton *et al.*, 1995). The proportion of digestible energy obtained from NDF varies from 20 to 40% for legumes (60-80%) from cell solubles and from 50 to 80% for grasses (20-50% from cell solubles (Buxton *et al.*, 1995). .

The nutrient components of the ten sorghum varieties were significantly ($P \leq 0.05$) different for NDF, ADF, and IVDMD but were similar ($P > 0.05$) for DM, CP, HC and ADL as shown in Table 10. Their nutrient contents and dry matter digestibility would give an indication of the level of nutrients available to the animal, thus rank them in respect to this among agronomic parameters determined earlier by ICRISAT researchers for further breeding.

**Table 10:** Nutritional components and in vitro dry matter digestibility of the ten sorghum varieties in the study.

| VARIETIES | DM | CP | NDF | ADF | HEM-CEL | ADL | IVDMD |
|---|---|---|---|---|---|---|---|
| BTX 623 | 92.05 | 5.52 | $64.13^{bc}$ | $27.41^{cd}$ | 37.13 | 5.01 | $61.56^{c}$ |
| IESV91131DL | 92.19 | 5.91 | $63.92^{bc}$ | $28.01^{bc}$ | 36.44 | 5.15 | $60.96^{c}$ |
| IESV92089DL | 91.69 | 5.68 | $64.02^{bc}$ | $28.72^{bc}$ | 33.85 | 4.86 | $60.44^{c}$ |
| IESV92165DL | 91.64 | 6.61 | $60.97^{cd}$ | $24.93^{de}$ | 36.10 | 4.59 | $65.82^{ab}$ |
| IESV99006DL | 91.52 | 6.29 | $58.52^{d}$ | $23.94^{e}$ | 35.69 | 4.92 | $67.43^{a}$ |
| IESV99027DL | 91.24 | 5.13 | $66.36^{b}$ | $27.35^{cd}$ | 39.59 | 5.09 | $61.72^{bc}$ |
| IESV99095DL | 92.02 | 5.82 | $66.69^{b}$ | $30.57^{b}$ | 34.77 | 4.72 | $59.93^{c}$ |
| MACIA | 91.2 | 5.64 | $65.94^{b}$ | $28.29^{bc}$ | 37.73 | 5.04 | $61.28^{c}$ |
| NGUUGU | 92.05 | 5.42 | $73.79^{a}$ | $34.23^{a}$ | 39.56 | 5.8 | $55.72^{d}$ |
| SDSL90162-2 | 92.05 | 5.14 | $65.2^{b}$ | $27.04^{cd}$ | 37.77 | 4.55 | $64.25^{ab}$ |
| Mean | 91.82 | 5.26 | 64.95 | 28.05 | 36.86 | 4.97 | 61 93 |
| Lsd $_{(p \leq 0.05)}$ | 0.94 | 0.78 | 4.51 | 3.21 | 0.92 | 0 97 | 3.93 |
| Significance | NS | NS | *** | *** | NS | NS | *** |
| CV% | 1.3 | 18.2 | 8.6 | 14.1 | 22.5 | 24.1 | 7.8 |

NS = P>0.05 * = P<0.05 ** = P<0.01 *** = P<0.001

Units are expressed as % DM basis

Values followed by the same superscript letter (a, b, c) in a column are not significantly ($P \geq 0.05$) different.

The dry matter content of the forage increases as plant matures. The dry matter content is also known to be highly correlated with dry matter intake, with high moisture

content resulting to reduction in dry matter intake. The concentration of DM and OM increases with increasing maturity (Sonon *et al.*, 1991). Since average yields of nutrients increase so dramatically during maturation, changes in nutrient content of the DM are considered of little practical importance. Paradoxically, the moisture content relates more closely with nutritive value than DM component. The process of maturity is highly complex, involving numerous alterations in plant morphology and composition. Consequently, the effects of maturity on nutritive value are difficult to understand. Water acts both as a diluent of nutrients and as an important factor in silage fermentation. In this case water exerts a significant indirect influence on animal performance.

Crude protein is one of nutrient components widely used to determine forage quality and its effect is of paramount importance in determining animal performance. In general, as CP increases in a forage, livestock perform better (i.e. gain more weight, produce more milk). Thus, there is a reasonably good relationship between forage quality and crude protein content. However, there are several problems with crude protein as a predictor of animal performance. The first is the concept of first limiting nutrient. Put simply, if a feed is deficient in energy, any amount of protein in excess of requirements will do little to increase performance. Crude protein levels in feed are a major concern, particularly when young growing animals are part of the livestock fed. In the present experiment the CP contents among the ten sorghum varieties were low and similar (Table 10). According to National Research Council (1984) intake is usually restricted when the dietary CP levels fall below 7% and this may lead to protein deficiency symptoms on the animal. Elsewhere Blümmel and Parthasarathy (2006) working on economic value of sorghum stover reported crude protein content of all stover types to be well below 7.5%,

the level widely considered as the minimum requirement for rumen microbes to efficiently digest the feed. For example pregnant cows requires from 7 to 9.5% CP depending upon age and weight, while lactating cows, growing calves and yearlings require a higher percentage for maintenance and growth (NRC 1984). This limitation in the tropics occurs more frequently with grasses than legumes since very few tropical legumes have CP values falling below 9% which is considered minimal protein for ruminant requirement (Blümmel and Parthasarathy 2006). Crop residues are generally low in protein and usually require protein supplementation, therefore chemical treatment methods, for crop residues must be carefully weighed for cost effectiveness, if they are to be used successfully in a feeding program.

The higher values of NDF in the present study might have been attributed to the late stage of maturity (hard dough stage) at which samples were collected. As a plant matures the cell wall contents increase as a percent of the total plant cell. Plant cell walls are much less digestible than the other parts of the cell (intracellular contents). Accordingly, as the cell wall component of the cell increases with maturity, digestibility or quality of the forage decreases. Neutral detergent fibre is a general indicator of energy value of a feed (Johnson and deOliveira, 1989). Thus forage with a low NDF or ADF content is higher in quality than one with a high NDF or ADF content. On the other hand NDF is closely associated with total potential intake of the forage by an animal while ADF is more related to digestibility of the forage. Hence, both values are used in predicting forage quality. According to Johnson and deOliveira (1989) feeds with high NDF content (above 70%) have limited energy value. Thus, require energy supplementation to prevent animal weight loss. An NDF range of 55-70% meets only the

maintenance requirements. For adequate lactation and reproductive performance, dietary NDF range of 45-55% is required. Feeds with less than 45% NDF are considered excellent sources of energy (Johnson and deOliveira, 1989). Therefore, the results of the current study for the stems, leaves, panicles, and whole plant of the most varieties fall in the range where forage from these varieties would meet energy requirements for maintenance. Higher fibre concentrations in stems occur in part because stems contain more structural and conducting tissues than say leaves, whereas a large portion of leaves is occupied by thin-walled mesophyll. For efficiency of production needs for supplementation with high energy feed is of paramount importance if forage from these varieties is to be fed as a basal diet.

Lignin content was not significant ($P \geq 0.05$) among the ten sorghum varieties in this study and all the varieties contained low lignin levels and therefore high feed potential. Lignin being the primary indigestible component of plant cell walls, limiting digestion of cell wall carbohydrates in the rumen (Oliver *et al.*, 2004; Ball *et al.*, 2001) then the level obtained in the present study is desirable. Lignin is important in that it gives the plant cell wall its strength and water impermeability (Ball *et al.*, 2001). According to Aydin *et al.* (1999) and also Oliver *et al.* (2004) higher lignin concentration reduces ruminal fibre digestion; it often results in increased ruminoreticular fill, reduced dry matter intake (DMI) and less milk productions. Chemical and genetic approaches have been employed to improve forage fibre digestibility by reducing the amount of lignin or the extent of lignin across linking with cell wall carbohydrates. For instance, brown midrib (BMR) forage genotypes usually contain less lignin and may have altered lignin chemical composition (Vogel and Jung 2001; Oliver *et al.*, 2004). As shown in section 3.4.5.2,

lignin is negatively correlated with IVDMD and positively associated with NDF and ADF thus; lowering the lignin content in the plant increases the overall digestibility of the fibre component of the forage, and thus improving overall quality. One potential negative associated with less lignin content is lodging potential. However, this potential problem can be compensated for with appropriate management practices (Bean and McCollum 2007). It is worth noting that, not all plant fibre is digestible, even if it remains in the rumen for a long time. In mature forage stems, up to two-thirds of the NDF and more than half of the structural polysaccharides may be completely indigestible (Buxton and Casler, 1993). Lignin concentration is closely related to the proportion of indigestible dry matter in forages (Buxton et al., 1996).

The effect of *in vitro* dry matter digestibility is in the determination of nutrient availability to the animal. Thus digestibility provides a measure of feed quality because it indicates the portion that actually can be used by the animal body. The *in vitro* dry matter digestibility of the varieties analyzed in this experiment ranged from 55.92 to 67.29%. This range is above 45% reported by Younguist *et al.* (1990) to be acceptable level to maintain weight and 55% dry matter digestibility to gain 0.5 to 0.6 kg a day for cattle in the tropics. However, all the varieties had lower values than 72.5 and 73.3% recommended by Felix and Funso (1994) working with sheep.

According to Madibela *et al.* (2002) the limitation imposed by higher fibre content is the reduction in dry matter digestibility leading to insufficient intake of energy. Energy availability from forages is limited by fibre concentration because fibre is slowly and incompletely digested, whereas cell solubles are almost completely digestible. Thus, the proportion of fibre to cell solubles is a major determinant of energy availability in

forages. Improvement in, *in vitro* dry matter digestibility is now a priority in many breeding programs. Genetic variation for *in vitro* digestibility and fibre concentration has been shown in many grasses and legumes species (Buxton and Casler, 1993). Improvements in dry matter digestibility can occur from changes in both fibre concentration and fibre digestibility. The most logical way of improving forage digestibility is to reduce fibre concentration. Once the lower limit of fibre for plant growth and survival or for animal health is attained, fibre digestibility will be the remaining limitation to nutrient availability in forages. Also forage digestibility could be improved by reducing the amounts of lignified cells or by developing improved cultivars so that lignified cells are more digestible. It is however, important to note that since the dry matter disappearance were assessed using artificial rumen in the laboratory the values may not truly reflect the true digestibility in the rumen.

# CHAPTER FIVE

## 5.0 CONCLUSIONS AND RECOMMENDATION

### 5.1 Conclusions

The study general objective was to compare the ten dual purpose sorghum varieties for semi-arid areas of Kenya in terms of nutritional composition and dry matter digestibility. Different conclusions can be drawn from the study findings;

1. It is clear from this study that each plant part (leaves, stems and panicles) differed in terms of nutritive value, hence a deduction that animal fed with these part separately will derive the nutrient component at different level. In terms of animal feed the higher the digestibility the better value in nutrient availability and panicles were found to be superior than other parts. On the other hand the varieties had low crude protein.

2. Most varieties and plant parts had met the theoretical requirement level for animal maintenance in terms of IVDMD, NDF and ADF, but the CP levels were not consistently sufficient for minimum ruminant requirement. Thus, most varieties had an acceptable source of energy for ruminants, although their level could be limiting for optimum fermentation *in vivo*. Therefore results in this study suggest that the most rapid way to improve these sorghum varieties for forage would be by improving fibre concentration, fibre digestibility and crude protein contents through suitable breeding programs. Reducing the amount of fibre especially in stems and leaves should be one of the most straightforward methods for improving their digestibility.

3. The combination of various parameters investigated in the present and previous studies have shown varieties IESV99006 DL, IESV92165 DL and SDSL90162-2 to have ability to produce high biomass and grain yield, higher digestibility, crude protein and lower levels of fibre constituents (NDF, ADF and ADL) compared to other varieties. It may be concluded that these varieties would be ranked best suitable to be considered for dual purpose production. Other varieties such as Macia and IESV91131 DL are better considered for grain production.

4. Prior data by ICRISAT scientists indicated NGUUGU to be distinct and ranked first in terms of forage production demonstrated by high biomass yield (44.2t/ha). Though this is a positive attribute, on the other hand NGUUGU was inferior in terms of chemical composition, digestibility and grain yield. Thus for effective productivity, strategies to enhance high grain yield, digestibility and nutritive value need to be incorporated. NGUUGU may also possess greater potential of producing better chemical composition and digestibility if harvested at the right stage of grazing. Therefore greater emphasis being laid on development of forage sorghum as a livestock feed/fodder in dry areas where forage quantity is the major constraint, it may be of more benefit to grow NGUUGU purely as forage sorghum.

5. The results of the present study lead to a conclusion that sorghum crop residues especially those produced in marginal environments have poor nutritional value. Although nutritional supplements can enhance the feed quality of crop residues, they may not provide a long-term solution because of difficulties in adapting them

to local conditions, limited availability and expense. Genetic enhancement of crop-residue nutritional quality is an alternative approach that can naturally, cost-efficiently and permanently improve productivity of crop-livestock systems.

## 5.2 Recommendations

As a result of the findings reported in this study, it is recommended that:

1. Owing to low crude protein contents, to achieve high CP contents in these varieties and others, plant breeder's needs to come up with breeding programmes which attempt to increase the essential amino acid levels in sorghum and genetic modification (GM) of grain producing plants has the potential to overcome some of these problems. Knowledge about the inheritance of specific traits in forage sorghum is also needed to permit the optimal development of breeding strategies for improving traits of investigation in the current study.

2. From the current study stems/stalks recorded low values in term of chemical composition and digestibility. The stalk being the main reservoir for soluble carbohydrate and water then, they require the most modification so as to be used for silage since stems make up the largest portion of the silage.

3. There is great scope to develop dual purpose sorghum with specific adaptation and with fodder emphasis. In a given location, different genotypes can perform differently in terms of nutritive value, yield and yield components. In the present study only three locations were considered and no stability recorded and

therefore, similar study needs to be conducted across agro-ecological zone and seasons because it is important to have food/feed crops that give security in terms of production irrespective of environmental condition.

4. Forage sorghum study should be conducted to determine the effect of fertilization and suitable stage of grazing in relation to biomass production capacity and nutritional value attributes. Further studies to incorporate levels and effect of energy, vitamins, minerals and antinutritive factors of these varieties.

5. The *In vitro* dry matter digestibility analysis is performed *in vitro*, and may therefore not be an accurate reflection of *in-vivo* digestibility in this particular case. Thus, it may be worth performing animal feeding studies with these specific varieties so as to develop a better understanding on their effect on dry matter digestibility, palatability, feed intake, measurement of metabolisable energy and thus visualize practically the extent of digested nutrients and animal performance.

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## 7.0 APPENDICES

**Appendix 1:** Moisture availability zones in Kenya with rainfall and proportion of land

| Agro - Climatic Zone | Classification | Moisture Index (%) | Annual Rainfall (mm) | Land Area (%) |
|---|---|---|---|---|
| I | Humid | >80 | 1100-2700 | |
| II | Sub-humid | 65 - 80 | 1000-1600 | 12 |
| III | Semi-humid | 50 - 65 | 800-1400 | |
| IV | Semi-humid to semi-arid | 40 - 50 | 600-1100 | 5 |
| V | Semi-arid | 25 - 40 | 450-900 | 15 |
| VI | Arid | 15 - 25 | 300-550 | 22 |
| VII | Very arid | <15 | 150-350 | 46 |

**Appendix 2:** Mean biomass yield (t/ha) of the ten sorghum varieties grown in three environments of Kenya

| Varieties | Kambi ya Mawe | Kiboko | Machang'a |
|---|---|---|---|
| IESV91131 DL | 12.6 | 22.5 | 9.3 |
| BTX 623 | 8.7 | 17.1 | 5.4 |
| IESV92089 DL | 8.3 | 23.9 | 6.5 |
| IESV92165 DL | 14.1 | 28.9 | 11.8 |
| IESV99006 DL | 15.5 | 29.7 | 8.2 |
| IESV99027 DL | 9.4 | 27 | 7.5 |
| IESV99095 DL | 12.0 | 22.0 | 8.3 |
| MACIA | 12.5 | 22.0 | 8.1 |
| NGUUGU | 34.7 | 44.2 | 15.9 |
| SDSL90162-2 | 24.9 | 36.1 | 12.0 |

**Source:** ICRISAT – Nairobi

**Appendix 3:** Mean agronomic traits of the ten sorghum varieties

| Varieties | Biomass Yield (t/ha) | Grain Yield (t/ha) | Leaf length (cm) | Leaf width (cm) | Leaf No. | Leaf Sen | No of Tiller | Plant stand | Plant. height (cm) |
|---|---|---|---|---|---|---|---|---|---|
| IESV91131 DL | 14.8 | 3.2 | 80.3 | 9.4 | 10.3 | 2.6 | 0.2 | 24.4 | 125.2 |
| BTX 623 | 10.4 | 2.2 | 71.5 | 7.8 | 10.7 | 2.6 | 0.4 | 16.4 | 132.7 |
| IESV92089 DL | 12.9 | 2.2 | 68.6 | 7.5 | 8.9 | 7.3 | 0.3 | 23.1 | 150.4 |
| IESV92165 DL | 18.3 | 3.2 | 72.2 | 7.4 | 9.0 | 2.8 | 0.4 | 29.8 | 172.0 |
| IESV99006 DL | 17.8 | 3.0 | 80.1 | 7.7 | 8.7 | 3.8 | 0.1 | 30.0 | 176.7 |
| IESV99027 DL | 14.6 | 2.8 | 71.9 | 7.5 | 8.9 | 2.1 | 0.7 | 25.7 | 162.7 |
| IESV99095 DL | 14.1 | 2.6 | 77.1 | 7.7 | 9.8 | 2.3 | 1.6 | 21.2 | 144.5 |
| MACIA | 14.2 | 2.9 | 66.7 | 8.6 | 10.1 | 2.3 | 0.3 | 20.8 | 133.4 |
| NGUUGU | 31.61 | 0.8 | 83.8 | 6.5 | 11.7 | 3.2 | 2.1 | 30.6 | 282.1 |
| SDSL90162-2 | 24.34 | 2.8 | 82.4 | 7.6 | 11.1 | 2.3 | 1.1 | 23.9 | 177.9 |

**Source:** ICRISAT - Nairobi

**Appendix 7:** Correlation observed between IVDMD and chemical components

| | DM | CP | NDF | ADF | ADL | HEMICEL |
|---|---|---|---|---|---|---|
| CP | -0.210 | | | | | |
| NDF | 0.214 | -0.650* | | | | |
| ADF | 0.236 | -0.416 | 0.937** | | | |
| ADL | -0.091 | -0.294 | 0.700* | 0.658 | | |
| HEMI-CEL | -0.075 | -0.575 | 0.572 | 0.291 | 0.563 | |
| IVDMD | -0.172 | 0.513 | 0.90** | -0.940** | -0.706* | -0.285 |

* Correlation is significant at the 0.05 level (2-tailed),
** Correlation is significant at the 0.01 level (2-tailed).

**Appendix 8:** Correlation between IVDMD and chemical components as influenced by plant parts (Panicles, leaves, stems and whole plant)

| | PANICLES | | |
|---|---|---|---|
| **Variables** | **Correlation** | **P - value** | **R - Squared** |
| Crude Protein | 0.617 | 0.057 | 0.391 |
| Neutral Detergent Fibre | -0.812** | 0.004 | 0.659 |
| Acid Detergent Fibre | -0.961** | 0.001 | 0.924 |
| Acid Detergent Lignin | -0.003 | 0.994 | 0.0001 |
| Hemicellulose | -0.267 | 0.456 | 0.071 |

| | LEAVES | | |
|---|---|---|---|
| **Variables** | **Correlation** | **P - value** | **R - Squared** |
| Crude Protein | 0.238 | 0.508 | 0.057 |
| Neutral Detergent Fibre | -0.599 | 0.067 | 0.358 |
| Acid Detergent Fibre | -0.821** | 0.004 | 0.674 |
| Acid Detergent Lignin | -0.413 | 0.235 | 0.171 |
| Hemicellulose | -0.221 | 0.539 | 0.049 |

| | STEMS | | |
|---|---|---|---|
| **Variables** | **Correlation** | **P - value** | **R - Squared** |
| Crude Protein | 0.31 | 0.383 | 0.096 |
| Neutral Detergent Fibre | -0.615 | 0.058 | 0.378 |
| Acid Detergent Fibre | -0.67* | 0.034 | 0.449 |
| Acid Detergent Lignin | -0.524 | 0.12 | 0.275 |
| Hemicellulose | -0.169 | 0.641 | 0.028 |

| | WHOLE PLANT | | |
|---|---|---|---|
| **Variables** | **Correlation** | **P - value** | **R - Squared** |
| Crude Protein | 0 409 | 0.24 | 0.168 |
| Neutral Detergent Fibre | -0.578 | 0.08 | 0.334 |
| Acid Detergent Fibre | -0.653* | 0.041 | 0 426 |
| Acid Detergent Lignin | -0.519 | 0.124 | 0.27 |
| Hemicellulose | 0.013 | 0.971 | 0.0001 |

* Correlation is significant at the 0.05 level (2-tailed)
** Correlation is significant at the 0 01 level (2-tailed)