بسم الله الرحمن الرحيم

Sudan University of Science and Technology

College of Graduate Studies

Characterization of Sudanese Sorghum (Sorghum bicolor L. Moench) Germplasm for Some Morphological and Yield Traits

توصيف موارد وراثية سودانية من الذرة الرفيعة لبعض الصفات المظهرية والانتاجية

By

Ahmed Elhaj Mohammed Ahmed

B.Sc. (Agriculture) Honours

Omdurman Islamic University

2008

A Thesis Submitted to the Sudan University of Science and Technology in Partial Fulfillment of the Requirements for Master Degree in Agriculture

Supervisor

Dr. Nada Babiker Hamza

Department of Agronomy

December,2015

الآية

قال تعالى:

﴿وَاضْرِبْ لَهُمْ مَثَلَ الْحَيَاةِ الدُّنْيَا كَمَاءٍ أَنْزَلْنَاهُ مِنَ السَّمَاءِ فَاخْتَلَطَ بِهِ نَبَاتُ الْأَرْضِ
فَأَصْبَحَ هَشِيمًا تَذْرُوهُ الرِّيَاحُ ۗ وَكَانَ اللَّهُ عَلَىٰ كُلِّ شَيْءٍ مُقْتَدِرًا﴾

(صدق الله العظيم)

سورة الكهف الآية (45)

DEDICATION

This study is dedicated to my lovely mother, my father, my wife, my friends & colleagues.

To all who have been helpful, tolerant and patient and offered me unconditional assistance in performing this task and whom without their great assistance I could have not to accomplish this achievement.

ACKNOWLEDGMENT

This work would not be successful without Allah who guides me in my everyday life. I thank Allah for the good health he has given me, and for the success of my study.

I wish to express deepest gratitude and sincere thanks to my supervisor Dr. Nada Babiker Hamza, for her providing research topic and financing and supervision for the work.

I would like to thank the Agricultural Research Corporation for the support to carry the M.Sc study, also the Plant Genetic Resources Conservation and Research Centre (PGCRC) for providing the sorghum seeds.

My gratitude to all staff members of the department of Agronomy, Faculty of Agricultural Studies, Sudan University of Science and Technology.

My deep thanks and gratefulness to my family for supporting me to complete this work.

Last but never least, I offer my regards and blessings to all of those who supported me in any respect and love during the duration of the project.

CONTENTS

Title **page No.**
الاية.. I
DEDICTION.. II
AKCNOWLEDGMENT.. III
CONTENTS... IV
LIST OF TABLES VII
ENGLISH ABSTRACT... VIII
ARABIC ABSTRACT... IX
CHAPTER ONE 1
INTRODUCTION 1
CHAPTER TWO.. 4
LITERATURE REVIEW 4
2.1.Background of sorghum 4
2.2. Botanical classification of Sorghum 4
2.3. Botanical description of Sorghum 5
2.4. Sorghum types 7
2.5. Chemical composition and nutritional value of sorghum grains 9
2.6. Importance of sorghum 9
2.7. Top ten sorghum producers 10
2.8. Sorghum in the Sudan 10
2.9. The most important varieties of sorghum in Sudan 11
2.10. The current situation of sorghum production in Sudan ... 11
CHAPTER THREE 13
MATERIALS AND METHODS 13
3.1. Location of the experiment 13
3.2. Plant material 13
3.3. Experimental design and management 14
3.4. Data collection 14
3.4.1. Qualitative traits 14
3.4.2. Quantitative traits … 19
3.5. Statistical analyses 20

CHAPTER FOUR 22
RESULTS 22
4.1. Qualitative traits 22
4.1.1. Seedling vigour 22
4.1.2. Leaf midrib colour 22
4.1.3. Inflorescence exsertion 22
4.1.4. Stalk juiciness 22
4.1.5. Juice flavor 23
4.1.6. Inflorescence compactness and shape 23
4.1.7. Glume colour 23
4.1.8. Grain colour 23
4.1.9. Grain covering 23
4.1.10. Shattering 24
4.1.11. Grain sub-coat 24
4.1.12. Grain luster 24
4.1.13. Overall plant aspect 24
4.1.14. Endosperm texture 24
4.1.15. Endosperm colour 25
4.2. Agronomic Traits (Quantitative) 26
4.2.1. Agronomic performance 26
4.2.1.1. Plant height 26
4.2.1.2. Stem diameter 27
4.2.1.3. Number of leaves per plant 27
4.2.1.4. Leaf area index 28
4.2.1.5. Inflorescence length 28
4.2.1.6. Inflorescence width 29
4.2.1.7. 100 seed weight 29
4.2.1.8. Grain number per panicle 29
4.2.1.9. Days to flowering 30
4.2.2. Phenotypic correlations 33
CHAPTER FIVE 34
DISCUSSION 34
5.1. Qualitative traits 34
5.2. Agronomic traits (Quantitative) 35

5.2.1. Agronomic performance ………………………………… 35
5.2.2. Agronomic correlations …………………………….…. 36
CONCLUSION …………………………………………………... 37
REFERENCES …………………………………………………... 38
APPENDICES ……………………………………………………. 42

LIST OF TABLES

Tables	Page No.
Table 3.1 Sorghum accessions used in the study	13
Table 4.1 Categorization of frequency distributions of qualitative characters	25
Table 4.2 Phenotypic variability of some characters of 13 sorghum accessions grown at demonstration farm of the faculty of Agriculture, University of Khartoum in winter, season 2015	31
Table 4.3 Statistical parameters for quantitative characteristics of sorghum	31
Table 4.4 Means for the different quantitative characters for 13 sorghum accessions	32
Table 4.5 Correlation coefficients of agronomic attributes between different quantitative characters	33

ABSTRACT

This study was carried out to assess the variation in morphological and yield traits for 13 sorghum germplasm. A field experiment was executed during winter season of 2015 at the demonstration farm of the faculty of Agriculture, University of Khartoum, Shambat. Sorghum accessions were morpho-agronomically characterized by using the sorghum descriptors lists from the International Board of Plant Genetic Resources, IBPGR/ICRISAT (1993) as reference for the observations. The agronomic performance of the accessions was evaluated in regular field experiment with two replications. The results obtained from this study showed that phenotypic variation was detectable for all qualitative characters studied (descriptors). Frequency of occurrence of the different descriptor states varied between rare (<20%), moderate (20% - 60%), common (61% - 90%) and abundant (>90%). A highly significant difference among accessions for all of the studied traits was revealed. Days to flowering, plant height, stem diameter, leaf area, inflorescence length, 100 seed weight and grain number per panicle showed wide variation. While, the inflorescence width and number of leaves per plant showed a little significant differences . Plant height was significant and positively correlated with the Inflorescence length, but significant and negatively correlated with 100 seed weight. The stem diameter was significant and positively correlated with the Inflorescence width, leaf area , grain number per panicle and days to flowering. Moreover, leaf area had significant and positive correlation coefficients with grain number per panicle and days to flowering. The Inflorescence length was significant and positively correlated to the grain number per panicle, but negatively correlated to 100 seed weight. Also the Inflorescence width was significant and positively correlated with days to flowering .While the number of leaves was negatively correlated to 100 seed weight. Also the 100 seed weight was negatively correlated to grain number per panicle. It is concluded that sorghum in Sudan contain high genetic variations in wide spectrum of quantitative and qualitative parameters. Such variations can be very useful to increase the efficiency of sorghum breeding and improvement programs. It is also important to continue conservation of Sudan sorghum germplasm.

الخلاصة

اجريت التجربة لدراسة التباين المظهري لثلاثة عشر مورد وراثي من الذرة السودانية. وقد تمت زراعة التجربة في الموسم الشتوي 2015 بالمزرعة التجريبية- كلية الزراعة جامعة الخرطوم، شمبات. تم تقييم التوصيف المظهري لمداخيل الذرة في تجربة حقلية وذلك باستخدام قوائم المجلس الدولية للموارد الوراثية النباتية لتوصيف الذرة (IBPGR, 1993). وتم تقييم الاداء المظهري للمداخيل في تجربة حقلية باستخدام مكررين. النتائج المتحصل عليها من الدراسة اظهرت وجود تباين ظاهري في كل الصفات النوعية. تكرار الحدوث لحالات الصفات المختلفة تنوعت ما بين نادرة (<20%)، متوسط الحدوث (20% 60%)- ، شائعة الحدوث (61% - 90%) وغزيرة الحدوث (>90%). وكشف تحليل التباين اختلافات كبيرة جدا بين المداخيل لجميع الصفات مما يدل علي ان هناك درجة عالية من التنوع المظهري بين المداخيل لكل من عدد الايام حتي الازهار، طول النبات، قطر الساق، مساحة الورقة، طول القندول، وزن المائة حبة، عدد البذور في القندول . بينما اظهر عرض القندول وعدد الاوراق في النبات اقل نطاق من التباين المظهري.اظهر طول النبات ارتباطا موجبا بطول القندول وسالبا بوزن المائة حبة. كما اظهر قطر الساق ارتباطا موجبا بكل من مساحة الورقة، عرض القندول،عدد البذور في القندول و عدد الايام حتي الازهار. مساحة الورقة اظهر ايضا ارتباطا موجبا بعدد البذورفي القندول وعدد الايام حتي الازهار. طول القندول اظهارارتباطا موجبا بعدد البذور في القندول. عرض القندول اظهر ارتباطا موجبا بعدد الايام حتي الازهار. اظهر ايضا وزن المائة حبة ارتباطا سالبا بعدد البذور في القندول. وقد استنتجت الدراسة ان الذرة الرفيعة في السودان تحتوي علي قدر عالي من التباين الوراثي. هذا التباين يمكن ان يستخدم لزيادة الكفاءة في برامج تربية وتطوير الذرة. ومن الاهمية ايضا المحافظة علي المصادر الوراثية القيمة للذرة الرفيعة في السودان.

CHAPTER ONE

INTODUCTION

Sorghum (*Sorghum bicolor* (L.) Moench) 2n=20. belongs to *Andropogoneae* tribe of the *Poaceae* family (FAO, 1995). It is a self pollinated crop (Idris and Mohammed, 2012). It ranks fifth cereal worldwide after Wheat (*Triticum spp*), Rice (*Oryza spp*), Maize (*Zea mays*) and barley (*Hordeum vulgdre*) in terms of production (FAO, 2010). It was first domesticated in the region of North East Africa (Doggett, 1988). It is a staple food crop of millions people of poor in semi-arid tropics (SAT) of the world. It is mostly grown as a subsistence dry land crop by resource limited farmers under traditional management conditions in SAT regions of the Africa, Asia and Latin America (FAO, 1995). Besides being a staple food crop in the semi-arid regions of the world, sorghum is also used for feed, traditional beverages, fuel, construction material, confection (sweet sorghums), brooms, as well as for making sugar, syrup and molasses (Doggett and Rao, 1995; Duncan, 1996). In addition to cultivated sorghum, there is a number of wild and weed sorghum species. Taxonomically , It is classified into five races such as : Kafir ,Guinea, Caudatum , Dura and Bicolor (Romain and Raemaekers, 2001). This crop is adapted to a wider range of ecological conditions. It is typically cultivated in the tropical, sub-tropical and temperate regions of the world generally in those dry areas with low soil moisture that are not suitable for maize cultivation (ICRISAT and FAO, 1995). It is planted in areas considered to be too dry and hot for other cereals, because of its tolerance to drought and heat stress (Poehlman, 1987). India, Nigeria and Sudan grows the largest acreage of sorghum in the world and the USA is the top producer of Sorghum with a harvest of 9.7 million tons (FAO STAT, 2010).

In Africa it comes second after maize in terms of production (Romain and Raemaekers ,2001). In tropical Africa most sorghum is grown for home consumption. In southern and eastern Africa malting sorghum for beer brewing has developed into a large-scale commercial industry, using about 150,000 t of sorghum grain annually, according to FAO (2010).

In the Sudan, sorghum is the main staple food crop. It ranks first in both total of acreage cultivated and total tonnage of grain consumed (FAO, 2001). In Sudan the first sorghum improvement varieties program started in mid-fifties, as conventional methods such as introduction, hybridization and selection were used. A large number of accessions from the local germplasm were screened for morphological adaptations mainly earliness. The screened lines were further evaluated for yield and yield components, the drought tolerant genotypes released earlier include, (Tozi Um Binien-7, TUB-11, TUB-22 and Fet.Matoug. These varieties are now out of cultivation due to their low yield potential and poor grain quality. Late in the 20th century many open pollinated crop varieties such Ingaz, Tabat, Wad Ahmed and Mugaawim Buda. Hybrids, Hageen Dura-1 (HD-1), Rabih and sheikan were released for irrigated sector and high rain-fall areas (Ibrahim and Mahmoud, 1992). Whereas, Yaruasha and Aroos ELrimal were released for dry area in kordofan and darfur. Recently two early maturing varieties, Bashayer and Butana were released for low rain-fall areas (ELzain, 2008). In Sudan the area under irrigated schemes is about 8% while 92% under rain-fed (Fedlelmula, 2009).The national average grain yield is about 539 kg/ha, which is very low compared with that of the world (1278kg/ha). Grain yield per unit area is extremely low both in the rain-fed and irrigated sector compared with yield obtained in the countries such as USA, Australia and South Africa (Mohammed, 1998).

In Sudan the crop is fully utilized ,the grain is ground into flour which is fermented and used for making local bread (Kissra) it also used as porridge, soft drink called (Abrieh). The stalk is used as building material and as animal feed or as fuel (Elzain and Elasha, 2005).

The objectives of this study were to:-

1- Assess the variation in morphology and yield traits for the 13 studied sorghum germplasm collected from five regions in Sudan.
2- Estimate the interrelation between the studied characters.

CHAPTER TWO

LITERATURE REVIEW

2.1 Background of sorghum

Sorghum has been domesticated since approximately 3000 years B.C. in the Ethiopian region (Ayana and bekele, 1998), and part of Congo, with secondary centre of origin in India, Sudan and Nigeria, where it is mainly used for human food (Esperance, 2009). The crop is found in tropical and subtropical countries of the world. Sorghum is the fifth cereal grown worldwide in terms of both production and area planted (FAO, 2004). Several studies on sorghum have concluded that it can successfully survive in semi-arid areas, which are too dry or too hot for maize. It is waxy leaves that curl during moisture stress help the plant to be more drought tolerant. In addition to tolerating natural stress, temperature and water stress, the crop adapts well to varied soil types and toxicities. These factors affecting in sorghum and make it an ideal crop for growing in stressfull environments (Medraoui *et al*, 2007).

2.2 Botanical classification of sorghum

Sorghum (*Sorghum bicolor* (L.) Moench) belongs to the tribe *Andropogonae* of the grass family *Poaceae* . Sugar cane, *Saccharum officinarum*, is a member of this tribe and a close relative of sorghum. The genus sorghum is characterized by spikelets borne in pairs. In 1753 Linnaeus described in his Species plantarum three species of cultivated sorghum; *Holcus sorghum, Holcus sacaratus* and *Holcus bicolor*. In 1794 Moench distinguished the genus sorghum from the genus *Holcus*, and in 1805 Person suggested the name *Sorghum vulgare* for Holcus sorghum (L). in 1961 Clayton proposed the name *Sorghum bicolor* (L.) Moench as the correct name for cultivated sorghum and this is currently being used. The classification of sorghum by Snowden (1936) is detailed and completed. Other classification proposed since that time have been modifications or adaptations of the Snowden system. Harlan and de Wet (1972) published a simplified classification of sorghum which has been checked against 10000 head samples. They divided cultivated sorghum into five basic groups or races; bicolor, guinea, caudatum, kafir and durra. The wild type and shatter cane are considered two other spikelet types of *S. bicolor*. A study of polymorphism of 11enzymes permitted classification of sorghum into three enzymatic groups. The first includes mainly guinea varieties of West Africa; the second southern African varieties of all five races; and the third durra and caudatum types of Central and East Africa (Ollitrault, Escoute and Noyer, 1989). The cultivated sorghum of the present arose from a wild progenitor belonging to the subspecies *verticilliforum*. The greatest variation in the genus *Sorghum* is observed in the region of the north east quadrant of Africa comprising Ethiopia, the Sudan and East Africa (Doggett, 1988).

2.3 Botanical description of sorghum

Morphological features and growth of *Sorghum bicolor* have been described by many researchers (Harlan and de Wet,1972; Doggett, 1988; House,1995 and others) .

Stem

Stem of sorghum like those of corn are oval in shape and have a pronounced groove or indentation. Sorghum tillers much more than corn and stem height and thin, depending on the type and cultivar, ranges from 2 feet to more than 12 feet (0.6 - 3.6 m) Harlan and de Wet (1972).

Leaves

The sorghum has wide leaves, quite similar to those of corn, but it is readily distinguished from corn by the toothed margins of the leaves (Chapman and Carter, 2000).

Inflorescence (panicle)

The inflorescence of a sorghum plant is a panicle. It may be either compact or loosely branched. In either case, two spikelets, each having a single floret, are borne on each branch. The sessile spikelet bears a fertile floret, whereas the floret in the pedicellate spikelet is either sterile or staminate (Chapman and Carter, 2000).

Flower

The flowering occurs prior to sunrise and extended up to mid-day, the blooming starts from tip of the panicle in downward direction. The stigma is receptive before flowering and remains receptive for 6 to 8 days. Pollens are viable for few hours and fertilization is completed within 2 to 4 hours of pollination.

Seed

The grain (seed) of sorghum show considerable diversity in colour, shape, size and certain anatomical components, the principal colours of sorghum grains are white, red brown, orange and yellow with a range of intermediate colours (ICRISAT,2008). The principal anatomical components are pericarp, endosperm and germ or embryo (Hubbard, Hall and Earle, 1950). Grain is partially covered with glumes. Large grains with corneous endosperm are usually preferred for human consumption. Yellow endosperm with carotene and xanthophylls increases the nutritive value. Sorghum grain that has a testa contains tannin in varying proportions depending on the variety (Purseglove, 1972).

Pericarp

Pericarp is the outermost structural of the caryopsis and is composed of three sub-layer, namely epicarp, mesocarp and endocarp. The epicarp is further divided into epidermis and hypodermis. In the sorghum caryopsis, the epidermis is composed of thick, elongated, rectangular cells which have a coating of cut in on the outer surface. Often a pigment is present in the epidermis. The hypodermis is composed of slightly smaller cells than the epidermis and is one to three cell layers in thickness. The mesocarp, the middle part, is the thickest layer of the sorghum pericarp, but its thickness varies widely among genotype. Mould resistance in sorghum is associated with thin mesocarp. Grains with thick mesocarp on a hard endosperm are preferred for dehulling by hand-pounding. The endocarp, the innermost sublayer of the pericarp, consists of cross cells and a layer of tube cells which transport moisture into the kernel (FAO,1995)

Seed-coat (testa)

Just underneath the endocarp is the testa layer or seed-coat. In some sorghum genotypes the testa is highly pigmented. The presence of pigment and the colour are genetic character. The thickness of the testa layer is not uniform. It is thick near the crown area of the kernel and thin near the embryo portion. In some genotypes there is a partial testa, while in others it is not apparent or is absent (Chandrashekar and Kirleieis, 1988).

Endosperm

The largest component of the cereal kernel is the endosperm, which is a major storage tissue. It is composed of an aleurone layer and peripheral corneous and floury zones. In sorghum the aleurone layer is a single layer of cells which lies just below the seed-coat or testa. The aleurone cells are rich in minerals, B-complex vitamins and oil and contain some hydrolyzing enzymes. The peripheral endosperm is distinguished by long rectangular cells which are densely packed and contain starch granules and protin bodies enmeshed in the protein matrix. The starch in these cells is therefore not easily available for enzyme digestion, unless the protein associated with is also reduced (Chandrashekar and Kirleieis, 1988).

Germ

The embryonic axis and the scutellum are the two major parts of the germ. The scutellum is a storage tissue rich in lipids, protein, enzymes and minerals. The oil in the sorghum germ is rich in polyunsaturated fatty acids and is similar to corn oil (Rooney, 1978).

2.4 Sorghum types

Harlan and de Wet (1972) recognized 15 races of *Sorghum bicolor*, 5 primary races (bicolor, guinea, caudatum, kafir and durra) and 10 intermediate races originating from the 10 possible hybrid combination among the primary races (guinea-bicolor, caudatum-bicolor, kafir-bicolor, durra-bicolor, guinea-caudatum, guinea-kafir, guinea-durra, kafir-caudatum, durra-caudatum, kafir-durra).

The five primary races of *Sorghum bicolor* are identified as the following:

1- **Bicolor race :** It contains several sub-races, primarily sorgos (sweet sorghums), broom corn and Sudan grass. The most primitive cultivated sorghum, characterized by open inflorescences and long clasping glumes that enclose the usually small grain at maturity. Cultivars are grown in Africa and Asia, some for their sweet stems to make syrup or molasses, others for their bitter grains used to flavour sorghum beer, but they are rarely important. They are frequently found in wet conditions.
2- **Guinea race:** It is characterized by usually large, open inflorescences with branches often pendulous at maturity; the grain is typically flattened and twisted obliquely between long gaping glumes at maturity. Guinea sorghum occurs primarily in West Africa, but it is also grown along the East African rift from Malawi to Swaziland and it has also spread to India and the coastal areas of South-East Asia. Many subgroups can be distinguished, e.g. with cultivars especially adapted to high or low rainfall regimes. In the past the grain was often used as ship's provisions because it stored well.
3- **Caudatum race:** It is consists of feterita and hegari types. characterized by turtle-backed grains that are flat on one side and curved on the other; the panicle shape is variable and the glumes are usually much shorter than the grain. Cultivars are widely grown in north-eastern Nigeria, Chad, Sudan and Uganda. The types used for dyeing also belong here and are known as 'karan dafi' by the Hausa people in Nigeria.
4- **Kafir race:** It is characterized by relatively compact panicles that are often cylindrical in shape, elliptical sessile spikelets and tightly clasping glumes that are usually much shorter than the grain. Kafir sorghum is an important staple across the eastern and southern savanna from Tanzania to South Africa. Kafir landraces tend to be

insensitive to photoperiod and most commercially important male-sterile lines are derived from kafir type sorghum.

5- **Durra race :** It is characterized by compact inflorescences, characteristically flattened sessile spikelets, and creased lower glumes; the grain is often spherical. Cultivars are widely grown along the fringes of the southern Sahara, western Asia and parts of India. The durra type is predominant in Ethiopia and in the Nile valley in Sudan and Egypt. It is the most specialized and highly evolved of all races and many useful genes are found in this type. Durra cultivars range in maturity from long to short-season. Most of them are drought resistant (includes the variety milos).

2.5 Chemical composition and nutritive value of sorghum grains

The main components of whole grain sorghum is carbohydrates, protein and lipids. Lesser quantities of fiber, vitamins and minerals are also present. The mean nutrient composition of sorghum and various other cereals is (moisture 12%; protein 10.4g; fat 3.4g; energy 1468 joules; carbohydrate 71g; fiber 2g; calcium 32mg; iron 4.5mg; thiamine 0.50mg; riboflavin 0.12mg; niacin 2mg. The nutrient composition is influenced both by environment and genetics, although the most common sources of variation are factors such as soil fertility, soil moisture and cultural practices. Sorghum has naked caryopses (hulls). In sorghum lysine is the primary limiting amino-acid. In most sorghum the amylose content is reported to range from 20-30 per cent (Hulse *et al*, 1980) .

2.6 Importance of sorghum

According to Medraoui *et al* (2007), sorghum is more drought tolerant. In addition to tolerating natural stress, temperature and water stress, the crop adapts well to varied soil types and toxicities. These factors make sorghum an ideal crop for growing in stressful environments.

FAO (1988) reported that, sorghum is used for two distinct purpose; human food and animal feed. Although in the early 1960s a very large part of the sorghum output was used directly as human food, its share has continuously declined since then. In fact consumption of sorghum as animal feed has more than doubled, from 30 to 60 percent, since the early 1960s, while the volume of total food use has remained unchanged or has slightly declined. In North and Central America, South America and Oceania most of the sorghum produced is used for animal feed. in USA and Australia people mainly used sorghum as animal feed and more recently with research on bio-energy products, sorghum is a multipurpose crop for food, fodder and fuel.

2.7 Top ten sorghum producers

Sorghum grown as a subsistence dry land crop by resource limited farmers under traditional management conditions in SAT regions of the Africa, Asia and Latin America, (FAO, 1995; ICRISAT, 2004; Nadia *et al*., 2009). The top ten producers of sorghum in world are United states of America, Nigeria, India, Mexico, Sudan, Australia, Argentina, China, Ethiopia, Brazil. The USA is the top producer of Sorghum with a harvest 9.7 million tons (FAO STAT, 2010).

2.8 Sorghum in the Sudan

Sudan located within the geographical range where sorghum is believed to be domesticated for the first time and where the largest genetic variation for both cultivated and wild sorghum is found. A large collection of Sudanese landraces from different parts of Sudan was collected and conservet at the ARC Gene bank. Today this collection is amount to more than 4900 accessions (personal communicate with Dr. Awad Alkareem).

Sorghum improvement in Sudan was started in mid-fifties, and conventional methods such as introduction, hybridization and selection were used. A large number of accessions from the local germplasm were screened for morphological adaptations mainly earliness. The screened lines were further evaluated for yield and yield components (Ibrahim and Mahmoud, 1992). In Sudan the area under irrigated schemes is about 8% while 92% under rain fed (Fedlelmula, 2009).The national average grain yield is about 539 kg/ha, which is very low compared with that of the world (1278kg/ha) grain yield per unit area is extremely low both in the rain-fed and irrigated sector compared with yield obtained in the countries such as USA, Australia and South Africa (Mohammed, 1998).

According to (Elzain and Elasha, 2005) the main groups of food prepared from sorghum in Sudan include :

Unfermented breads :	Aceda
Fermented breads :	Kissra
Stiff porridge:	Aceda
Thin porridge :	Nasha
Alcoholic beverages:	Marissa
Non-alcoholic beverages:	Abreh

2.9 The most important varieties of sorghum in Sudan

There are many varieties released. In irrigated areas, most common sorghum varieties that are cultivated are Tabat and Wad Ahmed due to better grain yield and late than the other varieties. Whereas, in the rain-fed areas, varieties are Arffagadamak-8 (AG-8) Bashayer and Butana due to early maturity and drought tolerance (Ibrahim and Mahmoud, 1992; Elzain *et al*, 2008).

2.10 The current situation of sorghum production in Sudan

In the Sudan sorghum is grown throughout the country in all agricultural sub-sectors (irrigated, rain-fed mechanized and traditional) from June to October. The rain-fed produces 92% and only 8% of sorghum is produced in the irrigated sector . sorghum is grown annually in an area ranging between 4.3 to 7.1 million hectares (Elamin and Elzain, 2006). In Sudan despite of the large areas cultivated annually with sorghum food shortage may occur. This is mainly due to low productivity which is caused by many factors such as low and erratic rainfall, striga stress, pest and diseases, poor adaptation of improved and lack of high yielding hybrids (Elzain, 2008). The national average grain yield reported is about 539kg/ha which is very low compared to the world average of 1278kg/ha.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Location of the experiment

The experiment was conducted in the winter season 2015 at the demonstration farm of the Faculty of Agriculture, University of Khartoum, Shambat. It is located latitude15° 40́N, longitude 32° 32́ E and 380 meters above the sea level. The soil at Shambat site is heavy clay with pH 8.5. Shambat climate is semi arid.

3.2 Plant material

The plant materials (seeds) used in the experiment consisted of 13 accessions of sorghum obtained from Plant Genetic Resources Conservation and Research Centre (PGCRC) of the Agricultural Research Corporation (ARC) Wad Medani, Sudan. These accessions were collected from five different regions in Sudan, (West Darfur, South Kordofan, North Kordofan, Blue Nile and White Nile). The list of these accessions are shown in table 3.1.

3.3 Experimental design and management

The experiment was laid out in a randomized complete block design (RCBD) with two replicates. The land was disc plough, disc harrow, then leveled and ridged. Plot size was 4 rows, 4 meters long. Plants were spaced 20 cm between holes and 80 cm between ridges. The plots were watered before sowing to ensure fine seed bed. Seeds were sown at the rate of four seeds per hole, then thinned to two plants. Sowing date was in 8 of February 2015. Irrigation was applied every 10 to 12 days. Nitrogen fertilizer (urea) was applied as one dose (80kg/fed) on third of March 2015. Weed population was kept at minimum by hand weeding .

Table 3.1: List of sorghum germplasm accessions used in the study and collected from five regions in Sudan

No.	Accession	Region	Source
1	HSD 5657	West Darfur	ARC/Sudan
2	HSD 3231	West Darfur	ARC/Sudan
3	HSD 10033	South Kordofan	ARC/Sudan
4	HSD 6425	South Kordofan	ARC/Sudan
5	HSD 4724	South Kordofan	ARC/Sudan
6	HSD 8176	Blue Nile	ARC/Sudan
7	HSD 5612	Blue Nile	ARC/Sudan
8	HSD 3255	Blue Nile	ARC/Sudan
9	HSD 6378	White Nile	ARC/Sudan
10	HSD 5611	White Nile	ARC/Sudan
11	HSD 4022	White Nile	ARC/Sudan
12	HSD 6444	North Kordofan	ARC/Sudan
13	HSD 6029	North Kordofan	ARC/Sudan

3.4 Data collection

Scoring of phenotypic characters was done on five randomly selected plants in the middle of the ridge. Two categories of data were recorded, one group contained 15 qualitative data while, the second contained the nine quantitative data. The characters measured following the sorghum descriptors lists from the International Board of Plant Genetic Resources, IBPGR/ICRISAT (1993).

3-4-1 Qualitative traits:

3.4.1.1 Seedling vigour (SV)

The seedling vigour observed 15 days after emergence and were assessed into three classes :

3 Low

5 Intermediate

7 High

3.4.1.2 Stalk juiciness (SJ)

The stalk juiciness scoring was done at the fifth internode of the stalk at plant maturity stage and was divided into:

0 not juicy (dry)

+ juicy

3.4.1.3 Juice flavour (JV)

The juice flavour taken at maturity from the base of the main stalk and was classified into two classes as follows:

1 Sweet

2 Insipid

3.4.1.4 Leaf midrib colour (MC)

The leaf midrib colour was assessed at plant flowering stage on any of the fully bloomed leaves and divided into six classes as follows:

1 White

2 Dull green

3 Yellow

4 Brown

5 Purple

6 Other

3.4.1.5 Inflorescence compactness and shape(ICS)

The inflorescence compactness and shape was assessed into 13 classes according to the descriptor as follows:

1 Very lax panicle (typical of wild sorghum)

2 Very loose erect primary branches

3 Very loose drooping primary branches

4 Loose erect primary branches

5 Loose drooping primary branches

6 Semi-loose erect primary branches

7 Semi-loose drooping primary branches

8 Semi-compact elliptic

9 Compact elliptic

10 Compact oval

11 Half broom corn

12 Broom corn

13 Other

3.4.1.6 Glume colour(GLC)

The glume colour was assessed at maturity stage and was divided into eight classes as follows**:**

1 White

2 Sienna

3 Mahogany

4 Red

5 Purple

6 Black

7 Grey

8- Other

3.4.1.7 Grain covering(CRC):

The grain covered by the glumes was estimated into five classes at maturity stage

1 25% grain covered

3 50% grain covered

5 75% grain covered

7 Grain fully covered

9 Glume longer than grain

3.4.1.8 Shattering (SH)

The shattering (the way grains are easily or difficultly removed from the panicle) character was scored immediately after maturity into five classes:

1 Very low

3 Low

5 Intermediate

7 High

9 Very high

3.4.1.9 Inflorescence exsertion (IE)

The inflorescence exsertion was assessed into four classes as follows:

1 Slightly exserted (<2cm but ligule of flag leaf definitively below inflorescence base)

2 Exserted (2-10cm between ligule and inflorescence base)

3 Well-exserted (>10cm between ligule and inflorescence base)

4 Peduncle recurved (inflorescence below ligule and clearly exposed splitting the leaf sheath)

3.4.1.10 Overall plant aspect (PA)

The overall plant aspect indicated the overall agronomic desirability of the accession and was assessed into three classes as follows:

3 Poor

5 Medium

7 Good

3.4.1.11 Grain colour (GRC)

The grain colour was assessed at maturity stage and colour codes found in the sorghum descriptor was used to identify the grain colour six classes as follows:

1 White

2 Yellow

3 Red

4 Brown

5 Buff

6 Other

3.4.1.12 Grain luster (GRL)

The grain luster was assessed into two classes at maturity stage:

0 Absent

+ Present

3.4.1.13 Grain sub-coat (GRS)

The grain sub-coat was assessed at physiological maturity by scratching the outer seed cover and scored as absent or present.

0 Absent

+ Present

3.4.1.14 Endosperm texture (ET)

The endosperm texture divided into five classes and was assessed at maturity stage:

1 Completely corneous

3 Mostly corneous

5 Intermediate

7 Mostly starchy

9 Completely starchy

3.4.1.15 Endosperm colour (EC)

The endosperm colour 2 classes was assessed at maturity stage and divided into two classes as follows:

1 White

2 Yellow

3.4.2 Quantitative traits:

3.4.2.1 Plant height(PH/cm)

The plant height was measured in cm at plant physiological maturity. The measurements of five plants randomly selected were taken from the base of the plant to the tip of the head.

3.4.2.2 Inflorescence length (IL/cm)

The inflorescence length, measured in cm from the base to the tip of the head as mean of five randomly selected plants

3.4.2.3 Inflorescence width (IW/cm)

The inflorescence width measured in cm at the wider part of the panicle as a mean of five randomly selected plants.

3.4.2.4 Days to flowering (DF)

The number of days to 50 percent flowering was counted from emergence (five to ten days after sowing) until 50 percent of the plants had started flowering.

3.4.2.5 Stem diameter (SD)

The stem diameter was measured after heading as an average of five random selected plants .

3.4.2.6 Leaf area (LA)

The leaf area was measured after heading from leaf number four (from five random selected plants). Calculated using the formula; {Maximum leaf length (cm) × Maximum leaf breadth (cm) × 0.75 }(Ali *et al*., 2006)

3.4.2.7 Number of leaves per plant (NL)

The number of leaves per plant counted after heading as an average number of leaves from five randomly selected plants.

3.4.2.8 100-seed weight (SW)

The weight in g of 100 seeds was assessed at physiological maturity when the seeds were at approximately 12 percent of moisture content.

3.4.2.9 Grain number per panicle (GRN)

The grain number per panicle counted as an average of seeds from five panicles in the plot.

3.5 Statistical analysis

Before analysis of variance, the overall data set was divided to two groups. Group one contained qualitative and group two quantitative data. Excel program was used for all data entry. Also, it was used for analysis of qualitative data. Analysis of variance was carried out on data collected using MSTAT-C computer package to detect differences among the means compared by Duncan's Multiple Range Test (DMRT) at significance level 0.05. Descriptive statistics : mean value, coefficient of variation obtained from ANOVA, analysis were used to compare the level of characters variation between accessions involved in this study. The mean values for all the characters was used to calculate correlation coefficients.

Coefficient of variation (C.V) for each character was determined according to the following formula.

$$C.V. = \frac{\sqrt{(\text{MSE})}}{(G)} \times 100$$

Where:

MSE = mean square of error

G = grand mean

CHAPTER FOUR

RESULTS

Results were categorized into two main groups, the first group included qualitative traits and the second group included quantitative traits.

4.1 Qualitative traits

Description of sorghum accessions

The frequency of distribution for the 15 qualitative descriptors among the 13 sorghum accessions, frequency of occurrence of such states varied between rarely occurring to abundantly as presented in table (4.1).

4.1.1 Seedling vigour

Low and intermediate descriptor states were observed. These descriptor states were distributed between medium and common level of occurrence. The seedling vigour in low was categorized moderate 23.08% and intermediate was categorized common 76.92% (Table 4-1).

4.1.2 Leaf midrib colour

White and dull green descriptor states were observed. These descriptor states were distributed between rare and common level occurrence. White colours was dominant it had recorded 84.62% and dull green15.38% (Table 4-1)

4.1.3 Inflorescence exsertion

Slightly exserted, exserted and well-exserted descriptor states were observed. These descriptor states were distributed between rare, moderate and common level of occurrence as 15.38%, 23.08% and 61.54%, respectively of all accessions table (4-1).

4.1.4 Stalk juiciness

Dry and juicy descriptor states were observed. These descriptor states were distributed on moderate level occurrence only. Dry stalk had recorded 46.15% and juicy stalk had recorded 53.85% table (4-1).

4.1.5 Juice flavor:

Sweet and insipid descriptor states were observed. These descriptor states were distributed between moderate and common level occurrence. The juice flavor sweet was categorized as 30.77%, and insipid was categorized as 69.23% (Table 4-1).

4.1.6 Inflorescence compactness and shape

In this study observed four shape for Inflorescence compactness and shape was distributed between rarely occurring to common occurring, ranged between Loose drooping primary branches (7.69%), Semi-loose erect primary branches (7.69%),Semi-compact elliptic (15.38%) and Compact elliptic (69.23%) table (4-1).

4.1.7 Glume colour

Four colours were recorded with glume colour. Those colour were sienna, red, white and black. Sienna (7.69%) and red (7.69%) were rare descriptor states. Glume with white (30.77%) and black (53.85%) colours were moderate (Table 4-1).

4.1.8 Grain colour

In this collection , the dominant grain colours of accessions were white (84.62%), yellow (7.69%) and buff (7.69%) table (4-1).

4.1.9 Grain covering

The result obtained with regard to grain covering distributed between rare and moderate. More than 15.38% was recorded for 75% grain covered, 15.38% for fully covered and they were rare while 25% grain covered recorded 23.08% and 50% grain covered was 46.15% and they were moderate (Table 4-1).

4.1.10 Shattering

Intermediate, low and very low descriptor states were observed. These descriptor states were distributed between rare and common level occurrence. Rare, moderate and common recorded 61.54%, 30.77% and 7.69%, respectively of all accessions (Table 4-1).

4.1.11 Grain sub-coat

The result obtained with regard to grain sub-coat distributed between rare and common. Absent and present recorded 11.54% and 88.46%, respectively of all accessions (Table 4-1).

4.1.12 Grain luster

The result obtained with regard to grain luster distributed between rare and abundant. Present (7.69%) and absent (92.31%) of all accessions (Table 4-1).

4.1.13 Overall plant aspect

Poor and intermediate descriptor states were observed. These descriptor states were distributed between moderate and common level occurrence. Moderate (23.08%) and common (76.92%) of all accessions (Table 4-1).

4.1.14 Endosperm texture

Completely starchy (26.92%) Mostly starchy (30.77%) Intermediate (34.61%) Mostly corneous (7.69%) mostly corneous descriptor states were observed. Those descriptor states were distributed between rare and moderate. Mostly corneous (7.69%) was rare and completely starchy (26.92%), mostly starchy (30.77%) and intermediate (34.61%) were moderate (Table 4-1).

4.1.15 Endosperm colour

White and yellow descriptor states were observed. Those descriptor states were distributed between rare and abundant level of occurrence. White colour was dominant (92.31%) and yellow was rare (7.69%) (Table 4-1).

Table 4.1. Categorization of frequency distributions of 15 qualitative characters studied

Descriptor	Frequency level			
	Rare >20%	moderate 20% - 60%	Common 61% - 90%	Abundant <90%
SV		low (23.08%)	Intermediate %(76.92)	
MC	Dull green (15.38%)		White (84.62%)	
IE	Slightly exserted (15.38%)	Exserted (23.08%)	Well-exserted (61.54%)	
SJ		Dry (46.15%) Juicy (53.85%)		
JV		Sweet (30.77%)	Insipid (69.23%)	
ICS	Loose drooping primary branches (7.69%) Semi-loose erect primary branches (7.69%) Semi-compact elliptic (15.38%)		Compact elliptic (69.23%)	
GRC	Red (7.69%) Buff (7.69%)		White (84.62%)	
GRS	Absent (11.54%)		Present (88.46%)	
GRL	Present (7.69%)			Absent (92.31%)
GLC	Sienna (7.69%) Red (7.69%)	White (30.77%) Black (53.85%)		
CRC	75% grain covered (15.38%) Grain fully covered (15.38%)	25% grain covered (23.08%) 50% grain covered (46.15%)		
SH	Intermediate (7.69%)	Low (30.77%)	Very low (61.54%)	
ET	Mostly corneous (7.69%)	Completely starchy (26.92%)		

		Mostly starchy (30.77%) Intermediate (34.61%)		
EC	Yellow (7.69%)			White (92.31%)
PA		Poor (23.08%)	Intermediate (76.92%)	

Seedling vigour (SV); Leaf midrib colour (MC); Stalk juiciness (SJ); Juice flavor (JV); Inflorescence exsertion (IE); Inflorescence compactness and shape (ICS); Glume colour (GLC); Grain colour (GRC); Grain covering (CRC); Shattering (SH); Grain sub-coat (GRS); Grain luster (GRL); Overall plant aspect (PA); Endosperm texture (ET); Endosperm colour (EC).

4.2 Agronomic Traits (Quantitative)

4.;2.1 Agronomic performance

This study on morphological characterization of the 13 sorghum revealed significant differences for all accessions concerning Days to flowering (DF); Plant height (PH); Inflorescence length (IL); Inflorescence width (IW); Stem diameter (SD); Number of leaves per plant (NL); Leaf area (LA); Grain number per panicle (GRN) and 100 seed weight (SW) (Table 4.2).

4.2.1.1 Days to flowering (days)

Days to 50% heading serve as a useful criterion for determining the maturity range of the genotypes. Performance of the genotypes for this trait depicted low variation. Means for days to 50% flowering among the genotypes ranged from 46 to 56 days(Table 4.3). Accession HSD5657 took minimum days (46 days) to reach 50 % maturity, followed by HSD 6029 (49 days). Germplasm accessions HSD 4724 and HSD 5611 took maximum days (56 days) to reach 50 % maturity. The coefficient of variation for days to flowering was 3.70% indicating that, these accessions were with little variability. The analysis of variance (Table 4.2) revealed that highly and significant variable for days to 50% flowering of the total number of accessions tested, all the accessions were early, because they all recorded less than 60 days to flowering time.

DMRT revealed that, the earliest accessions were HSD 5657 and HSD 6029 while, HSD 5611 and HSD 4724were the latest (Table 4.4) .

4.2.1.2 Plant height (cm)

The result showed that, plant height was highly and significantly variable. The minimum plant height attained was 91 cm while, the maximum was 203 cm and a mean plant height of 132 cm attained (Table 4.3). HSD3255 had the shortest plant height (91cm). Whereas, HSD10033 had the tallest plant height (203cm). The coefficient of variation for plant height 24.23% indicated that, these accessions were greatly variable. From the analysis of variance table 4.2. Among all accessions tested, 73% of the accessions were dwarf and 27% were intermediate. DMRT revealed that the tallest accessions were HSD 10033 and HSD 3231 while, HSD 3255 and HSD 6444 were the shortest (Table 4.4).

4.2.1.3 Inflorescence length (cm)

The inflorescence of sorghum plant is a determinate panicle which is usually compact. The length of the panicle varies from 7.5 to 50 cm. The data reported in Table 4.3 showed that, inflorescence length varied from 17.6 to 41.5 cm for the evaluated genotypes. Maximum inflorescence length was recorded, by germplasm accession HSD 10033, with inflorescence lengths of 41.5cm. The minimum inflorescence length was 17.6 cm, recorded by genotype HSD 6425.The coefficient of variation for inflorescence length was 25.28%, indicated that, these accessions were greatly variable. The analysis of variance (Table 4.2) showed that inflorescence length was highly variable. Among out of the 13accessions tested, 23.07% of the accessions were with short inflorescence, 53.84% were intermediate. while, the rest (23.07%) were long.

DMRT revealed that, HSD 10033 and HSD4724 were having the longest inflorescences. while, HSD 6425 and HSD6378 were the shortest (Table 4.4) .

4.2.1.4 Inflorescence width (cm)

The width of the panicle of sorghum generally varied from 4.0 to 20 cm. The minimum inflorescence width attained was 4 cm while the maximum was 6.5 cm and a mean inflorescence width recorded was 4.95 cm (Table 4.3). HSD 5611 had recorded the minimum inflorescence width (4cm). whereas, HSD 8176 recorded the maximum inflorescence width (6.5cm). The coefficient of variation for inflorescence width was 14.14% indicated that these accessions were variable. The analysis of variance Table 4.2 showed that inflorescence width was significantly variable. Among accessions tested all the accessions were thin, because all accessions recorded less than 7 cm inflorescence width.

DMRT revealed that the widest inflorescence width were HSD 8176 and HSD4724 while, HSD 5611 and HSD 5657 were the narrowest (Table 4.4).

4.2.1.5 Stem diameter (cm)

The basal circumference of the stem of cultivated sorghum plants is about 2 to 3 centimeters. The stem grows erectly and is solid, although the core may be spongy and have cavities in the center. The minimum stem diameter attained was 1cm while the maximum was 1.76cm and a mean stem diameter 1cm was recorded (Table 4.3). HSD 5657 had recorded the minimum stem diameter (1cm), whereas HSD 3255 recorded the maximum stem diameter (1.76cm). The coefficient of variation for stem diameter was 18.27% indicated that these accessions were variable. The analysis of variance table 4.2 for stem diameter was highly and significantly variable . Of the 13 sorghum accessions tested, all the accessions were thin because they recorded less than 2cm stem diameter and from DMRT these accessions HSD5657 and HSD 5611 were thinner (Table 4.4).

4.2.1.6 Number of leaves

The data reported in Table 4.3 showed that, the number of leaves varied from 6 to 9 per plant. Accession HSD 4022 had maximum number of leaves per plant (9), followed by HSD 6444 having 8 leaves plant. Minimum leaves plant (6) were recorded by HSD10033.The coefficient of variation for number of leaves was 10.48%, indicated that, these accessions were variable. The analysis of variance showed that (Table 4.2) number of leaves was highly and significantly variable. The 13 sorghum accessions tested, 92.3% of the accessions were with few leaves and 7.7% were intermediate.

DMRT revealed that HSD 4022 and HSD 6444 were with intermediate leaves while HSD 3231 and HSD 10033 were with few leaves (Table 4.4).

4.2.1.7 Leaf area $(cm)^2$

The minimum leaf area attained was $104.4cm^2$ while the maximum was $340.2\ cm^2$ and a mean leaf area of $200cm^2$ attained (Table 4.3). HSD 6425 had recorded the minimum leaf area ($104.4cm^2$), whereas HSD

3231recorded the maximum leaf area (340.2cm²). The coefficient of variation for leaf area was34.84%, indicated that, these accessions were greatly variable. The analysis of variance Table 4.2 showed that leaf area was highly and significantly variable. The 13 sorghum accessions tested, 65% of the accessions were with narrow and 19% were intermediate while the rest (16%) were with wide leaf area.

DMRT revealed that, HSD 3231 and HSD 4724 were with widest leaf area while HSD 6425 and HSD 6444 were with narrowest leaf area (Table 4.4).

4.2.1.8 Grain number / panicle

The minimum grain number per panicle attained was 527 seeds/panicle while the maximum was 1733 seeds/panicle and a mean grain number per panicle of 913 seeds/panicle counted (Table 4.3). Accession HSD 6425 had recorded the minimum grain number per panicle (527 seeds/panicle), whereas HSD 3231recorded the maximum grain number per panicle (1733 seeds/panicle). The coefficient of variation for grain number per panicle was 38.28%, indicated that these accessions were greatly variable. The analysis of variance Table 4.2 grain number per panicle was highly and significantly variable. Of the total number of accessions tested, 65% of the accessions were with few numbers of seeds and 35% was intermediate.

DMRT revealed that, the accessions with intermediate seeds were HSD 3231 and HSD 4724 while HSD 6425 and HSD 5657 were recorded the lowest (Table 4.4).

4.2.1.9 Seed weight

The seed consists of 3 main components . The coat constitutes about 8%, the embryo or germ 10% and the endosperm 80% of the mature sorghum seed. The minimum seed weight attained was 2.4g while the maximum was 3.8g and a mean seed weight of 3g recorded (Table 4.3). Accession HSD 10033 had recorded the lowest seed weight (2.4g), whereas HSD 3255 recorded the greater seed weight (3.8g). The coefficient of variation for seed weight was 15.75%, indicated that, these accessions were variable. The analysis of variance (Table 4.2) showed that seed weight was significantly and highly variable. All the accessions were intermediate (2-4g).

DMRT revealed that, HSD3255 and HSD6425 were the heaviest while HSD 10033 and HSD 8176 were the lightest (Table 4.4).

Table 4.2. Phenotypic variability of some quantitative characters of 13 sorghum accessions grown at demonstration farm of the faculty of Agriculture, University of Khartoum in season 2015

Characters	DF	MS	Probability	CV%	SE
PH	12	2045.295	***	6.93	2.5400
SD	12	0.101	***	8.18	0.0287
NL	12	0.968	*	7.62	0.1422
LA	12	9491.218	***	13.23	7.3642
IL	12	77.096	***	8.09	0.5525
IW	12	0.994	*	10.80	0.1490
SW	12	0.459	***	6.15	0.0534
GRN	12	248966.378	***	8.38	21.2290
DF	12	6.135	**	2.16	0.3037

* Significantly different at 0.05 probability level, ** Significantly different at 0.01 probability level and *** Significantly different at 0.001 probability level

Plant height (PH); Stem diameter (SD); Number of leaves per plant (NL); Leaf area (IA); Inflorescence length (IL); Inflorescence width (IW); 100 seed weight (SW); Grain number per panicle (GRN); Days to flowering (DF).

Table 4.3. Range, mean, standard deviation and coefficients of variation observed values for different traits evaluated at demonstration farm of the faculty of Agriculture, University of Khartoum in season 2015

Trait	Minimum	Maximum	Mean	Std. Dev.	CV%
PH	91	203	132	32.03625	24.23
IL	17.6	41.5	24	6.221018	25.28
IW	4	6.5	4.95	0.699857	14.14
DF	46	56	50	1.882715	3.70
SD	1	1.76	1.26	0.231363	18.27
LA	104.4	340.2	200	69.97305	34.84
NL	6	9	7	0.71245	10.48
SW	2.4	3.8	3	0.492966	15.75
GRN	527	1733	913	349.7388	38.28

Characters abbreviations as in table (4-2)

Table 4.4. Means for the different quantitative characters for 13 sorghum accessions

ACC.NO	PH	SD	NL	LA	IL	IW	SW	GRN	DF
HSD 3255	127CDF	1.030E	6 C	136.5E	19.5CD	4.15 D	3.15BCDE	557 F	48 D
HSD 3231	138 BC	1.4 C	6.5BC	307.5A	305 B	5 BCD	2.7 EFG	1654A	51 BC
HSD 4022	200.5A	1.1DE	6 C	151.5DE	39.5 A	5 BCD	2.4 G	800.5E	50 CD
HSD 4724	185A	1.71A	7BC	320A	31.5 B	5.5ABC	2.95DEF	1389 B	55 A
HSD 5611	131.5CD	1.3CD	6.5BC	208.5CD	29.0 B	6.5 A	2.45 G	1041CD	53 AB
HSD 5612	94.5G	1.66AB	7BC	180.5DE	22.0CD	6 AB	3.8 A	956 DE	50.5BCD
HSD 5657	119CDEF	1.22CDE	6.5BC	169DE	20.0CD	4.5 CD	3.55 AB	821 E	50.5BCD
HSD 6029	105.5EFG	1.21CDE	6.5BC	126.5E	19.5CD	5 BCD	3.75 A	530.5 F	50.5BCD
HSD 6378	157.5B	1.44BC	8.5A	244BC	23.5C	5 BCD	3.05CDEF	1215 C	50 CD
HSD 6425	112DEFG	1.1DE	7BC	297AB	18.5D	5 BCD	3.45ABC	614.5 F	52 BC
HSD 6444	134CD	1.12DE	6.5BC	154.5DE	23.5C	4 D	3.25BCD	591.5 F	49.5CD
HSD 8176	99FG	1.08DE	7.5AB	138.5E	21.5CD	4.5 CD	3.55 AB	613.5 F	50.5BCD
HSD 10033	115DEFG	1.09DE	6C	175.5DE	21.5CD	4.5 CD	2.65 FG	1095CD	49.5 CD
SE±	6.476	0.07416	0.3626	18.77	1.409	0.3801	0.1360	54.12	0.7743

The characters having the same letter within column do not differ significant at 0.05 probability levels according to Duncan's Multiple Range Test.

Plant height (PH); Stem diameter (SD); Number of leaves per plant (NL); Leaf area index (IA); Inflorescence length (IL); Inflorescence width (IW); 100 seed weight (SW); Grain number per panicle (GRN); Days to flowering (DF).

4.2.2 Phenotypic correlations

Table 4.5 Showed the correlation coefficients of pairs of the 9 traits that were measured from the mean of 13 sorghum accessions. Plant height was significant and positively correlated with the Inflorescence length (r = 0.833***), but it was significant and negatively correlated with 100 seed weight (r = -0.668*). The stem diameter was significant and positively correlated to the Inflorescence width (r = 0.641*), leaf area (r = 0.554*), grain number per panicle (r = 0.666*) and days to flowering (r = 0.595*).The other significant and positive correlation coefficients were detected between leaf area with grain number per panicle (r = 0.716**) and days to flowering (r = 0.683**). Also the Inflorescence width was significant and positively correlated with days to flowering (r = 0.565*). The Inflorescence length was significant and positively correlated to the grain number per panicle (r = 0.488*), but it was negatively correlated to 100 seed weight (r = -0.740**). The 100 seed weight was significant and negatively correlated to grain number per panicle (r = -0.510*).

Table 4.5. Phenotypic correlation coefficients of agronomic attributes between different quantitative characters

Quant	PH	SD	NL	LA	IL	IW	SW	GRN	DF
PH	1.000	0.209	0.030	0.326	0.833***	0.082	-0.668*	0.393	0.283
SD		1.000	0.420	0.554*	0.258	0.641*	0.068	0.666*	0.595*
NL			1.000	0.333	-0.185	0.171	0.315	0.189	0.218
LA				1.000	0.262	0.363	-0.261	0.716**	0.683**
IL					1.000	0.348	-0.740**	0.488*	0.351
IW						1.000	-0.187	0.403	0.565*
SW							1.000	-0.510*	-0.152
GRN								1.000	0.447
DF									1.000

*Significantly different at 0.05 probability level,** Significantly different at 0.01 probability level and *** Significantly different at 0.1 probability level

Plant height (PH); Stem diameter (SD); Number of leaves per plant (NL); Leaf area (IA); Inflorescence length (IL); Inflorescence width (IW); 100 seed weight (SW); Grain number per panicle (GRN); Days to flowering (DF).

CHAPTER FIVE

DISCUSSION

5.1 Qualitative traits

Description of sorghum accessions

The present different morphological states of panicle compactness included; Loose drooping primary branches, Semi-loose erect primary branches, Semi-compact elliptic and Compact elliptic were showed in this study. The result obtained with regard to the distributions of different panicle compactness and shape is attracting attention.

The morphological characterization analysis of Sudan sorghum landraces (13 accessions) showed a high occurrence of white grain colour. The predominance of white sorghum seed may be explained by the fact that sorghum is mainly grown for porridge, while, red and brown sorghum grains which were very few in this sample are grown for traditional beer where red and brown grains with high content in tannins are preferable to make a coloured beer with good flavour. Variable social habits concerning the use of sorghum may lead variation in abundance and occurrence of landrace (Adeline *et al,* 2007).

The present of sub-coat in most of the accessions may be explained by the fact that most of the accessions were white, in other words sub-coat is usually associated to white grain colour. In the studied material there was a total absence of completely corneous endosperm texture, which is preferred when making thick African porridge and for long storage period of the grain (Ayana *et al*, 1998).

In the present study, most of accessions were observed to be dry at maturity stage. This character of juiciness may be related to environmental conditions during the crop season. Juicy cultivars are likely to be interesting and hold a potential with regard to ethanol production, juiciness should be associated to high biomass production. Sweet stalked cultivars with high yield of dry matter are also interesting as forage for livestock feed or used for cowshed roofs. In fact, according to utilization sorghum disposes interesting panicle characters for those who are using sorghum grains as human food. For human consumption sorghum with white seed is recognized to make good porridge while red and brown are preferable for good traditional beverage. Sorghum has also important vegetative characters which are preferable for feeding animals, such as cultivars with high fresh or dry biomass (Habindavyi, 2009).

5.2 Agronomic traits (Quantitative)

5.2.1 Agronomic performance

The main effect of the accessions was significant for all the agronomic characters. Analysis of 13 sorghum accessions using nine morphological traits showed the presence of variations among accessions. Sorghum trait variations were also observed by Habindavyi (2009) where five traits were used to classify sorghum in Burundi and the high variations exhibited by Plant height, Inflorescence length, Inflorescence width , 100 seed weight and days to flowering indicated the potentiality of these accessions as breeding materials.

The results revealed that, days to flowering was considerably variable. similar result was reported by Viswanthan and Francis (2002) . Average height of 132 cm was observed among the accessions with a minimum height of 91cm and a maximum of 203cm. While, Mohammed (2011) found average height of 274.61cm among the accessions with a minimum height of 151.67cm and a maximum of 339.17cm. Rao *et al*. (1996). However, reported heights of Indian sorghum varieties reaching 655cm. The reduced plant height in Sudanese sorghum germplasm in this study is either due environmental condition (winter) or due to selection of dwarf germplasm. Generally, height has to be reduced on promising parents, the development of short stature sorghum cultivars can be used for adapting sorghum to mechanical harvesting. The data reported showed that number of leaves were variable. This similar to work reported by Chaudrhy *et al*. (1990) and Naeem *et al*. (2002). Leaf area is a prominent yield component regarding fodder yield and all the genotypes showed considerable variation for leaf area, similar result was obtained by Chaudrhy *et al*. (1990), Din *et al*. (2002) and Nabi *et al*. (2006). The results revealed that Inflorescence length was highly significant variable, similar result also observed by Ayana and Bekele (1999) for Inflorescence length while studying 415 sorghum accessions in Ethiopia.

5.2.2 Phenotypic correlations

The result revealed that, Inflorescence length was highly and significantly correlated to seed weight (0.833***). A similar result was reported by Mohammed (2011). Days to flowering and plant height were found to be not correlated. Similar result was reported by Elagib (2008). In contrast, significant correlation was obtained by Ayana *et al* (2000). Plant height was not correlated to number of leaves. In contrast, significant correlation was obtained by patil *et al* (2003).The possible reason for this could be differences of genetic material and season.

CONCLUSIONS

To understand the morphological diversity correlated to the sorghum landraces distribution in a country is an important tool for efficient exploitation of crop genetic resources. This study reveals sufficient genetic diversity in the available sorghum germplasm for different traits. Different genotypes of sorghum displayed potential for selection of the desired characters. Based on maturity traits, HSD5657 minimum days to maturity. Accession HSD 10033 was the tallest genotypes among the studied accessions. On the basis of leaf area and grain number per panicle, accession HSD 3231 performed well for these traits. The above mentioned genotypes can be suitable for more studies in sorghum breeding and improvement programs.

REFERENCES

Adeline, B., Monique, D., Eric, G., Doyle, M.K. and Helene, I.J. (2007). Local genetic diversity of sorghum in a village in northern Cameroon: Structure and dynamics of landraces. Theoretical and Applied Genetics 114:237-248.

Ali S, Rahman H, Raziuddin S, Shah S and Hassan G (2006). Estimation of variability, heritability and genetic advance for fodder yield trails in two maize populations. Pak. J. Biol. Sci. 9(14): 2618-2623.

Ayana A. and bekele E. (1998). Geographical patterns of morphological variation in sorghum germplasm from Ethiopia and Eritrea: Qualitative characters. Heredities 129:195-205.

Ayana A. and Bekele E (1999). Multivariate analysis of morphological variation in sorghum germplasm from Ethiopia and Eritrea. Genet. Res. Crop Evol. 46: 273-284.

Ayana, A., Bryngelsson, T. and Bekele, E. (2000). Genetic variation of Ethiopian and Eritrean sorghum (Sorghum *bicolor* L. Moench) germplasm assessed by random polymorphic DNA (RAPD). Genetic Resource and Crop Evolution 47, 471-428.

Chandrashekar,A. and Kirleieis, A.W. (1988). Influence of protein on starch gelatinization in sorghum. Cereal Chem., 65:457-462.

Chapman, S.R. and Carter, L.P. (2000) Crop production principle and practices Montana State University.

Chaudhry, A.R., Ghani, A. and Rehman, N. (1990).Variability for fodder yield and its components in sorghum. J. Agric. Res. 28(4): 379-383.

Din, S.S., Naeem, M., Khan, A.H. and Chauhan, M.S.M. (2002). Green fodder yield performance of different varieties of sorghum. Asian J. Plant Sci.1(5): 542-543.

Doggett, H. and Rao, P. (1995). In: Smartt J. and N.W. Simmonds (eds), Evolution of Crops Plants, 2nd ed. Longman, UK, pp. 173-180.

Doggett, H. 1988. The Sorghum crop. In Sorghum (2nd ed). Longm group U.K. Limited, London, U.K. pp 368-404.

Duncan, R.R. (1996). Breeding and improvement of forage sorghums for the tropics. Adv. Agron. 57: 161-185.

Duncan, R. R., P. J. Bramel-cox, and F. R. Miller. (1991). Contributions of introduced sorghum germlpasm to hybrid development in the USA. P. 69-102. In H. L. Shands and L. E. Weiner (ed). Use of plant introduction in cultivar development. Part 1. CSSA Spec. Publ. 17 CSSA, Madison, WI.

Durrishahwar, Muhammad, N., Hidayat ,R., Ihteramullah, Irfan, A.S. Farhan, A., Syed Mehar, A. S. and Nasir M. (2012). Characterization of sorghum germplasm for various morphological and fodder yield parameters. Pakistan.

Elagib, T. Y. (2008). Marker-assisted heterotic grouping of Sudanese sorghum landraces. Submitted to the Office of Graduate Studies of Hohenheim University in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

Elangovan, M., Prabhakar and Reddy, D.C.S. (2007). Characterization and evaluation of sorghum germplasm from Karnataka, India.

Elzain, I.N. *et al* (2008). A proposal for the release of short maturing sorghum genotypes for drought prone areas of the Sudan. National Variety Release committee, Khartoum, Sudan.

Elamin, A.E. and Elzein I.N. 2006. Experience of sorghum and Millet production in Sudan. Sorghum and Millet Network of ASPECA, Machakos, Kenya, 24th - 28th July.

Elzain, I. N. and Elasha A. E.(2005). Sorghum grown under irrigated and rain-fed conditions in the Sudan. ARC . Pp.4.

Fadlelmula, A.A. (2009). Effects of sowing date on the incidence of sorghum midge, sterodiplosis sorghicola (coq.), (cecidomyiidae : Diptera) in sorghum. ARC, Sudan.

FAO, (2010). Food and Agriculture organization of the United Nations. Rome, Italy.

FAO, (2009). Food and Agriculture organization of the United Nations. Production year book. Rome, Italy.

FAO, (2008). Food and Agriculture organization of the United Nations. Production year book. Rome, Italy.

FAO, (2004). Food and Agriculture organization of the United Nations. Production year book. Rome, Italy.

FAO, (2001). Food and Agriculture organization of the United Nations. World sorghum and millet p. p. 8-9.

FAO, (1995). Production Yearbook. Vol. 49. FAO, Rome, Italy.

FAO, (1995).Sorghum and Millets in Human Nutrition.FAO Food and Nutrition Series; No. 27, ISBN 92-5-103381-1.

FAO, (1988). Structure and characteristics of world sorghum economy. CCP:GR88/ 4 Rome. 15pp.

FAOSTAT,(2010) food and Agricultural organization of the United Nations. Data bases, http//faostst.fao.org/defult.asox.

Grenier, C., P.J. Bramel, J.A. DDahlberg, A. El-Ahmadi, M. Mahmoud, G. C. Peterson, D.T. Rosenow, and G. Ejeta. (2004). Sorghum of the Sudan: analysis of regional diversity and distribution. Genetic Resources and crop Evolution 51:489-500.

Habindavyi, E. (2009). Morphological characterization of sorghum diversity in Burundi . Master's thesis at the Swedish Biodiversity centre No. 55. Uppsala Uni. Swedish.

Harlan, J.R. and de Wet, J.M.J.(1972). A simplified classification of cultivated sorghum. Crop Sci., 172-176.

House, L. R. (1995). Sorghum: One of the world's great cereala. African Crop Sci J 3:135-142.

Hubbard, J.E., Hall, H.H. and Earle, F.R.(1950). Composition of the component parts of the sorghum kernel. Cereal Chem., 27:415-420.

Hulse, J.H., Laing, E.M. and Pearson, O.E. (1980). Sorghum and the millets: their composition and nutritive value. New York, Academic Press. 997pp.

Ibrahim, O.E. and Mahmoud, M.A. (1992). Improved sorghum genotypes suitable for irrigated and rain-fed land of Sudan; Proceeding of Sudan National Variety Release Committee. Wad Madani, Sudan.

IBPGR/ICRISAT, (1993). Descriptor for sorghum (Sorghum bicolor (L.) Moench). International Board of Plant Genetic Resources. Rome, Italy/ International Crop Research Institute for the Semi Arid Tropics, Patancheru, India. 38pp.

ICRISAT and FAO, (1996). The world sorghum and millet economies: facts,trends and outlook. Rome/Patancheru: Food and Organization of the United Nations/International Crops Research Institute for the Semi-Arid Tropics, pp. 1.

Idris, A.E. and H.I. Mohammed, (2012). Screening and Evaluation of Forage Sorghum Cultivars for Forage production using multi-criterion decision analysis. Advances in Environmental Biology, 6(3): 1141-1151.

International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) (2004). Sorghum, a crop of substance. (In En.) Patancheru 502 324,Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. ISBN-92-9066-473-8.

Medraoui, L., Mohammed, A., Ouafae, B., Driss, M. and Abdelkarim, F. M. (2007). Evaluation of variability genotypes from Maroc.

Mohammed Abdrahman, A. (1998). The potential of Raton cropping in

sorghum. under irrigation. M.Sc. (Agric) Thesis Uni. of Gezira Wad madani, Sudan.
Mohammed, A. H. (2002). Identification and characterization of genetic variants in sorghum for specific mechanisms of Striga resistance. Ph.D. Thesis Purdue University. West Lafayette, IN.
Mohammed, S.S. (2011). Genetic diversity among some Sudanese sorghum accessions using molecular markers and phenotypic characterization. Master's thesis ARC Sudan.
Nabi, C.G., Riaz, M and Ahmad, G. (2006). Comparison of some advanced lines of *sorghum bicolor* L. Monech for green fodder/dry matter yields and morpho-economic parameters**.** J. Agric. Res. 44(3).
Naeem, M., Chauhan, S.M., Khan, A.H. and Salahudin, S. (2002).Evaluation of different varieties of sorghum for green fodder potential. Asian J. Plant Sci. 1(2): 142-143.
Ollitrault, P., Escoute, J. and Noyer, J.L. (1989). Polymorphism of enzymes in sorghums. I. Description of 11 enzymatic systems, genetical control and linkage. Agron. Trop., 44:203-210.
Patil S.L., Sheelavantar M.N. and Lamani V.K. (2003). correlation analysis among growth and yield components of winter sorghum. Central Soil and Water Conservation Research and Training Institute (CSWCRTI), Research Center Bellary 583-104, Karantaka,India.
Rao, M.R.G. and S. J. Patil. (1996) Variability and correlation studies in F2 population in sorghum. Kararatak. J. of Agri. Sci.9:78-84.
Poehlman, J.M. (1987). Breeding sorghum and millet. In: Breeding Field Crop. AVI Pub CO., Westport, CI. pp. 508-588.
Purseglove, J.W.(1972). Tropical crops: monocotyledons, Vol. i. London, Longman Group Limited. 334pp.
Rooney, L.W. (1978). Sorghum and pearl millet lipids. Cereal Chem., 55: 584-590.
Romain, H. and Raemaeker, S.(2001).(dgic) Directorate General for International Cooperation, ministry of foreign Affairs, External Trade and International Cooperation. Brussels, Belgium (crop production in tropical Africa.
Snowden, J.D. (1936). The cultivated races of sorghum. London, Adlard and Son. 274pp.

Viswanthan, M. and Francis R. B. (2002). Evaluation of Stay-Green

Sorghum Germplasm Lines at ICRISAT. Crop Sci. 42: 965-974.

APPENDICES

Appendices 1. Pictures of some of the reference characters used in the morphological characterization (Sorghum descriptor IBPGR/ICRISAT, 1993)

Fig. 1. Plant height

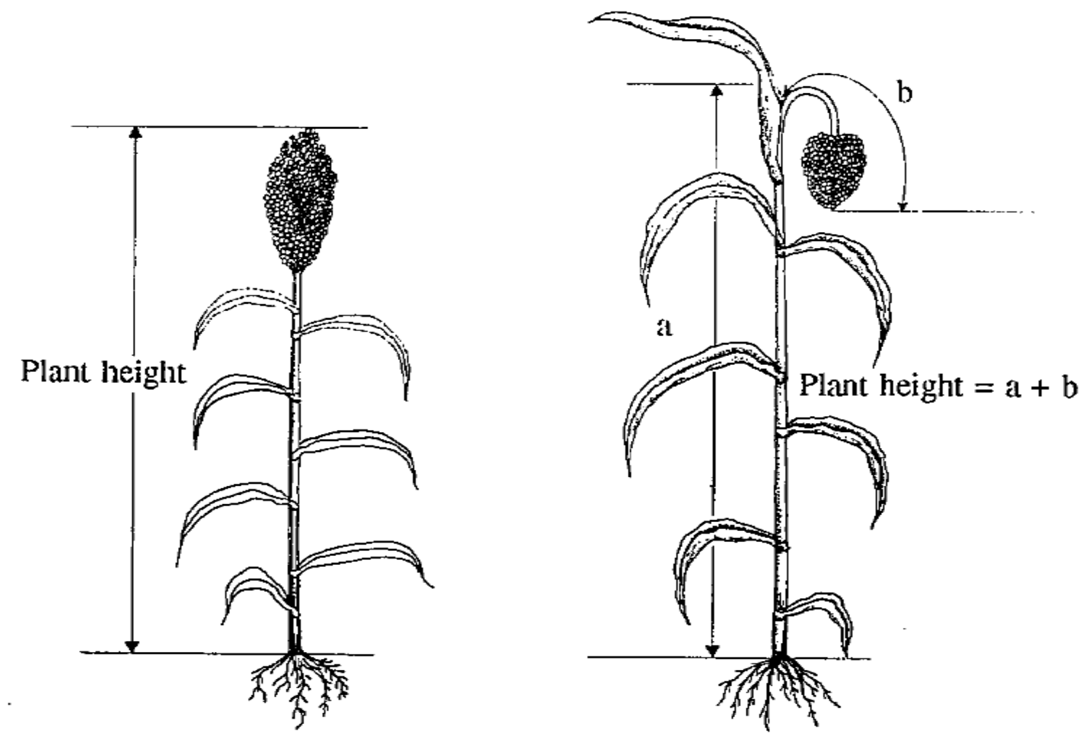


Fig. 2 Inflorescence compactness and shape

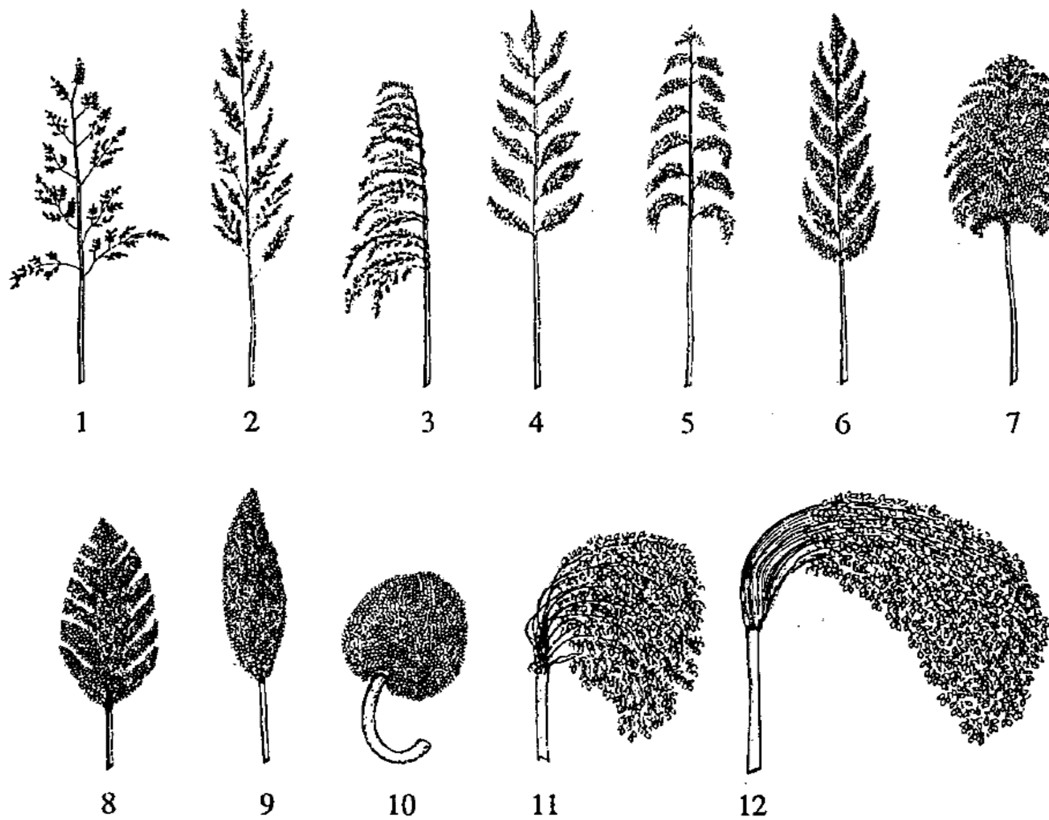


Fig. 3 Grain covering

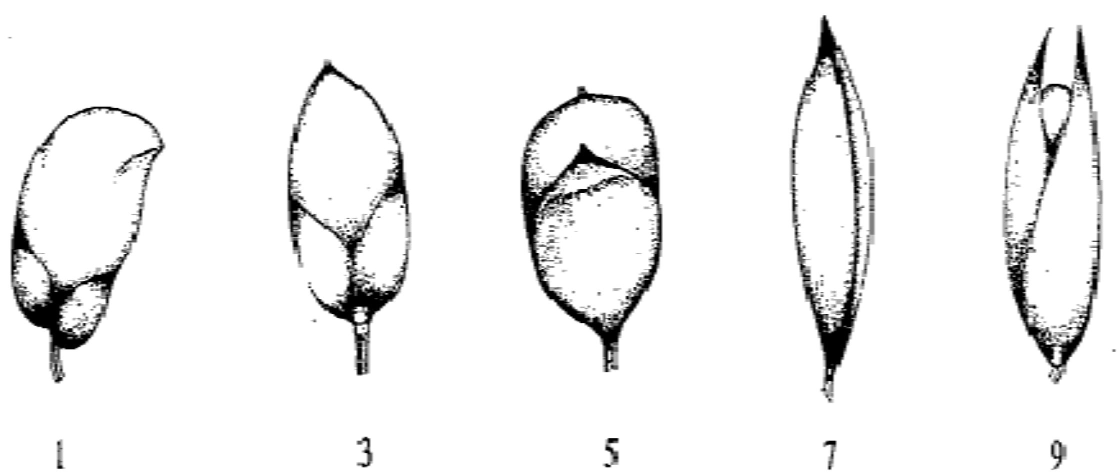
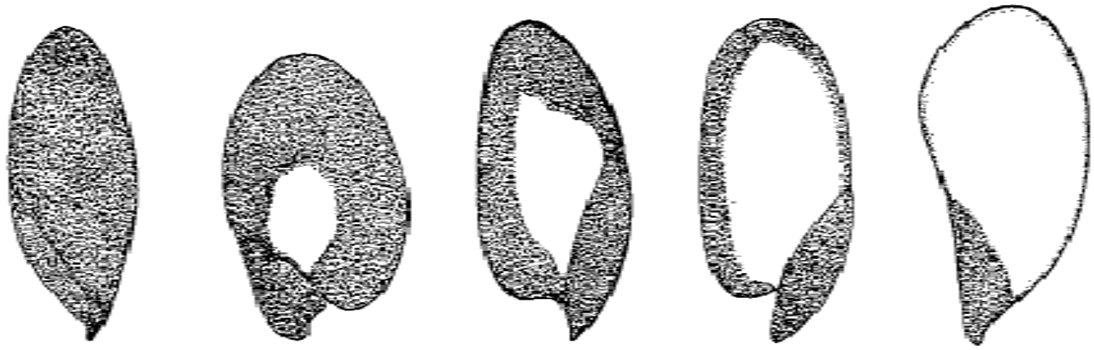
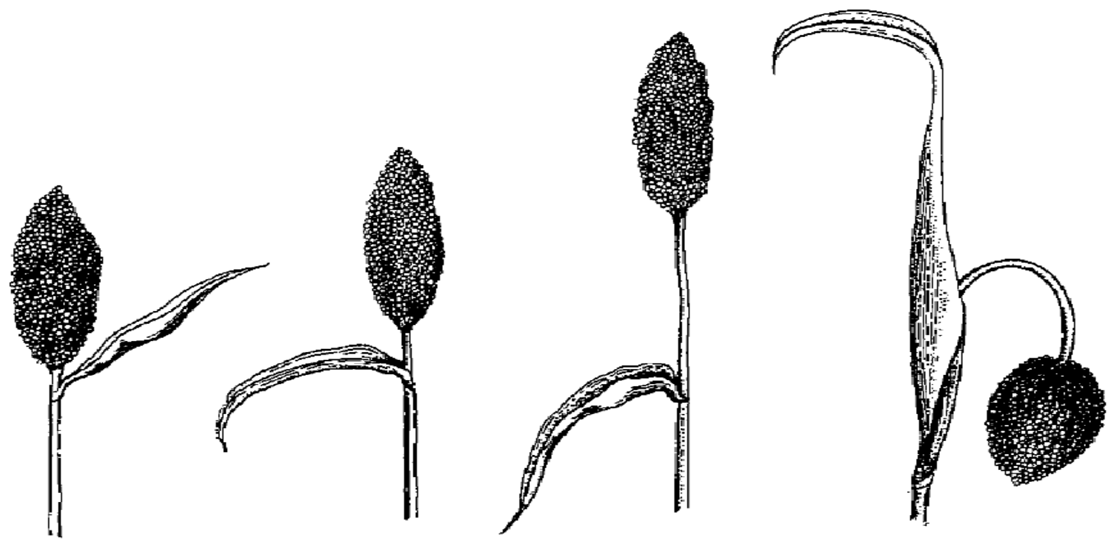


Fig. 4 Endosperm texture



1 3 5 7 9

Fig. 5 Inflorescence exsertion



1 2 3 4

Appendices 2. Pictures of different stages from experiment

Fig. 1 Stage of sorghum growth at field

2.1. sorghum accessions after three weeks from germination

2.2. sorghum accessions in flowering stage

Fig. 2 Images showing the diversity ofglume colour, grain colour and Inflorescence compactness and shape of four sorghum accessions used in the study

HSD 6029 **HSD 3255**

HSD 10033 **HSD 8176**