Biological and Chemical Variations Among the Cultivars of Sweet Sorghum (*Sorghum bicolor* (L.) Moench) in Gedarif State, Sudan

A dissertation presented to the University of Khartoum for the requirements of the degree of Doctor of Philosophy in Biology (Plant Taxonomy)

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Dedication
This work is dedicated to the souls of my father and my mother, may God forgive them.
Acknowledgements

First of all my thanks are due to Allah who gave me the strength and health to conduct this study.

I am deeply grateful to my supervisor Dr. Abdelgabbar Nasir for his great help, advice, patience and encouragement throughout this work.

Sincere gratitude is due to all members of Halfa Sugar Factory especially the chief engineer Hafiz Ibrahim and his team for doing the chemical analysis of sweet sorghum stem juice for the two seasons.

Also special thanks to Dr. Salah Balla, and his colleagues from the Faculty of Agriculture (University of Gedarif) for their great cooperation throughout this study.

Last but not least, my special regards to the chemistry laboratory technician Kamal Eddao and his team and also to my family for their support and patience during the course of this study.
Abstract

Name: Mohammad Abdelgadir Mohammad
Title: Biological and Chemical Variations Among the Cultivars of Sweet Sorghum (*Sorghum bicolor* (L.) Moench) in Gedarif State, Sudan

The main objective of this study was the establishment of a base-line taxonomic data that can be used for the identification of cultivars of sweet sorghum at Gedarif State. Other objectives include the study of the ecology of cultivars and chemical composition of their stem juice and its importance as a potential source of ethanol and jaggery production.

In this study seeds of seven cultivars of sweet sorghum (*Sorghum bicolor* (L.) Moench) were collected from Gedarif State and cultivated at the Demonstration Farm at Towawa, University of Gedarif for two rainy seasons 2008 and 2009. The study is composed of two major parts: botanical and chemical studies.

The botanical studies dealt with the following morphological traits: days to physiological maturity, stem height, stem diameter, number of internodes per plant, leaf area per plant, peduncle length, panicle length, panicle width, glume color, grain color, 100 seeds weight (g), and the number of seeds per panicle. The chemical studies included determination of the percentages of brix, pol (sucrose), purity and the reducing sugars in stem juice of the studied cultivars.

The cultivars have been identified, described and illustrated by digital camera images. Notes on the ecology and distribution of the cultivars in Gedarif State have also been written. Taxonomic keys have been constructed based on morphological and chemical characters for the collected cultivars.

Samples of stem juice of the cultivars were chemically analyzed at New Halfa Sugar Factory (Chemistry Laboratory) for both of the seasons 2008 and 2009.

Statistical analysis of data was carried out using SPSS program.
The major findings of the study can be summarized as follows:
- Significant variations were observed among the cultivars in 12 of the 16 traits studied.
- Glumes color could be considered as the major character used to differentiate between the cultivars.
- Cultivar 3 and 5 showed low seed weights, and a high number of seeds per panicle.
- Cultivar 7 had white grains which resemble as those of grain sorghum varieties.
- Cultivars 1 and 7 showed high sucrose and brix percentages as compared to the other cultivars.
- Cultivar "7" had a high purity (>70%), an advantage that can be used in the production of jaggery, crystalline sugar and ethanol.
- The cultivars 1, 2, 4, 6 and 7 are rich in stem juice sugars. Therefore, the researcher recommends the cultivation of these cultivars for initiation of industries related to jaggery and ethanol production at Gedaref State in the future.
sweet sorghum (Sorghum bicolor(L.)Moench)

Sorghum bicolor (L.) Moench

2009-2008 

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Chapter 1
Introduction

1-1 General Introduction:

Sorghum (*Sorghum bicolor*) (L.) Moench, is an important food and feed crop. It is known to be a major grain crop of the warm subhumid and semi-arid areas (Ustimenko-Bakomvaky, 1983). Sorghum grows in areas where the annual rainfall is not less than 350-450 mm (Elbassam et al, 1999). It is a warm season crop, and is a member of the grass family Gramineae, (Poaceae), subfamily Panicoideae, species *Sorghum bicolor* (L.) Moench.

Sweet sorghum is a group of the cultivated sorghums that have succulent stems, which contain high sugar in their juice. Seeds are usually smaller than in grain sorghums and are bitter. Two types of sweet sorghum were recognized: syrup varieties which contain enough convert sugars in the juice which prevent crystallization, and sugar varieties which contain mostly sucrose and very little convert sugars and these can be readily crystallized. Both types are used in alcohol production (Schaffert and Gourley, 1982).

Sweet sorghum is a multipurpose crop plant. It is a source of grain and its stem can be used for the production of sugar, alcohol, syrup, jiggery, bicerude oil, compost, charcoal pellets and high quality paper (Figure 1.1). It can also be used for bedding, roofing and fencing. It is commonly used for the production of forage and silage for animal feed (Grassi, 2001).

Sweet sorghum is an African crop. It has been cultivated in Ethiopia for more than 5000 years and for over 3000 years in Southern Africa (Duke, 1983). The cultivation of this crop has spread throughout the world and it is grown in nearly all temperate and tropical areas. It is usually an annual, but some cultivars are perennials.

In Sudan the plant is called ankolib and is mainly cultivated in the
areas south of Gedarif, the Blue Nile State and to a lesser extent in El-Gezira State. In Gedarif it is grown in small plantings called "bildat" with an area not exceeding 50 acres. It is mainly cultivated in the south and south east of Gedarif. This area is characterized by high temperature, heavy rainfall and good fertile soil. Villagers used to grow ankolib side by side with other crops eg. maize every autumn in Elzarayeb "small areas behind their homes". The stems when harvested are sold in ElGedarif main market for chewing only.

Sweet sorghum in Sudan is mainly used for chewing, but in some villages it is sun-dried after peeling and is used later to sweeten tea or coffee when sugar is not available (Alsharief, 1993). Alsaadawi et al. (2005) reported that all sorghum genotypes significantly inhibited growth of *Lolium tenuinatum*. Some cultivars exhibited different allelopathic potentials against weeds (Schaffert and Gourley, 1982). The sucrose in stalk juice of ripe plants ranges from 6 to 15% (Coleman, 1970).

Comparing the water requirements of sweet sorghum with those of sugar-cane, it has been found that it needs one-third of the water required by the sugar-cane. Similarly its growing period is shorter than that of sugar-cane. Sweet sorghum is propagated by seeds and only 4.5kg is enough for a hectare of land. Sugarcane is propagated by stem cuttings (FAO, 2002).

Sweet sorghum has been extensively crossed with other varieties for the combined production of sugar and grain. In India, varieties known as S21-3-1 and S21-1-1 were produced by crossing the American lines with a local variety Maldandi (M357) as a pollinator. The resulting hybrids were found to be quite promising in stalk juice quality and grain yields per unit land area (Rajvanshi and Nimbkar, 2001).

2
Source: (Rajvanshi, 1989).

Figure (1.1) Annual production of different products from 1 hectare of sweet sorghum.
This research is conducted to study the taxonomy and the chemical composition (juice sugar content) of "7" cultivars of sweet sorghum cultivated in Gedarif State.

The study consists of "5" chapters. Chapter "1" provides a brief information about sweet sorghum including classification, global distribution and uses. The chapter also includes the main objectives of this research.

The second chapter deals with the ecology, cultivation, diseases, chemistry of sweet sorghum. Chapter "3" provides information on the study area which lies in Gedarif State. The methods and materials used in this study were outlined in chapter "4". Chapter "5" presents results and discussion. Chapter "6" deals with conclusions and recommendations.

1-2 Objectives of the study:

This study aims to:

- identify, classify and construct a taxonomic key for the "7" cultivars of sweet sorghum cultivated in Gedarif based on morphological characters.
- study the ecology of the sweet sorghum cultivars grown in Gedarif State.
- study the chemistry of the "7" sweet sorghum cultivars in an attempt to determine
  1. their sugar contents (brix%+ sucrose %+ reducing sugars %).
  2. the feasibility of sweet sorghum as a potential source of ethanol and jaggery production.
  3. the most suitable cultivars for commercial utilization and processing of extracted sugar.
  4. compare the results obtained with other varieties of sweet sorghum grown around the world (India, China, South Africa and USA) and with sugar-cane and grain sorghum.
1-3 Expected outputs :-

- establishment of a base-line data that can be implemented in industries related to ethanol and jaggery production in Gedaref State.
- Initiation of a base line taxonomic data for use by botanists and agriculturists nationwide.
Chapter 2

Literature Review

2-1 Global distribution:

The origin of sorghum seems to be located in the dry lands of Sudan 5000 years ago and diffused from there to Korea, Borma, India and China (A fossil sorghum grain dated 5000 years ago was found) (Grassi, 2001). Since then, it has become a life-saving crop, the staple food for more than 500 million people in more than 30 countries (Hilario, 2007). About 90% of the area planted as sorghum lies in developing countries, mainly in Africa and Asia, where it is grown generally for food by low-income farmers (MDidea, 2009). FAO (2002) also reported that it has been cultivated for over 3000 years in Southern Africa (MDidea, 2009).

Sweet sorghum is one of many varieties of sorghum, a cane-like plant with high sugar content. The Africans introduced the crop, which then was known as "Guinea corn" into the United States in the early part of the 17th century. It has been widely cultivated in the U.S since 1850, for use in sweeteners, primarily in the form of molasses. Some sweet sorghum syrup has, at one time or another, been produced in every one of the 50 States in the U.S.A. (Wikipedia, 2006).

Sweet sorghum has been called "a camel among crops" owing to its wide adaptability, its marked resistance to drought and saline-alkaline soil and tolerance to water logging. FAO (2002) reported that the Chinese Ministry of Agriculture set up pilot farms in Shandong and Shanaki provinces to demonstrate and develop sweet sorghum and transfer it for use in livestock farming and processing industries. In India sweet sorghum was introduced by Nimbkar Agricultural Research Institute (NARI) in late 1960s. The American varieties were crossed at "NARI" with the local grain types. Madhura hybrid has been developed for ethanol, syrup and jaggery production.
Rajvanshi and Nimbkar (2001) reported that Madhura hybrid is now one of the major crop in India for ethanol production from sweet sorghum. It has been taken up by large number of distilleries both in India and abroad.

2-2 Ecology:

Sweet sorghum is an extra ordinarily promising multifunctional crop not only for its high economic value (due to its high productivity 20-50 t/ha and to the wide range of its products, grains, sugar, ling cellulose), but also for its capacity to provide a very wide range of renewable energy products, industrial commodities, food and animal feed products. It can be considered, thus, a crop of universal value, because it can be grown in all continents, in tropical, subtropical temperature regions as well as in poor quality soils and semi-arid regions (Grassi, 2001).

The optimum temperature for sweet sorghum growth is 22- 33°C while the absolute temperature is between 8- 40°C and that freezing temperature (0°C) is a killing temperature during rest or early growth (Grassi, 2001). Planting must be delayed until a soil temperature of 20 to 23°C is reached as the optimum germination temperature is 23°C (Kanemasu, et al. 1975).

Sweet sorghum is a plant with limited day- light hours. It is a warm-season crop that matures earlier under high temperature and short days. Mask and William (1991) observed that late plantings grow more rapidly than early plantings. The crop tolerates drought and high temperatures better than many other crops, but it does not grow well under low temperatures. In Gedarif State the temperature ranges from 20- 45°C during the warm heavy rainfall season "autumn", especially in the southern and south eastern parts of the state.

Sweet sorghum varieties vary in time of maturity. It was reported that most varieties produced in the tropics reach maturity in 110-150 days (Schaffert and Grouley, 1982). Cowley and Smith (1972) and Ferraris and
Stewart (1979) classified landraces that matured within 100 to 120 days after emergence as early maturing, and those that reached maturity after 120 days as late maturing. Varieties grown in south of Gedarif that reach maturity in 80-120 days are called (Ankolib khafif) and these that reach maturity in more than 120 days are called (Ankolib tagiel). Usually all varieties are cultivated in June and harvested in October and November.

Water demand for cultivation of sweet sorghum is 4000 m$^3$/hectare with an average of rainfall of 500 mm to 600 mm (Hilario, 2007). Sweet sorghum lines have some tolerance to drought. A good variety must have some tolerance to high moisture stress associated with drought, plus the ability to live and grow for a time in poorly drained soils (Coleman, 1970). When compared with sugar-cane, sweet sorghum needs ⅓ of water requirements of sugar-cane and ½ of that of corn (Gassi, 2001). Alsharief (1993) reported that the 5 varieties "from Gedarif" showed no variations in sugar content or growth parameters on application of two water intervals, one week and two weeks. ICRISAT has been developing improved hybrid parents and varieties rich in sugar content, high stalk yield and tolerant to drought (Reddy et al., 2006).

There are two climatic regions in Gedarif. In the north and northwest the rainfall season extends from July to November with a range of annual rainfall of 550-750 mm. A humid climate prevails in the south and southwest of Gedarif with an annual average range of rainfall of 550-900 mm. In this region the rainy season begins at May and extends through November and December (Ministry of Agriculture, 2008).

2-3 Soil:

Sweet sorghum is cultivated in different types of soil ranging from heavy clay to soils with high percentage of sand, salt-alkaline and arid soils. The optimum soil pH range is between 4.5 to 8.5. (Grassi, 2001).
Grassi (2001) reported that sweet sorghum hybrids were sensitive to low pH and low P and K fertilization levels. In general, fertilizers inputs are: 30-60kg/ha of P, 120kg/ha of K and 150 kg/ha of N (Duke, 1983). Soils that have good physical characteristics and good fertility produce the best yield. In general, loam and sandy loam soils are best for the growth of sweet sorghum for syrup production. Freeman et al. (1986) noticed that soils high in organic matter had a detrimental effect on syrup quality. The soil should have a good surface drainage. Traditional farmers cultivate sweet sorghum in well drained soils. They prefer fertile high lands that have not been cultivated for at least 5-7 years. These land areas are available in south of Gedarif especially at Dokah locality.

Bitzer (2009) reported that clayey soils usually produce poor stands, poor yields, and poor syrup. Clay soils fertilized with a moderate amount of N can produce a good yield of sweet sorghum juice. Clay soils prevail in Gedarif area. Sandy soils may require more fertilizers for good growth (Bitzer, 2009).

Sweet sorghum shows salt stress. Senseri et al., (2009), reported that sweet sorghum showed a major salt tolerance mechanism. The concentration of Na⁺/K⁺ ratio increased significantly in all genotypes tested in treatments in their study.

2-4 Taxonomy:

Sweet sorghum (*Sorghum bicolor*) (L.) Moench. belongs to the family: Poaceae subclass: Commelinidae class: Liliopsida (Monocots).

This family contains of about 600-650 genera and over 7500 to 10000 of species. It is considered as the most important plant family to humans and animals. Poaceae is the source of all cereal crops cultivated throughout the world such as; wheat, rice, maize (corn), barley, millet, rye, sugar-cane and sorghum. The grasses are also significant as grazing crops such as grass bermuda. As building materials and a source for matting, the bamboos are
highly valued in Asia. The Poaceae, has been classified by characters of the spikelet, but this has changed at present to focus on different micro and macro anatomical features.

Flowers are zygomorphic and perfect or unisexual/monoecious or dioecious. Perianth may be lacking. Inflorescence is of spikelets which are then arranged into panicles, racemes or spikes. Each spikelet is subtended by 2 glumes. The florets are each enclosed by two bracelets termed the lemma and palea. The bracelets sometimes produce a stiff bristle termed an awn. If the floret has a perianth, it is modified as two fleshy lodicules. Fruit is a caryopsis or grain with the lemma and palea persistent. Seeds are fused to the pericarp and with endosperm present. Placentation is basal (Alaroosi and Ebdelhamid, 1998). Habit is as herbs or rarely woody trees. Leaves are simple, linear, narrow and alternate or basal in two ranks (rows). Bases are sheathed with open, overlapping margins. Auricles or ligules are present where the stem, leaf blade and sheath meet. The family is widespread in all climates and regions. Grasslands made up of species in the Poaceae make up 20% of the world's vegetational cover.

kingdom: Plantae
Sub kingdom: Tracheobionta
Super division: Spermatophyta
Division: Magnoliophyta
Class: Liliopsida
Subclass: Commelinidae
Order: Cyperales
Family: Poaceae (Gramineae)
Genus: Sorghum
Species: *Sorghum bicolor*
The scientific name of sweet sorghum is *Sorghum bicolor* (L.) Moench. This name originates from Germany. It has first been named *Sorghum bicolor* and then modified by Moench, a German botanists (Hilario, 2007). The species includes all annual taxa (all wild and cultivated sorghum subspecies, classified as bicolor subspecies). The wild subspecies include common wild sorghum (Subsp. Arundinaceum). Subsp. Drummondii also belongs to the species of *Sorghum* Subsp. The cultivated *Sorghum bicolor* species is subdivided into "5" races these are, Kafir, Dura, Bicolor, Caudatum and Guinea. Each race has several varieties and cultivars with different agronomic values and diverse utilizations (Grassi, 2001).

1/*Guinea*: It is characterized by large open inflorescence with branches often pendulous at maturity. Grains are flattened and twisted obliquely between long gaping glumes at maturity. Guinea sorghum occurs in West Africa and also along East Africa from Malawi to Swaziland. It is also grown in India and Southeast Asia. Many subgroups can be distinguished esp. adapted to high or low rainfall regimes (Smith and Frederiksen, 2000).

2/*Bicolor*: It is the most primitive cultivated sorghum characterized by open inflorescence and long clasping glumes that enclose the small grain at maturity. Cultivars are grown in Africa and Asia, some for their bitter grains used to flavor sorghum beer, others for their sweet stems to make syrup or molasses. This race is rarely important.

3/*Durra*: It is characterized by impact inflorescence, flattened sessile spikelets and creased lower glumes. Grains are spherical. Cultivars are spread in Southern Sahara, Asia and predominant in Ethiopia, Sudan and Egypt. It is the most specialized and highly evolved of all races and many useful genes are found in this type (drought resistant, long or short season cultivars).

4/*Caudatum*: Cultivars have turtle-backed grains that are flat on one side and curved on the other. Panicle shape is variable and glumes are much shorter
than the grains. They are grown in Nigeria, Chad, Sudan and Uganda.

5/Kafir: This race 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. It is an important staple from Tanzania to South Africa. Hybrid races exhibit various combinations and intermediate form of characteristics of the "5" races (Brink et al., 2006).

SethC. et al. (2009) identified three main genetic groupings of sweet sorghum on the bases of observed phenotypes and known origins, namely: historical and modern syrup, modern sugar /energy types and amber types. They also detected three significant associations for height, two of which were on chromosomes 9 and 6 and one significant association for brix, on chromosome 1.

2-5 Sweet sorghum varieties:

The best sweet sorghum varieties should have the following desirable characteristics according to Bitzer (2009) who studied the cultivation of sweet sorghum in Kentucky:

- produce high yield of medium to large stalks/acre.
- have strong, erect growth so they will not readily lodge.
- contain a high % of extractable juice.
- contain juice with high total soluble solids (TSS) (Brix) content, mostly sugars.
- resist diseases.
- tolerate drought.
- tolerate excessive water.
- produce a high quality syrup.

ICRTSAT renewed its sweet sorghum research in 2000 to identify the potential sweet sorghum lines from existing restorer lines and varieties developed for grain at ICRISAT (Reddy et al., 2007). Varieties differ in these
qualities and in their adaptation to various soil and climatic conditions. Promising lines such as ICSB631 and ICSB264 among the seed parent; and Sered, ICSR 93034, S35 ICSV 700, ICSV 3046 E 36-1 NTJ2 and Entry 64 DTN among the varieties /male parents were identified for their high stalk sugar content. The sugar % in these seed parents varieties ranged from 16.8% to 21.6%. The National Sorghum Program through extensive testing in AICSIP (All India Coordinated Sorghum Improvement Program), released a sweet stalk variety SSV 84 in 1992/1993 for general cultivation (Reddy, 2004). In NARI center a total of 22 sweet sorghum accessions were tested for 3 years to identify the most promising in terms of stalk and grain yields, juice quality and total energy production per unit land area (Rajvanshi and Nimbkar, 2001).

In U.S.A sweet sorghum is cultivated in almost all states for syrup. Studies were conducted in Iowa to evaluate the productivity of a group of sweet sorghum cultivars of varying maturity and morphology to determine sugar accumulation patterns, and to select some of them an energy crops for producing ethanol. These cultivars are Waconia, Kansas, Orange, Smith, Sugar Drip, Cowley, Theis, MBIE., Dale, Keller, Wray and Grassi (Bitzer, 2009). In a study conducted in Botswana by Balole (2001), 10 landraces of sweet sorghum were collected and cultivated for evaluation and determination of the morphological characters sugar contents of stem juice of each. Studies were also conducted in China to determine sugar content and brix degree of different varieties in different stages of growth stages. These varieties included Rio US, Shennog No.2 6AX1022, Jitian 2, Longshi I and 6AXN249 (FAO, 1989). Very few studies were conducted in Sudan to evaluate the Sudanese varieties. Alsharief (1993) studied "5" cultivars collected from Gedarif to determine the sucrose %. These varieties included ankolib Tagiel red, Tagiel dark red, Khafif light, Khafif dark and Tagiel black.

ICRISAT participated strongly during the last few years from 2002-
2007 in spreading the culture of cultivating sweet sorghum and other crops all over the world for the production of ethanol. Hybrids developed in ICRISAT center in India were further studied in other countries such as Egypt, Italy, France, India, Philippine, China and Azrabigan.

2-6 Cultivation:

Sweet sorghum is a warm season crop that matures earlier under high temperatures and short days. The optimum time to plant sweet sorghum in Gedarif is from June 15 to July 20 for the full-season varieties. Bitzer (2009) reported that sweet sorghum should be seeded in 36" to 40" in rows to make weed control and harvesting easier. The ideal seeding rate for most sweet sorghum varieties is 3-4 seeds/linear foot of row with a final stand of 2-3 plants/linear foot of row. If the sorghum is planted too thick, the canes will be spindly and yield less juice than the same tonnage of larger canes. In dry-land conditions, seeds are normally sown in rows 75-100 cm apart (distance 14-30 cm on the row) at a rate of 3-9kg/ha. Higher seed rates are used for more humid areas (Duke, 1983). Seeds may be planted to a depth of 1.5-5cm depending on soil texture and moisture. Martin and Kelleher (1984) noticed that narrow row spacing (30-75cm) with a plant population of 8-16 plants/m² resulted in significantly greater dry matter of water soluble carbohydrate and taller thicker stems. Small areas of one acre or less can be seeded by hands. In Gedarif, areas up to 20 acres are usually seeded by hand. In the U.S.A transplanting is used for the cultivation of sweet sorghum with an advantage of reaching maturity 3 weeks earlier than normal (Bitzer, 2009). In a study conducted in Shenyang Agricultural University (1989) in China on the mechanization of sweet sorghum cultivation, the following observations had been cited:

(1) Deep plow changed the physics and chemical characters of soil, set a good condition for the growth of the plants, promoted the development of the roots
and raised the yield of the stems and seeds.

(2) Stripping by leaf device equipped with high stem harvester, allows cutting of leaves and harvesting of stems to be done at the same time.

The leaf of sweet sorghum is not desirable when crushing stems for juice extraction because it decreases the amount and quality of the juice. It also increases the load in transportation. In an ICRISAT report (2006) the cost of stripping the leaves of sweet sorghum (t/ha+) is about 40US dollars. Grain sorghum compared with sweet sorghum is harvested only for its grain and stalk value without stripping off the leaf. The Chinese have developed a technology for growing sweet sorghum in large areas. The machines used include a pneumatic sprayer, a deep plow machine, stripping leaf device which was used in harvesting, harrowing and smoothing disk (FAO, 1989).

2-7 Weed Control:

Thinning should be done as early as possible before the young plants begin to tiller, usually at 7 to 10 cm in height after 14-15 days of planting when the plants are well established (Balole, 2001). Bitzer (2009) reported that, the best way to control weeds is through transplantation. Weed competition is greatly reduced with transplants because they shade out weeds much quicker than do direct seed plants. Use of herbicides in sorghum is less satisfactory than with many other field crops, as sorghum plants are more sensitive to herbicides (Martin et al., 1975). In U.S.A, Bitzer (2009) reported that several states are requesting a new label for the use of propazine at 2.0 lb active ingredient /acre on sweet sorghum. In the Republic of South Africa this was achieved by pre-emergence application of atrazine at the rate 3kg/ha (Inman-Bamber, 1980). Post emergence applications of atrazine, bendioxide and bromfenoxin have also been found to give excellent control of broadleaf weeds but have little effect on grasses (Coleman, 1972, Inman- Bamber, 1980). Alsaadawi et al. (2005) have noticed that all sorghum genotypes significantly
inhibited growth of *Lolium tenuintum* weed and to some extent *Echinochloa colonum* due to presence of P-hydroxy benzoic acid which is found up to 3-5 times in the screened genotypes experimented.

2-8 Pests and diseases:

Sweet sorghum is subject to a range of insects and diseases. The major reported diseases include: *Carpospores sorghi*, anthracnose of leaves and stems, leaf blight, charcoal rot and rust. Several nematodes have been isolated from sorghum (Grassi, 2001). In South Africa the important pests of sorghum observed are chilo borer (*Chilo partellus*), maize aphids (*Phopalosphum maidis*), sorghum aphids (*Melanaphis sacchari*) and false wireworms (*Mesomorphus spp*) larvae (Balole, 2001).

In the U.S.A it has been reported that insects are: the lesser corn stalk borer (*Clasmopalpus lignosellus*), sorghum midge (*Strenediplosis sorghicola*), sugarcane borer (*Diatraea saccharalis*), aphids armyworms (*Spodoptera frugiperda*) and wireworm (*Heteroderes spp*) (Coleman, 1970). It is reported that disease resistant varieties have been developed. For example, Rio is resistant to rust (*Puccinia purpurea*), leaf anthracnose (*Collectotrichum graminicollia*) and red rots and moderately resistant to downy mildew whilst Roma is resistant to downy mildews, rust and leaf anthracnose (Cowley and Smith, 1972). Maize dwarf mosaic (MDM) and sugarcane mosaic (SCM) viruses have been observed occasionally in Mississippi, Georgia, Kentucky, and Texas as destructive diseases in fields of sweet sorghum.

In South Africa, common diseases of sorghum are covered kernel smut (*Sphaclotheca sorghi*), ergot (*Claviceps africana*), fusarium rot and stalk disease complex and anthracnose stalk rots (McLaren and Smit, 1996).

In Gedarif State very little information is available at the Ministry of Agriculture about the pests and diseases of sweet sorghum. The traditional farmers have observed charcoal rot and rust, leaf anthracnose and worms.
attacking the stems after physiological maturity of the plant. There is no published information on the occurrence or severity of insects or diseases as this crop is cultivated in very small areas in Gedarif State.

2-9 Lodging:

One of the major problems in sweet cultivation sorghum is lodging. It is affected by disease like root and stalk rot, movement of reserves out of the culms into the grain, morphologically thin stalk walls, long internodes and whether the pith remains strong and alive (Stoskopf, 1985).

Lodging resistance in some sweet sorghum cultivars is inherited as a single dominant gene and can easily be recovered in a segregating population such as in the cultivar Sart (Coleman and Stokes, 1958). Some cultivars eg. Brandes have superior flexible stalks that sway with the wind and a very good root system that holds the plant erect even under adverse conditions. Lodging can be aggravated by high plant population which reduces stem thickness, and drought occurring during ripening, or by wet and windy weather.

2-10 Harvesting:

The optimum harvesting period is when the soluble carbohydrate content is at its highest level (Ferraris, 1981). Broadhead (1972) reported that the best harvesting period is between the soft dough and ripe grain stages depending on variety or ripening conditions. Inman-Bamber (1980) recommended harvesting at the hard dough stage because at this stage the sucrose content level is fairly consistent and stems have reached an acceptable quality for milling. Harvesting can be done by hand or by sugar cane harvesters, cutting the plants at the base. Broadhead (1972) noticed that stems harvested 3-4 weeks after the seeds had matured, had significantly decreased brix and sugar values. Hansen and Ferraris (1985) found that storage in the first 48 hours decreased sucrose content by 34 to 19% but some cultivars (Rio cultivar) could be stored outdoors up to 48 hours without a decrease in sucrose.
content. Therefore it is advisable to process sweet sorghum stems within 24 hours of harvesting to retain maximum sucrose content.

**2-11 Morphology of sweet sorghum:**

Sweet sorghum and other cultivated species have a chromosome number of \( n = 10 \) and is primarily self-pollinated with about 2-5% cross pollination (Martin et al, 1975).

1/ **Height:**

Sweet sorghum stem are generally taller (1.5-6.00m) and juicier than grain sorghum. The diameter of the stem varies from 10 to 50mm. The height of the stem depends upon the number of nodes which equals the number of leaves produced. It also depends upon the internode length, peduncle length and panicle length (Dogget, 1988). The stalk height varies with the length and number of the internodes which is determined by maturity genes and by their reaction to photo-period and temperature (Coleman, 1970). Elbassam et al. (1990) reported that plant height is between 80-290cm in a 2- seasons experiment. Alsharief (1993) reported a height of 111-142,05cm for the first season and 164-191.5cm in the second season for the cultivars gathered from Gedarif and grown in the U.of K. Experimental Farm at Shambat (Sudan).

2/ **Stem diameter:**

Stem diameter of sweet sorghum varies from 10mm to 50 mm (Coleman, 1970). Alsharief (1993) reported a range between 1.45-1.75 cm for stem diameter in the first season and between 1.3-1.7 cm in the second season for five cultivars of sweat sorghum grown at Khartoum (Sudan). Bryan et al. (1985) showed that stem diameter for eight cultivars of sweet sorghum varied between 0.3 and 3.0 cm.

3/ **Tillers:**

Sorghum plants usually produce 2 to 4 tillers that develop into large diameter stalks under good growing conditions. Varieties that do not tiller well
usually produce low yield in commercial fields (Coleman, 1970). Tillering ability was found to be the same in the different cultivars of sweet sorghum studied in Sudan and the average number of tillers was 3.67 and 2.11 for the first and second seasons respectively (Alsharief, 1993).

4/ Buds:

On the stem of sweet sorghum there is a single bud at each node. The lowest nodes have buds that may develop into tillers and prop roots, while buds on the upper nodes may produce branches (Doggett, 1988).

5/ Leaves:

Sorghum leaves are similar to corn leaves in shape but are generally narrower. Total leaf surface is about half of that of corn. Sweet sorghum leaves differ from those of grain sorghum in having a dull midrib due to the presence of juice in the air spaces of the pitting tissue (Martin et al., 1975). The total number of leaves on the stalks, including those formed during the seedling stage, ranges from 7-27. This number tends to increase with increasing temperature and day length (Heskerth et al., 1969). Leaves vary in their length and a mature leaf may reach a length of 30 to 135cm and a width of between 1.5 and 13 cm (Doggett, 1988). Sweet sorghum leaves have numerous bulliform cells near the midrib on the upper side of the leaf. During drought stress, these cells result in longitudinal rolling of the leaf that reduces transpiration and stress associated with wilting (Stoskopf, 1985). Similarly the stomatal closure occurs during drought to reduce transpiration and stress due to wilting, stomatal sensitivity, however transpiration is gradually lost after flowering (Ackerson, et al., 1980). Leaf area significantly affects the ability of the plant to produce the dry matter through photosynthesis. Leaf area differs among the different sweet sorghum varieties. Saif (1984) reported that Collier cultivar had a larger leaf area than Tracy cultivar.

6/ Roots:
The roots of sweet sorghum are adventitious with numerous branched lateral roots (Dogget, 1988). Roots emerge from coleoptile node and from several leaf nodes above the coleoptile node. The root structure is very developed (two times the number of roots in corn). The smaller leaf surface, together with the considerable root structure, are behind the great resistance of sorghum to drought (Grassi, 2001).

**7/ Flowering (anthesis):**

Like other members of the genus Sorghum, sweet sorghum anthesis begins when the peduncle has completed elongation although occasionally flowering starts earlier. The first flower to open is the terminal one on the uppermost panicle branch. During anthesis, a typical panicle of sorghum may have: an upper region of the spikelets with dried anthers that have dehisced pollen (post flowering), a middle region of the spikelet, with yellow colored shed fresh pollen (flowering) and a basal position of immature florets (Pendleton et al., 1994). Flowering may continue over a period of 3-15 days depending on the size of the panicle, temperature and variety, with 6-9 days being typical (Henzell and Gillferon, 1973). Pollen shedding occurs freely after sunrise but it may be delayed on cloudy, damp mornings. The stigmas are receptive for a day or two before blooming of the flower (Maunder and Sharp, 1963). The length of sweet sorghum panicles varies from 2-25 cm or more and the width from 2-12 cm or more. A single panicle may carry between 800-3000 seeds. Although it is reported that sweet sorghum is self-pollinated, the upper part of the panicle has more outcrosses than the lower part (Stoskopf, 1985).

**8/ Seeds:**

Seeds from a panicle vary up to 10% in weight according to their position on the panicle. For some hybrids the top kernels are larger, for others the bottom kernels are larger (Weibel, 1982). In grain sorghum, physiological maturity is reached at a moisture content of approximately 30% (Bovey

20
and McCarthy, 1965). It occurs from 22-55 days after flowering in tropical zone areas and from 30-70 days in the temperate ones. In sweet sorghum the area of the grain covered by glumes at maturity varies from one cultivar to another.

Some sweet sorghum cultivars have seeds that remain enclosed by glumes even after threshing while others (25-75%) are easy to thresh (Stoskopf, 1985). The seed color varies from light brown to black with tannins usually being present in seeds which are dark in color. Seeds attain mass maturity within 31 days after anthesis(DAA) and 38 DAA in the case of grain sorghum. Maximum seed quality occurred 14 days after mass maturity in sweet sorghum whilst in grain sorghum it occurred 7 days after mass maturity (Balole, 2001). Balole (2001) studied seed quality of ten cultivars in Botswana. He reported that harvesting before physiological maturity may lower seed quality. Individual grains are small, about 3-4mm across. They vary in color from pale yellow through reddish brown to dark brown depending on the cultivar. The branches of the inflorescence alternate.

2-12 Chemical components of seeds:

In a 100 g sample, the seeds were reported to contain 342 calories, 12.0g H₂O, 10.0g protein, 3.7g fat, 72.7g total carbohydrate, 2.2g fiber, 1.5g ash, 22mg Ca, 242mg P, 3-8mg Fe, 8mg Na, 44mg K, 0.33mg thiamine, 0.18mg riboflavin, 3.90mg niacin, and other vitamins (WuLeung et al, 1972). Seeds contain butyric acid, formic, myristic, palmitic and stearic acids, maltose emulsine and are rather rich in vitamin B (Perry, 1980). Cultivars with highly pigmented seeds are rich in condensed catechin tanin and other phenols (anthocyanins). These are usually the darker bird-insect and fungus resistant cultivars (Morton, 1981).

Palmer and Bowden (1975) reported means of 81.15 mg of Mn, 3 mg of Cl, 15 mg of Mg and more than 20 4-dimethylsterols, 4-monoethylsterols, and triterpenes.
2-13 Toxicity:

Sorghum contains hydrocyanic acid and the alkaloid hardenine. Sometimes plants accumulate toxic levels of nitrate (Morton, 1981). Varieties differ considerably in HCN poisonings and danger is slight when grain is nearly mature. Young plants and suckers are dangerous, particularly when suffering from drought. HCN is destroyed when fodder is ensiled or cured as hay.

2-14 Chemical components of stem juice:

The stem juice of sweet sorghum is rich in fermentative sugar and it is thus a desirable alcoholic fermentation material. The stems of sweet sorghum are generally taller and juicer than grain sorghum (Dogget, 1988). Assimilates in the stems start accumulating during development of inflorescence (Mcbee and Miller, 1982). Eastin (1972) reported that after anthesis assimilates generally move down from the leaves for one to four internodes before moving upward in the central stem. The sucrose content increases, and once the seed reaches the hard dough stage, sucrose content of the stem is at its maximum (Eastin, 1972). Delay in juice extraction after the stalks have been harvested is associated with reduction of the sucrose content as it is converted to reducing sugar. The variety with the slowest rate of conversion tends to be the best choice for sugar production such as variety Brawley (Jonson et al. (1961). The juice of a good variety of sweet sorghum grown under suitable conditions contains 10 to 14% of sucrose and 13 to 17% total sugar (Cowley and Lime, 1976).

It is difficult to measure the juice sugar content in the process of production. The sugar content is commonly expressed in juice brix degree. In a study conducted in China it was found that the sugar content has a positive correlation with brix degree (FAO, 1989). Total soluble solids (TSS) of the extracted juice are expressed in brix degrees. Seetharama (1986) reported that
the total soluble solids for ten lines of sweet sorghum introduced from Sudan ranged between 22.8-25.8 brix degree. Balole (2001) reported a brix degree for the ten cultivars in Botswana were between 8.4 -15.1, a value much lower than those reported by Dempsey and Broadhead (1979) for three cultivars averaging 17.3 brix degree. The brix degree was found to be between 11.2 -14.7 for the "5" cultivars studied in Shenyang University in China (FAO, 1989). Fourteen varieties of sweet sorghum were grown in Brazil by Schaffert and Gourley (1982) who reported a range of 10-5-17.7 brix degree for the total soluble solids in the juice of these varieties.

Furthermore Neuse and Hunt (1983) analysed two varieties of sweet sorghum, Waconica Orange and Rox A. They found that the total solids for the two varieties were the same and it was about 13.3 brix degree.

At ICRISAT center (2006) six hybrids were selected at Patancheru (India) for the production of ethanol. The brix degree of these hybrids ranged between 15.65-20.32. Alsharief (1993) reported a brix degree range of 17.1 – 21.3 for five Sudanese cultivars from Gedarif State. The brix values of six cultivars from eleven cultivars grown in (1991) at Ames (USA) were between 10-15 (Anderson et al., 1995).

1/ Sucrose % and reducing sugars:

The quantity and composition of sugar in mature stem vary with the variety. Sucrose is the major disaccharide in the stem of sweet sorghum. Sucrose in the stalk juice of the ripe plants ranges from 6 to 15% (Coleman, 1970). Eleven cultivars were grown at Ames (U.S.A) for three years from 1991-1993. From these cultivars, Keller produced 741 pounds of sugar/acre, which is equivalent to 500 gallons of ethanol, assuming 14.7 pounds of sugar equals one gallon of ethanol in 1992. Most of the seven Gulf coast cultivars approached the yield of Keller. The cultivars varied in sugar accumulation during the season (Anderson et al.,1995). There were differences between
cultivars in the relative amounts of the two types of sugar for example, Keller and Wray had about twice as much sucrose as reducing sugars near harvest. On a weight basis, sucrose produces about 5% more ethanol than do reducing sugars. A study conducted in China by FAO (1989) for 5 cultivars of sweet sorghum revealed that many kinds of sugars existed in stem juice not only sucrose, fructose and glucose but also xylose, ribose, arabionose, sorbose, galactose, mannose, polyglucose. Based on the test results obtained from this study, it was suggested that to prolong the period of ethanol production and get more sugar, varieties should be combined and different harvest times should be planned. The sucrose content of the "5" cultivars studied in China ranged from 2.8 to 10%. The fructose % was between 2.6 to 4.8 % and glucose % was between 3.2 to 5.6%. These results showed that the highest brix degree differed among varieties in internode position but for most varieties they occurred at the 4 th to the 6th internode from the top (FAO, 1989). The total sugar content was very high in sweet sorghum stem juice, but not all of the sugars were fermentable. The fermentable glucose, fructose and sucrose sugars were dominant. The time of high sugar content is associated with maturity. Among the 5 tested varieties, Shenong 2 had the highest biological yield (stems/hectare), Longshi and 6Ax N249 ripened earlier. Longshi I could be taken as the first source of alcohol production. Balole (2001) reported that L10 (landrace)and L9 had the highest pol percentages (sucrose %), (5.82% and 4.57) with L3 being the lowest (1.86%). It is observed that the landraces of sweet sorghum studied by Balole (2001) in Botswana had lower content of sucrose compared to those varieties grown in Sudan, China, India and USA. In ICRISAT (India) Reddy (2006) reported that during the rainy season at Patancheru, six selected sweet sorghum hybrids produced a brix degree range of 15.65 -20.32, and sugar between 5-9.2%. These hybrids were ICSA 749x SSV74, ICSA 502 xSPV422, ICSA511 x SSU74, ICSA 474xSSV74, SSV84
Krishnaveni et al. (1990) reported that the percentage of reducing sugars of sweet sorghum juice varied between 0.81% and 4.2% with a mean of 2.2%. Alsharief (1993) reported sucrose percentage of 15.47% and 14.67% for two cultivars from the "5" cultivars in her study in Sudan. The reducing sugars % for the five cultivars tested ranged between 1.7 to 2.7% with an average of 2.2%.

2/ Protein and amino acids content in stem juice:

Because of the multiple nutrients in sweet sorghum juice, it has a foundation for being used in food production. For example, sweet sorghum can be used to produce non-alcohol drink. Protein contributes not only to the nutritional values but also the color, fragrance, odor and texture of the food. Natural food contains basically all kinds of nutrients with stable proportion and amount, and is high in nutritional value. Of the human essential amino acids, lysine, phenylalanine, valine, methionine, leucine, isoleucine and thereonine are found in the juice. Histidine, essential to babies, is also found (FAO, 1989).

3/ Mineral components in stem juice:

Only a small part of minerals takes part in the formation of organic matter. The majority of minerals are in the state of inorganic salts or electrolytes maintaining osmotic pressure, adjusting pH state besides keeping the protoplasm active in biochemical reactions elements. The minerals of sweet sorghum stem juice include P, Ca, K, Na, Mg, Fe and Mn (FAO, 1989).

2-15 Uses:

Sweet sorghum has juicy stems which may be used for forage and silage or to produce syrup. The juicy stems are often chewed as a snack by humans in South Africa and Sudan. Sweet sorghum bagasse is a suitable source of paper pulp. The pulp which is used to manufacture kraft paper, newsprint and fiber boards. Danish scientists have also made a good panelling
using the chips from internodes of sorghum (Anonymous, 1996).

The stems are fed to livestock and are used for fencing, while the plant bases provide fuel for cooking. Sorghum may be grown for forage like the modern Sudan grasses which are developed from wild sorghum (Balole, 2001). Stillage from sweet sorghum after the extraction of juice has a higher biological value than bagasse from sugarcane when used as fodder for animals (Reddy, 2004). At NARI in India efforts were aimed at developing technologies to produce jaggery (traditional unrefined sugar) and syrup from sweet sorghum using an efficient gasifier-powered furnace running on low-density biomass residues (Rajvanshi and Nimbkar, 2001).

1/ Ethanol production from sweet sorghum:  

Soaring prices of fossil-fuels and the environmental pollution associated with their use, have resulted in increased worldwide interest in the production and use of bio-fuels. Both developed and developing countries have made mix of policies which have triggered public and private investments in bio-fuel crop research and development of bio-fuels production. India, have made it mandatory to blend petrol with ethanol at 10%. Reddy (2004) reported that the estimated requirements for ethanol is about 1000 million liters, and for blending with diesel (at5%) another 3000 million liters are needed. Total ethanol requirement including other purposes is 5000 million liters. The possible ethanol production from available sugarcane molasses and other sources is 2000 million liters. This leaves a gap of 3000 million liters of ethanol. The deficit of ethanol can be met if sweet sorghum cultivation is promoted for ethanol production.

A comparison was made by FAO (2002) and Reddy et al.,(2006) for some crops used as sources of ethanol in Brazil, India, the Philippines, the USA, France and many other countries. Here is a summary of this comparison:

-Sweet sorghum can grow, like no other crop has grown, in dry-lands, acidic or
basic soils, and waterlogged fields.
- It grows faster than sugarcane, 200 days (2 crops) vs 365 days.
- It needs 4-5 times less water than sugarcane, 8000 (2 crops) vs 36000m³. No irrigation is necessary.
- Cost of cultivation of sweet sorghum is 3 times less than that of sugar-cane.
- Sweet sorghum is easily planted, 5kg of seeds to a hectare, sugar-cane requires the handling of 5000 cuttings.
- Ethanol production from sweet sorghum is environment-friendly and better while that from sugarcane is not, due to two reasons
  -(i) it has lower sulfur content (less polluting) and
  -(ii) has higher octane number (yields more power).
In India, ICRISAT inaugurated in 2006, the production of commercial ethanol by Rusni Distilleries Ltd. It was the first of its kind in the world (Reddy et al., 2006). Hilario (2007) reported that in the Philippines target distillery-farm sites are the Ilocos Region, Cagayan Valley, Central Luzon, Southern Tagalog Region and Central Philippines.

On comparing sweet sorghum with corn the following observations have been cited:

(1) the stalks of sweet sorghum can yield 1235 gallons of ethanol to a hectare twice that of corn (Anderson et al., 1995).
(2) In drought, sweet sorghum remains dormant; with the coming of rain, it resumes growth and recovers, unlike corn (FAO, 2002).
(3) Unlike corn, sorghum's above ground parts wait for the root system to be well established before they grow any further.
(4) Sorghum produces twice more roots than corn.
(5) Sorghum has ½ of the transpiring leaf area of corn and therefore, needs 30-50% less water than corn to produce a unit of matter.
The leaves have a waxy coating (called bloom) and have the ability to fold rather than roll-in during drought.

The plant competes favorably with most weeds (Hilario, 2007).

Sweet sorghum sugar consists of 85% sucrose, 9% glucose, and 6% fructose, on average, and only sucrose may readily be converted to white sugar (Woods, 2000).

2/ The potential use of sorghum as a non-polluting source of energy:

Any energy should be evaluated with consideration to its environmental impacts. World energy consumption has increased by 17 times in the last century, and emissions of CO₂ and NO₂ from fossil-fuel combustion are primary causes of atmospheric pollution. At present some 85% of the world's energy demand is met by fossil fuels. In the last two decades, the CO₂ content has increased by 27% and, as a result of the green house effect, an average global temperature increase of 0.5°C has been suggested. If use of fossil fuel is not restricted, a further 2-5°C temperature increase and perhaps a 1.8 -2.4m increase of sea level may occur. Averages of six billion tone of CO₂ are emitted yearly into the atmosphere as a result of the destruction of rain and other forests (Kangama, and Rumei, 2005). Due to its high productivity (20-40 dry ton/growing cycle) and fast plant cycle (120-152 days) sweet sorghum has an impressive capacity to absorb large amounts of CO₂ from the atmosphere during the 4-5 months growing cycle, with a small amount of CO₂ (~ 4% of the total absorbed ), emitted for the use of conventional energy during its cultivation.
Chapter (3)

The study area

3-1 Location:
Gedarif State lies within the Savanna belt between $12^\circ -42^\circ$, $15^\circ -40^\circ$ latitudes north and $33^\circ - 35^\circ$, $36^\circ - 30^\circ$ longitudes east. It occupies about 72263 km$^2$ on a height of 400-700m above sea level (Elnour, 1997).

Gedarif State is surrounded by; Khartoum State from the northwest, Kassala and Ethiopia from the east and Sinnar and Elgezira from the west. The state is divided into "8" localities which are, Center of Gedarif, Elgalabat East, Elgalabat West, Elrahad, Elfao, Elbutana, Galaa-enahal and Elfashaga (Figure 3.1). Gedarif city is surrounded by hills and has extensive agricultural areas. It is the capital of the state and is considered as a big crop trading and agricultural center in Sudan.

3-2 Population:
The population of Gedarif State is estimated at 1.348.378 according to the Fifth Estimation of Sudan Population in 2008. About 686.771 are under 16 years of age and 661.607 are over 17. The males are estimated at 669.817 and the females are 678.561. Table (3.1) shows the distribution of inhabitants in the 8 localities of the state (Sulieman, 2010). Musa (1986) reported that the original residents of Gedarif belonged to the nomadic tribes such as Elshukria, Elhalawein, Eldabina and Humaran. There are other tribes coming from different parts of Sudan such as Galeen, Fur, Fallata and Hausa.

3-3 Climate:-
1/ Rainfall:
Gedarif State has a tropical climate that is characterized by heavy rainfall which extends from June up to October. The average annual rainfall ranges between 400- 700mm per year. The north-east trades is the wind that prevails during winter (Eltiraifee, 2003).
Figure (3.1) Map of Gedarif State

Source (Survey Department: 1991)
Table (3.1) Population distribution in the 8 localities of Gedarif State (2008).

<table>
<thead>
<tr>
<th>Localities</th>
<th>Males</th>
<th>Females</th>
<th>Sum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elbutana</td>
<td>38375</td>
<td>32990</td>
<td>71365</td>
</tr>
<tr>
<td>Elphashaga</td>
<td>60005</td>
<td>60830</td>
<td>120835</td>
</tr>
<tr>
<td>Gedarif Center</td>
<td>192673</td>
<td>188391</td>
<td>381064</td>
</tr>
<tr>
<td>Elfao</td>
<td>86850</td>
<td>89812</td>
<td>176662</td>
</tr>
<tr>
<td>Elrahad</td>
<td>96671</td>
<td>99767</td>
<td>196738</td>
</tr>
<tr>
<td>Galaa-enahal</td>
<td>31373</td>
<td>34749</td>
<td>66122</td>
</tr>
<tr>
<td>West galabat</td>
<td>84827</td>
<td>90442</td>
<td>175269</td>
</tr>
<tr>
<td>East Galabat</td>
<td>79043</td>
<td>81580</td>
<td>160623</td>
</tr>
<tr>
<td>Total</td>
<td>669817</td>
<td>678561</td>
<td>1348378</td>
</tr>
</tbody>
</table>

Source (Statistics Dept. Gedarif: 2010)

2/ Temperature and Humidity:

The highest mean annual temperature was 40.4°C and the lowest was 27.7°C in the last 30 years. This was recorded during the summer seasons which usually begins in March and extends to May. The average relative humidity was about 27%. The average lowest temperature in winter was about 17.5°C and humidity was 35% for the last 30 years (Eltiraifee, 2003).

3-4 Geomorphology:

There are four groups of rocks which form the geological basement of Gedarif and these are:

(A) Basic rocks which are found in Galaa-enahal area.

(B) Nubian sand rocks which rarely appear on the surface because they are masked with bazelt. These occur on Jabal Tamargo and Kassamour.
(C) Volcanic rocks which are formed of green and black bazelts which exist as flows and dykes. They cover an area of about 8200km$^2$ from the north to the west.

(D) Modern surface deposits which are essentially made of mud and are rich in organic matter. They are brownish and black in color (Musa, 1986).

In general, Gedarif area is a slightly sloping plateau of a 400-700m elevation (Elawad, 1990). It slopes towards the west and northwest except at the area between Elrahad and Atbara streams where it slopes towards the east and west.

3-5 The soil:

The soil is muddy, black or brownish in color and belongs to vertisol group (ElTayeb, 1999). The silt in this soil ranges between 61% and 73%. There is a black or red soil composed of sand stones with very little proportion of silt found in isolated hills and high lands extending from Gedarif to Galabat. This type of soil is suitable for settlement purposes (Atta Elmula, 1984).

3-6 Water resources:

Gedarif is characterized by heavy rainfall that prevails from June to October and represents the major water resource in the area. Other water resources in Gedarif State are, hafirs, ground water, dams, khors and streams. The Atbara stream receives two branches: Settit and Elrahad. Khor Abufarga drains the rainfall water during the rainy season and is considered as a major branch of Elrahad stream.

3-7 Vegetation:

There are three vegetational zones according to the density of rainfall in Gedarif State and these are:

(a) The Butana Plain and the commonest plant species: in this zone are: *Acacia spp.*, *Belpharis spp.*, *Hesperisaeris*, *Andropogon spp.* and others. The plain is
considered as the best pasture area in the state. Average annual rainfall ranges between 100-300mm. Herbs, grasses, bushes, shrubs and trees are also available in this area making it suitable for grazing.

(b) The Gum belt. The rainfall is between 400-600mm/year. *Ricinus communis, Senna senna, Calotropis procera, Acacia seyal* …etc are dominant species in this belt (Eltiraifee, 2003).

(c) Southern Area: Average of rainfall in this area is between 600-700mm per annum. This area is occupied by a dense cover of trees and shrubs such as *Combretum hartmannianum* and *Ziziphus spinosa-christi*.

3-8 Population activities:

1/ Mechanized Agriculture:

Agriculture is the main activity for the majority of population of Gedarif State. This is due to the geographical location, the suitable climate, abundance of annual rainfall (400-800mm) and the lowland plains with fertile soil. Mechanized agriculture occupies about 5 million acres grown mainly with dura (grain sorghum) and sesame. In Elrahad and Atbara streams there is an irrigation system of cultivation. The main crops are cotton, sesame, wheat, groundnuts, dura (grain sorghum) and some horticultural crops.

2/ Traditional agriculture:

This type of agriculture is practiced around the villages in small areas of lands called bildat. It is estimated at 1.5 million acres in the state (Musa, 1986). The main crops cultivated are grain sorghum (dura), millet, sweet sorghum, and sesame. Recently new crops such as sunflower and groundnuts are also cultivated especially in the south of Gedarif.

3/ Pastoralism:

Pasture occurs in Elbutana area where herbs, grasses, bushes, shrubs and trees are available. Livestock is continuously increasing and is estimated at 5.301106 in 1997. This increase is attributed to veterinary care and the reliance
of pastoralists on livestock as the main income generating resource (Eltiraifee, 2003).

4/ Trade:

Eltiraifee (2003) reported that trade represents the third activity for the inhabitants of Gedarif State especially crop marketing. The state is considered as one of the biggest crop areas in the Sudan. Marketed crops include sesame, gum arabic, grain sorghum (dura), millet and groundnuts.
Chapter (4)

Materials and Methods

Two types of studies have been employed in this research: botanical studies and chemical studies.

4-1 Botanical studies:

The botanical studies included the following processes: Collection and viability testing of seeds, sowing, thinning and characterization of leaf, stem and inflorescence of mature plants.

Seeds of the seven cultivars of sweet sorghum (Sorghum bicolor) were collected from Gedarif market, Dokah town and Gregana and Jannan villages. The varieties were selected and identified on the basis of glume color of the spikes (Figure 4.1). Viability of seeds was tested by cultivation in small pots for 5 days. Twenty seeds of each cultivar were grown in pots and a percent germination of 80% was recorded for each cultivar. All the seeds were collected from 2007 growing season.

Before sowing 21 plots (6x2) m were disked and harrowed at the Demonstration Farm of the Faculty of Agriculture (University of Gedarif) at Towawa for two rainfall seasons, 2008 and 2009. A verage of rainfall for the two seasons at Towawa was presented in Appendix(1). Sowing dates were 15/7/2008 for the first season and 5/7/2009 for the second season 2009. About 4kg of Nitrogen fertilizer (Urea) as recommended by Duke (1983) were added and spread by hand before sowing. The experimental design used was the RCBD (Randomized Complete Block Design) with three replications.

Sowing was done manually at a spacing of 25-30cm in holes 2-3 cm deep. In each plot there were four rows. Thinning to 1-2 plants per hole was done after approximately 15-20 days prior to sowing when plants were 15-20 cm in height. Plots were hand- weeded whenever necessary. The plants were healthy and no diseases were observed.
Figure (4.1) Glumes of the "7" cultivars of sweet sorghum grown at Towawa for the two rainy seasons 2008 and 2009.
except for 3-4 plants which were infected by charcoal rot in the two seasons. Illustrations of the "7" cultivars of sweet sorghum grown at Towawa were presented in Appendix (3).

At hard dough stage (physiological maturity), five plants were randomly harvested from each plot. The harvested plants were investigated for the following traits: leaf area per plant, stem height, stem thickness, number of internodes per plant, juice sugar contents, inflorescence and seed characteristics. The cultivars were characterized according to Sorghum Descriptors (IBPGR and ICRISAT, 1993).

1/ **Determination of leaf area:**

The leaf area per plant (cm²) was calculated according to (Choudhari and Bhale, 1985) by the following equation:

Leaf length x leaf width x .747 x total number of green leaves.

2/ **Determination of stem characters:**

Stem diameter (cm) was determined using a vernier. Plant height was determined with a meter device. Number of internodes were obtained by observation, counted from the bottom to the top in each plant.

3/ **Characterization of inflorescence:**

The length of the panicle, peduncle and panicle width were determined (cm) also by a normal meter device.

Number of seeds per panicle were counted manually. Glume and grain color were recorded. The weights of 100 seeds of each cultivar were determined via sensitive balance. A digital camera was used to document the stages of growth and provide colored illustrations of panicles, seeds and glumes for each of the seven cultivars.

4-2 **Chemical studies:**

The chemical studies included the determination of the sugar content of
the juice which included brix %, pol, purity % and reducing sugars %.

1/ **Brix % :**

The brix degrees were determined in vacuum by a hydrometer brix device at juice temperature of 20°C. The procedure was adopted from S.T.A. (1965).

2/ **Pol (sucrose%)**:  

200ml of juice was transferred into a 300ml Erlenmeyer flask, after clarification with dry lead (Hornes dry lead) through filter paper No. 42. The pol tube was filled with the filtrate juice, then the pol reading was recorded from the Succharimeter. The procedure to determine pol % in stem juice was adopted from S.T.A. (1965).

3/ **Reducing sugars %:**  

Reducing sugars were determined by the method of Lane and Eynone (Meade and Chen, 1977). The method was as follows:

1. **Preparation of Fehling's solutions:**  
   
   Fehling's solution (A) was prepared by dissolving 34.64g of copper sulfate (CuSO₄, 5H₂O) in water and was made up to 500ml. Fehling's solution (B) was prepared by dissolving 173g of sodium potassium tartrate (KNa₂C₄H₄O₄, 4H₂O) in 300ml of water. 50g of sodium hydroxide was dissolved in 50ml of distilled water. The mixture was made up to 500ml.

2. **Preparation of methylene indicator:**  
   1g of pure methylene was dissolved in 100 ml of distilled water.

3. **Method of titration:**  
   
   - 10 ml of mixed Fehling's solution was measured into an Erlenmeyer flask of 250 ml capacity.
   - 10 ml of the sugar solution was pippeted into the flask and about 10-15 ml of distilled water were then added to the same flask.
- The flask containing the cold mixture was heated over an electric heater. After the liquid had begun to boil it was kept in moderate ebullition for 2 min. Red or orange color was observed.
- Then without removing the flask off the flame, 3 to 5 drops of methylene blue indicator were added.
- Titration was then completed in 1 min. and the mixture was then left to boil for 3 min, till decoloration or red orange color was observed.

(4) Calculation of the reducing sugars %:
- Tables V11 A for 10ml and V11 B for 25 ml were used to determine the mg of inverted sugars in the juice solution after titration was completed.
- The following equation was used to calculate the percentage of reducing sugars in the juice (S.T.A, 1965).
\[
\text{% of reducing sugars} = \frac{\text{Inverted sugar in mg} \times 100}{1000 \times \text{weight of sugar solution in (g)}}
\]

Statistical analysis of data was carried out for the two seasons separately and for the combined seasons together using SPSS program (two ways ANOVA test).
Chapter (5)

Results and Discussion

5-1 Botanical studies:

This study was conducted in the Experimental Farm of the Faculty of Agriculture, University of Gedari for two seasons, 2008 and 2009. Seven cultivars of sweet sorghum were evaluated for a number of morphological traits which included days to 50% physiological maturity, stem height, stem diameter, number of internodes, leaf area, peduncle length, panicle length, panicle width, glume color, grain color, 100 seeds weight (g) and the number of seeds per panicle.

5-1-1 Days to 50% physiological maturity:

There were significant differences among the "7" cultivars of sweet sorghum in the days to physiological maturity for both seasons 2008, 2009 and the combined seasons (Tables 5.1, 5.2, 5.3). Cultivar "5" reached maturity in 120 days in the season 2008 in Towawa. The other cultivars reached physiological maturity in less than 120 days, therefore they could be considered as early maturing types of sweet sorghum while cultivar "5" was the only late maturing variety according to Cowley and Smith (1972) classification.

Cowley and Smith (1972) and Ferraris and Stewart (1979) classified landraces that matured within 100-120 days after emergence as early maturing, and those that reached maturity in more than 120 days as late maturing. Schaffert and Gourley (1982) reported that most varieties produced in the tropics reach maturity between 110-140 days.

According to Coleman (1970) chlorophyll and other compounds are difficult to remove by the usual methods of clarification (using Horns dry lead and filter paper No. 42) when the stalks of some varieties of sweet sorghum are physiologically immature. The results were in line with those found by Alsharief (1993) who reported a range of 93.5 – 97.5 for the "5" cultivars of
Table (5.1) **Mean days to physiological maturity** for the "7" cultivars of sweet sorghum grown at Towawa (Gedarif) in the rainy season (2008).

<table>
<thead>
<tr>
<th>Cultivars</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
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<tbody>
<tr>
<td>Rep 1</td>
<td>85</td>
<td>90</td>
<td>89</td>
<td>96</td>
<td>120</td>
<td>85</td>
<td>85</td>
<td>92.857</td>
</tr>
<tr>
<td>Rep 2</td>
<td>86</td>
<td>91</td>
<td>87</td>
<td>96</td>
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<td>86</td>
<td>86</td>
<td>93.429</td>
</tr>
<tr>
<td>Rep 3</td>
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<td>97</td>
<td>121</td>
<td>85</td>
<td>85</td>
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</tr>
<tr>
<td>Mean</td>
<td>87.0</td>
<td>90.3</td>
<td>86.7</td>
<td>96.3</td>
<td>121.0</td>
<td>85.3</td>
<td>85.3</td>
<td>93.143</td>
</tr>
</tbody>
</table>

LSD at P (5%) = 2.746  
C.V % = 1.70

Table (5.2) **Mean days to physiological maturity** for the "7" cultivars of sweet sorghum grown at Towawa (Gadarif) in the rainy season (2009).

<table>
<thead>
<tr>
<th>Cultivars</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rep 1</td>
<td>80</td>
<td>82</td>
<td>80</td>
<td>89</td>
<td>118</td>
<td>80</td>
<td>87</td>
<td>88.00</td>
</tr>
<tr>
<td>Rep 2</td>
<td>82</td>
<td>82</td>
<td>82</td>
<td>86</td>
<td>119</td>
<td>82</td>
<td>86</td>
<td>88.43</td>
</tr>
<tr>
<td>Rep 3</td>
<td>82</td>
<td>84</td>
<td>82</td>
<td>88</td>
<td>119</td>
<td>80</td>
<td>90</td>
<td>89.29</td>
</tr>
<tr>
<td>Mean</td>
<td>81.3</td>
<td>83.0</td>
<td>81.3</td>
<td>87.7</td>
<td>118.7</td>
<td>80.7</td>
<td>87.7</td>
<td>88.57</td>
</tr>
</tbody>
</table>

LSD at P (5%) = 2.131  
C.V % = 1.39

Table (5.3) **Mean days to physiological maturity** for the "7" cultivars of sweet sorghum for the combined seasons.

<table>
<thead>
<tr>
<th>Cultivars</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>84.2</td>
<td>86.7</td>
<td>84.0</td>
<td>92.0</td>
<td>119.8</td>
<td>83.0</td>
<td>86.5</td>
<td>90.87</td>
</tr>
</tbody>
</table>

LSD at P (5%) = 2.344  
C.V % = 1.54
sweet sorghum studied at Shambat, U. of K. (Sudan). The results were supported also by the findings of Balole (2001) who reported 109 days for L2 and, L4 and 131-139 days for L9, L10 which were grown at Botswana in (South Africa). Reddy et al. (2007) found that physiological maturity was between 71-85 days for the 30 selected sweet sorghum varieties studied at ICRISAT (India) in the season 2004. The findings were also supported by Anderson et al. (1995) who found that days to maturity for the 10 varieties of sweet sorghum grown at Iowa (USA) for "3" years ranged between 83 days for Waconia cultivar And 108 days for Grassi cultivar.

**5-1-2 Plant height:**

There were significant differences in stem height among the "7" cultivars for the two seasons, 2008-2009 and the combined seasons (Tables 5.4, 5.5, 5.6). The ranges of heights were 185.033 – 225.8cm and between 176.4-251.4cm for the first and second seasons, respectively. For the combined seasons, the range of stem heights was 187.183 – 238.6cm. Cultivar "7" (Abumaksaben) had the longest stem while cultivar "6" (Elhabashi) was the shortest. These results were supported by Elbassam et al. (1990) who observed that the plant height of sweet sorghum in a two-seasons experiment ranged between 80-240cm in the first season and 80-290cm in the second season. Reddy et al. (2007) reported stem heights for the "7" hybrids grown at ICRISAT center in India ranged between 1.6 – 2.9m. Alsharief (1993) reported plant heights of the five cultivars of sweet sorghum grown at Khartoum, which ranged between 111.25-142.05cm in the first season and between 164.1 - 191.5cm for the second season. The results also were in line with those found by Dogget (1988) who reported an average between (1.5-3m) for stem height of sweet sorghum varieties grown in the USA. These findings also coincided with those reported by Balole (2001) who found stalks heights of 288cm for
Table (5.4): Mean **stem height** in (cm) for the seven cultivars of sweet sorghum grown at Towawa (Gedarif) in the rainy season (2008).

<table>
<thead>
<tr>
<th>Cultivars</th>
<th>Rep</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>194.2</td>
<td>228.2</td>
<td>205</td>
<td>196.6</td>
<td>244</td>
<td>191.4</td>
<td>224</td>
<td>211.914</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>189.8</td>
<td>218.8</td>
<td>205.8</td>
<td>209</td>
<td>206</td>
<td>183.2</td>
<td>245</td>
<td>208.229</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>184.2</td>
<td>223.4</td>
<td>186</td>
<td>205.4</td>
<td>200.8</td>
<td>180.5</td>
<td>208.4</td>
<td>198.386</td>
</tr>
<tr>
<td><strong>Mean</strong></td>
<td></td>
<td>189.40</td>
<td>223.467</td>
<td>198.933</td>
<td>203.667</td>
<td>216.933</td>
<td>185.033</td>
<td>225.80</td>
<td></td>
</tr>
</tbody>
</table>

LSD at P (5%) = 20.513  
C.V % = 5.59

Table (5.5): Mean **stem height** in (cm) for the seven cultivars of sweet sorghum grown at Towawa (Gedarif) in the rainy season (2009).

<table>
<thead>
<tr>
<th>Cultivars</th>
<th>Rep</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>206.6</td>
<td>164.6</td>
<td>246.5</td>
<td>220.2</td>
<td>201.2</td>
<td>191.6</td>
<td>264.2</td>
<td>213.557</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>197.4</td>
<td>179</td>
<td>213.8</td>
<td>226</td>
<td>222</td>
<td>188.4</td>
<td>250</td>
<td>210.943</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>190</td>
<td>185.6</td>
<td>236.8</td>
<td>218.4</td>
<td>221.4</td>
<td>188</td>
<td>240</td>
<td>210.029</td>
</tr>
<tr>
<td><strong>Mean</strong></td>
<td></td>
<td>198.00</td>
<td>176.40</td>
<td>232.367</td>
<td>221.533</td>
<td>211.533</td>
<td>189.333</td>
<td>251.40</td>
<td></td>
</tr>
</tbody>
</table>

LSD at P (5%) = 19.482  
C.V % = 5.17

Table (5.6): Mean stem height (cm) for the two combined seasons.

<table>
<thead>
<tr>
<th>Cultivars</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mean</strong></td>
<td></td>
<td>193.7</td>
<td>199.933</td>
<td>215.65</td>
<td>212.6</td>
<td>214.233</td>
<td>187.183</td>
<td>238.6</td>
</tr>
</tbody>
</table>

LSD at P (5%) = 18.783  
C.V % = 5.35

43
"L2" and 354cm for "L6" among the ten landraces studied at Botswana. The stalk height of sweet sorghum varies with the length and number of the internodes which is determined by maturity genes and by their reaction to photoperiod, moisture and temperature (Coleman, 1970). Traditional farmers reported that sweet sorghum had long stalks when it was grown at areas of sufficient rainfall and fertile soils.

Saif (1984) found that irrigation of sweet sorghum at two weeks interval caused a decrease in plant height. Environmental factors may affect stem heights of sweet sorghum. This was observed from the short stems reported by Alsharief (1991) which ranged between 111.25cm and 191.5 for the "5" cultivars grown at the experimental farm of the U. of K. (Sudan).

5-1-3 Stem Diameter:

There were no significant differences in stem diameter among the "7" cultivars in the season 2008 and the combined seasons (Tables 5.7, 5.9). Stem diameter ranged between 2.117cm for cultivar "7" (Abumaksaben) and 1.767cm for cultivar "4" (Tagiel) in the season 2008. In the season 2009 cultivar "3" (Khafif najadi) had a stem diameter of 2.2cm which was the widest while cultivar "2" (Duleljuhur) was the thinnest (1.94cm) (Table 5.8). Cultivar "7" also had the biggest stem diameter (2.095cm) for the combined seasons compared to cultivar "1" (Khafif fadasi) which had the least width (1.863cm).

These results coincided with those reported by Balole (2001) for stem thicknesses which ranged between 2.1 -2.8cm for the 10 landraces of sweet sorghum studied at Botswana. Also these findings were supported by those reported by Alsharief (1993) with an average range of 1.45 -1.75cm for the first and second seasons. The results were in line with those of Bryan et al.
(1985) who found that stem diameter for eight cultivars of sweet sorghum varied between 0.3-3cm. The results also coincided with those reported by Neuse and Hunt (1983) who found a stem diameter of 1.7cm for the variety "Waconia Orange", while "Rox A" variety reached a stem width of 1.54cm. Balole (2001) reported that thick stems are desirable because consumers tend to prefer thick stems for reasons of juiciness.

5-1-4 Number of Internodes:

Significant variation was observed among the "7" cultivars in the number of internodes for the two seasons 2008/2009 and the combined seasons (Tables 5.10, 5.11, 5.12). In the season 2008 cultivar "6" (Elhabashi) had the least number of internodes (9.2) while cultivar "5" (Tagiel white) had the largest number of internodes (12). For the combined seasons cultivar "5" had the largest number of internodes (12.5) while cultivar "2" (Duleljuhar) had the smallest number (10.4).

These results were in line with those found by Balole (2001) who reported a range of internodes of 10-14 for the 10 landraces of sweet sorghum studied at Botswana. The results revealed that stem height of sweet sorghum was not only affected by number of internodes, but also by the length of each internode.

Coleman (1970) reported that late maturing sweet sorghum cultivars have long thick stems with harder rinds and more internodes. It was observed from results obtained that cultivar "5" had more internodes than the other cultivars.

5-1-5 Leaf area:

There were highly significant differences among the "7" cultivars in the leaf area for the seasons 2008, 2009 and the combined seasons (Tables 5.13, 5.14, 5.15). The largest leaf area in the season 2009 was 7510.993cm² for cultivar "4" while cultivar "2" had the lowest leaf area (4184.87cm²). In the
Table (5.7): Mean **stem diameter** in (cm) for the seven cultivars of sweet sorghum grown at Towawa (Gedarif) in the rainy season (2008).

<table>
<thead>
<tr>
<th>Cultivars</th>
<th>Rep</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.96</td>
<td>1.92</td>
<td>1.74</td>
<td>1.84</td>
<td>2.3</td>
<td>1.96</td>
<td>2.25</td>
<td></td>
<td>1.996</td>
</tr>
<tr>
<td>2</td>
<td>1.78</td>
<td>2.04</td>
<td>2</td>
<td>1.8</td>
<td>2.16</td>
<td>1.96</td>
<td>2.3</td>
<td></td>
<td>2.006</td>
</tr>
<tr>
<td>3</td>
<td>1.6</td>
<td>1.84</td>
<td>2</td>
<td>1.66</td>
<td>1.9</td>
<td>1.85</td>
<td>1.8</td>
<td></td>
<td>1.807</td>
</tr>
<tr>
<td>Mean</td>
<td>1.78</td>
<td>1.933</td>
<td>1.913</td>
<td>1.767</td>
<td>2.12</td>
<td>1.923</td>
<td>2.117</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

LSD at P (5%) = 0.239
C.V % = 6.91

Table (5.8): Mean **stem diameter** in (cm) for the seven cultivars of sweet sorghum grown at Towawa (Gedarif) in the rainy season (2009).

<table>
<thead>
<tr>
<th>Cultivars</th>
<th>Rep</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>1.82</td>
<td>2.5</td>
<td>2.04</td>
<td>2</td>
<td>2</td>
<td>2.1</td>
<td></td>
<td>2.006</td>
</tr>
<tr>
<td>2</td>
<td>1.9</td>
<td>2.08</td>
<td>2</td>
<td>2.1</td>
<td>2.04</td>
<td>1.86</td>
<td>2</td>
<td></td>
<td>1.997</td>
</tr>
<tr>
<td>3</td>
<td>1.94</td>
<td>1.92</td>
<td>2.1</td>
<td>2.04</td>
<td>2</td>
<td>2</td>
<td>2.12</td>
<td></td>
<td>2.017</td>
</tr>
<tr>
<td>Mean</td>
<td>1.947</td>
<td>1.940</td>
<td>2.20</td>
<td>2.06</td>
<td>2.013</td>
<td>1.953</td>
<td>2.073</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

C.V % = 6.16

Table (5.9): Mean **stem diameter** (cm) for the two combined seasons.

<table>
<thead>
<tr>
<th>Cultivars</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1.863</td>
</tr>
</tbody>
</table>

LSD at P (5%) =19.482
C.V % = 6.91
Table (5.10): Mean **No. of internodes/plant** for the seven cultivars of sweet sorghum grown at Towawa (Gedarif) in the rainy season (2008).

<table>
<thead>
<tr>
<th>Cultivars</th>
<th>Rep</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>10</td>
<td>11.2</td>
<td>11.74</td>
<td>10.8</td>
<td>12.6</td>
<td>9.4</td>
<td>11.25</td>
<td>10.999</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>10</td>
<td>10.8</td>
<td>10</td>
<td>9.8</td>
<td>11.6</td>
<td>9.2</td>
<td>10.8</td>
<td>10.314</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>9</td>
<td>10.75</td>
<td>10.5</td>
<td>9</td>
<td>11.8</td>
<td>9</td>
<td>9.6</td>
<td>9.95</td>
</tr>
<tr>
<td><strong>Mean</strong></td>
<td></td>
<td>9.667</td>
<td>10.917</td>
<td>10.747</td>
<td>9.867</td>
<td>12.00</td>
<td>9.20</td>
<td>10.55</td>
<td></td>
</tr>
</tbody>
</table>

LSD at P (5%) = 0.752  
C.V % = 4.06

Table (5.11): Mean **No. of internodes/plant** for the seven cultivars of sweet sorghum grown at Towawa (Gedarif) in the rainy season (2009).

<table>
<thead>
<tr>
<th>Cultivars</th>
<th>Rep</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>11.8</td>
<td>10</td>
<td>14</td>
<td>13.2</td>
<td>13.4</td>
<td>12.4</td>
<td>11.4</td>
<td>12.314</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>11.8</td>
<td>10.4</td>
<td>12.6</td>
<td>13</td>
<td>13.2</td>
<td>11.8</td>
<td>10.6</td>
<td>11.914</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>12.2</td>
<td>9.6</td>
<td>13.4</td>
<td>13.8</td>
<td>12.6</td>
<td>11.2</td>
<td>11.5</td>
<td>12.043</td>
</tr>
<tr>
<td><strong>Mean</strong></td>
<td></td>
<td>11.933</td>
<td>10.0</td>
<td>13.333</td>
<td>13.333</td>
<td>13.067</td>
<td>11.80</td>
<td>11.167</td>
<td></td>
</tr>
</tbody>
</table>

LSD at P (5%) = 0.847  
C.V % = 3.94

Table (5.12): Mean **No. of internodes per plant** for the two combined seasons.

<table>
<thead>
<tr>
<th>Cultivars</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mean</strong></td>
<td>10.8</td>
<td>10.548</td>
<td>12.04</td>
<td>11.6</td>
<td>12.533</td>
<td>10.5</td>
<td>10.858</td>
</tr>
</tbody>
</table>

LSD at P (5%) = 0.805  
C.V % = 4.25
Table (5.13): Mean leaf area per plant in (cm²) for the seven cultivars of sweet sorghum grown at Towawa (Gedarif) in the rainy season (2008).

<table>
<thead>
<tr>
<th>Cultivars</th>
<th>Rep</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>3893.37</td>
<td>5618.04</td>
<td>5121.57</td>
<td>5375.67</td>
<td>7074.46</td>
<td>3903.04</td>
<td>5536.97</td>
<td>5217.589</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>3559.76</td>
<td>5761.79</td>
<td>4922.96</td>
<td>4537.86</td>
<td>5704.35</td>
<td>3867.15</td>
<td>6397.1</td>
<td>4964.424</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>3445.01</td>
<td>5223.72</td>
<td>5625.48</td>
<td>3960.89</td>
<td>6120.18</td>
<td>3844.97</td>
<td>4714.49</td>
<td>4707.820</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td>3632.713</td>
<td>5534.517</td>
<td>5223.337</td>
<td>4624.807</td>
<td>6299.663</td>
<td>3878.387</td>
<td>5549.52</td>
<td></td>
</tr>
</tbody>
</table>

LSD at P (5%) = 894.757
C.V % = 10.13

Table (5.14): Mean leaf area per plant in (cm²) for the seven cultivars of sweet sorghum grown at Towawa (Gedarif) in the rainy season (2009).

<table>
<thead>
<tr>
<th>Cultivars</th>
<th>Rep</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>5266.66</td>
<td>3696.66</td>
<td>7957.79</td>
<td>7121.81</td>
<td>6306.71</td>
<td>5419.93</td>
<td>6424.30</td>
<td>6027.694</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>5158.29</td>
<td>4885.86</td>
<td>6890.17</td>
<td>7394.02</td>
<td>6978.61</td>
<td>5222.19</td>
<td>4985.31</td>
<td>5930.636</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>5125.44</td>
<td>3972.09</td>
<td>7349.48</td>
<td>8017.15</td>
<td>6795.49</td>
<td>5154.54</td>
<td>5673.70</td>
<td>6012.556</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td>5183.463</td>
<td>4184.870</td>
<td>7399.147</td>
<td>7510.993</td>
<td>6693.603</td>
<td>5265.553</td>
<td>5694.437</td>
<td></td>
</tr>
</tbody>
</table>

LSD at P (5%) = 898.548
C.V % = 8.43

Table (5.15): Mean leaf area per plant in (cm²) for the two combined seasons

<table>
<thead>
<tr>
<th>Cultivars</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>4408.088</td>
<td>4859.673</td>
<td>6311.242</td>
<td>6067.9</td>
<td>6496.633</td>
<td>4571.97</td>
<td>5621.978</td>
<td></td>
</tr>
</tbody>
</table>

LSD at P (5%) = 843.438
C.V % = 9.16
season 2008, cultivar "5" had the highest leaf area (6299.663 cm²) whereas cultivar "1" had the lowest leaf area (3632.713 cm²). For the combined seasons the range was between 4408.088 cm² for cultivar "1" and 6496.633 cm² for cultivar "5". The leaf area was greatly affected by the quantity of rainfall during the autumn season. Late maturing landraces have larger and broader leaves while early maturing landraces have fewer and narrower leaves. These results were observed when comparing leaf area of cultivars "1" and "6" with cultivars "4" and "5" (Table 5.15).

The results of the current study were in agreement with those reported by Balole (2001) which ranged from 4584 cm² for L8 to 16399 cm² for L10, but not with those of Alsharief (1993) who reported a range of 1736.25 cm² - 2988.2 cm² in the first season, and a range of 1732 cm² - 2462.4 cm² for the second season. They also coincided with the findings of Elbakri (1990) who reported that water stress in sorghum resulted in a reduction in the number of tillers and leaf area. Heskerth et al. (1969) also reported that the number of leaves in sweet sorghum tends to increase with increasing temperature and day length.

5-1-6 Peduncle length:

There were significant differences in the length of peduncles among the cultivars for the two seasons 2008/2009 and the combined seasons (Tables 5.16, 5.17, 5.18). Cultivar "7" showed 50.958 cm in the combined seasons, 56.6 cm in season 2009 and 45.317 cm for the season 2008, while cultivar "6" had the smallest length of peduncle in the season 2009 (34.733) and 35.017 cm for the combined season. Therefore cultivar "7" had the longest peduncle length among the cultivars studied, which exceeded 50 cm in length while cultivar "6" had the shortest peduncle length.

These results were in agreement with those of Balole (2001) who reported
a range of 41.3 – 59.3cm of peduncle length for the ten landraces studied at Botswana. Short peduncles are a disadvantage in terms of pest and disease sensitivity because insects and fungi tend to develop around the sheath of the flag leaf and extend to the panicle attacking the seeds (Dogget, 1970).

5-1-7 Panicle length:

Significant differences in the length of panicles were observed among the cultivars in the seasons 2008, 2009 (Tables 5.19, 5.20). The panicle length of cultivars "2", "3", "4" and "7" were the longest and those of the cultivars "1", "5" and "6" were the shortest in the first season 2008. In the second season cultivars "4", "2" and "7" had the tallest panicles while cultivars "1", "3", "5" and "6" had the shortest panicles.

No significant differences were observed in panicle length among the cultivars in the combined seasons 2008, 2009 (Table 5.21).

The panicle length of the cultivars ranged between 31.467cm for cultivar "2" and 24.967cm for cultivar "1".

The results were in agreement of those reported by Balole (2001) who found that the panicle lengths range was between 23.5cm for the shortest landraces and 31.3 to 36.7 for the longest ones. Panicles of the "7" cultivars of sweet sorghum studied in the seasons 2008/2009 at Towawa (Gedarif) were illustrated in Figure (5.1).

5-1-8 Panicle width:

No significant differences were observed among the cultivars in panicle widths for the two seasons and the combined seasons (2008/2009).

Panicle width ranged from 6.433cm for cultivar "1" to 7.373cm for cultivar "7" in the season 2008 (Table 5.22). In the second season 2009 the panicle width was between 6.267cm for cultivars "2", "4" and 7.833cm for cultivar "6" (Table 5.23). This range was between 6.433cm for cultivar "2" and 7.533cm for cultivar "6" for the combined seasons (Table 5.24).
Table (5.16): Mean peduncle length in (cm) for the seven cultivars of sweet sorghum grown at Towawa (Gedarif) in the rainy season (2008).

<table>
<thead>
<tr>
<th>Cultivars</th>
<th>Rep</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>37.2</td>
<td>37.2</td>
<td>37.2</td>
<td>39.2</td>
<td>48.2</td>
<td>37.4</td>
<td>44.25</td>
<td>40.093</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>36.6</td>
<td>38.2</td>
<td>34.6</td>
<td>39.8</td>
<td>42.6</td>
<td>35</td>
<td>42.5</td>
<td>38.471</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>31.8</td>
<td>41.4</td>
<td>25</td>
<td>41.4</td>
<td>41.2</td>
<td>33.5</td>
<td>49.2</td>
<td>37.643</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td>35.2</td>
<td>38.933</td>
<td>32.267</td>
<td>40.133</td>
<td>44.0</td>
<td>35.30</td>
<td>45.317</td>
<td></td>
</tr>
</tbody>
</table>

LSD at P (5%) = 6.291  
C.V % = 9.12

Table (5.17): Mean peduncle length in (cm) for the seven cultivars of sweet sorghum grown at Towawa (Gedarif) in the rainy season (2009).

<table>
<thead>
<tr>
<th>Cultivars</th>
<th>Rep</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>36.2</td>
<td>39.4</td>
<td>45.4</td>
<td>38</td>
<td>33.2</td>
<td>36</td>
<td>52</td>
<td>40.029</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>35.2</td>
<td>38.8</td>
<td>39.8</td>
<td>38.2</td>
<td>34.2</td>
<td>32.2</td>
<td>59.3</td>
<td>39.671</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>34.4</td>
<td>42.2</td>
<td>43.4</td>
<td>34.4</td>
<td>37.6</td>
<td>36</td>
<td>58.5</td>
<td>40.429</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td>35.267</td>
<td>40.133</td>
<td>42.867</td>
<td>36.867</td>
<td>35.0</td>
<td>34.733</td>
<td>56.60</td>
<td></td>
</tr>
</tbody>
</table>

LSD at P (5%) = 4.594  
C.V % = 6.42

Table (5.18): Mean peduncle length in (cm) for the two combined seasons.

<table>
<thead>
<tr>
<th>Cultivars</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>35.233</td>
<td>39.533</td>
<td>37.567</td>
<td>38.5</td>
<td>39.5</td>
<td>35.017</td>
<td>50.958</td>
</tr>
</tbody>
</table>

LSD at P (5%) = 5.214  
C.V % = 7.85
Table (5.19): Mean **panicle length** in (cm) for the seven cultivars of sweet sorghum grown at Towawa (Gedarif) in the rainy season (2008).

<table>
<thead>
<tr>
<th>Cultivars</th>
<th>Rep</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>27.8</td>
<td>35</td>
<td>32</td>
<td>27</td>
<td>27.8</td>
<td>29.6</td>
<td>32</td>
<td>30.171</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>26.4</td>
<td>33.8</td>
<td>32</td>
<td>37.4</td>
<td>29.2</td>
<td>27.6</td>
<td>31</td>
<td>31.057</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>25.8</td>
<td>34.2</td>
<td>32.5</td>
<td>35</td>
<td>29.2</td>
<td>27</td>
<td>28</td>
<td>30.243</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td>26.667</td>
<td>34.333</td>
<td>32.167</td>
<td>33.133</td>
<td>28.733</td>
<td>28.067</td>
<td>30.333</td>
<td></td>
</tr>
</tbody>
</table>

LSD at P (5%) = 4.378
C.V % = 8.07

Table (5.20): Mean **panicle length** in (cm) for the seven cultivars of sweet sorghum grown at Towawa (Gedarif) in the rainy season (2009).

<table>
<thead>
<tr>
<th>Cultivars</th>
<th>Rep</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>23</td>
<td>27.8</td>
<td>25.4</td>
<td>27.2</td>
<td>24.4</td>
<td>25</td>
<td>30.6</td>
<td>26.2</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>23</td>
<td>28.8</td>
<td>26.6</td>
<td>29.6</td>
<td>23.8</td>
<td>25.4</td>
<td>28.6</td>
<td>26.543</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>23.8</td>
<td>29.2</td>
<td>25.4</td>
<td>29.8</td>
<td>28</td>
<td>24.8</td>
<td>26.75</td>
<td>26.829</td>
</tr>
</tbody>
</table>

LSD at P (5%) = 2.462
C.V % = 5.22

Table (5.21): Mean **panicle length** in (cm) for the two combined seasons.

<table>
<thead>
<tr>
<th>Cultivars</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>24.967</td>
<td>31.467</td>
<td>28.983</td>
<td>31.0</td>
<td>27.067</td>
<td>26.567</td>
<td>29.5</td>
</tr>
</tbody>
</table>

C.V % = 9.8
Figure (5.1) Panicles of the 7 cultivars of sweet sorghum grown at Towawa(Gedarif) for two rainy seasons 2008-2009.
Table (5.22): Mean **panicle width** in (cm) for the seven cultivars of sweet sorghum grown at Towawa (Gedarif) in the rainy season (2008).

<table>
<thead>
<tr>
<th>Cultivars</th>
<th>Rep</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>6.8</td>
<td>6.6</td>
<td>7.2</td>
<td>6.5</td>
<td>7.4</td>
<td>7.8</td>
<td>8.12</td>
<td>7.203</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>6.5</td>
<td>7</td>
<td>7.4</td>
<td>6.8</td>
<td>7</td>
<td>7.4</td>
<td>7.8</td>
<td>7.129</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>6</td>
<td>6.2</td>
<td>7.75</td>
<td>6.9</td>
<td>6.6</td>
<td>6.5</td>
<td>6.2</td>
<td>6.593</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td>6.433</td>
<td>6.6</td>
<td>7.54</td>
<td>6.733</td>
<td>7.0</td>
<td>7.233</td>
<td>7.373</td>
<td></td>
</tr>
</tbody>
</table>

C.V % = 6.75

Table (5.23): Mean **panicle width** in (cm) for the seven cultivars of sweet sorghum grown at Towawa (Gedarif) in the rainy season (2009).

<table>
<thead>
<tr>
<th>Cultivars</th>
<th>Rep</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>7.4</td>
<td>5.6</td>
<td>7.2</td>
<td>6</td>
<td>6.1</td>
<td>7.7</td>
<td>8.4</td>
<td>6.914</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>7</td>
<td>7</td>
<td>6.1</td>
<td>6.4</td>
<td>6.2</td>
<td>7.8</td>
<td>6.6</td>
<td>6.729</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>7.2</td>
<td>6.2</td>
<td>6</td>
<td>6.4</td>
<td>7</td>
<td>8</td>
<td>6.75</td>
<td>6.793</td>
</tr>
</tbody>
</table>

LSD at P (5%) = 1.086
C.V % = 8.95

Table (5.24): Mean **panicle width** in (cm) for the two combined seasons.

<table>
<thead>
<tr>
<th>Cultivars</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>6.817</td>
<td>6.433</td>
<td>6.942</td>
<td>6.5</td>
<td>6.717</td>
<td>7.533</td>
<td>7.312</td>
<td></td>
</tr>
</tbody>
</table>

C.V % = 7.96
These findings were in line with those found by Balole (2001) who reported a width of panicles ranging from 6.8cm for landrace "9" to 10cm for landrace "10" among the 10 landraces of sweet sorghum studied at Botswana. It was observed that cultivars "6" and "7" had the largest panicle width while cultivars "2" and "1" had the smallest ones.

**5-1-9 Number of seeds per panicle:**

Significant variations were observed among the seven cultivars in the number of seeds per panicle for both seasons, 2008 and 2009. Cultivar "3" had the highest number of seeds whereas cultivar "7" had the smallest number (Tables 5.26, 5.27). It was noticed that in cultivar "7" the number of seeds per panicle was less than 2000 whereas that of cultivar "3" exceeded 3000 seeds per panicle (Table 5.25). These results were in line with those found by Balole (2001) who reported a number of 1500 seeds per panicle for L8 and 3893 seeds for L3. The results indicated that some of these cultivars have the potential for more seed production as compared to grain sorghum with 800 to 3000 seeds per panicle (Stoskopf, 1985). Although seed yield is not a priority in sweet sorghum, during drought years sweet sorghum could alternatively be utilized for grain production (Ferraris, 1981). However, under normal conditions it is not recommended to encourage grain production by sweet sorghum since tall plants with heavy panicles lodge easily due to the leverage forces on the stem brought about by the weight of grain at the apex (Ferraris, 1981).

**5-1-10 100 seeds weight (g):**

Significant differences were observed among the "7" cultivars in the season 2008 and the season 2009 (Tables 5.28, 5.29). Significant variations also occurred among the "7" cultivars for the combined seasons.

100 seeds weight (g) varied between 2.485g for cultivar "7" which had the heaviest weight of seeds and 1.145 g for cultivar "3" (Table 5.30). In the
Table (5.25): Mean number of seeds per panicle for the seven cultivars of sweet sorghum grown at Towawa (Gedarif) in the rainy season (2008).

<table>
<thead>
<tr>
<th>Cultivars</th>
<th>Rep</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2150</td>
<td>2366</td>
<td>3430</td>
<td>3400</td>
<td>3245</td>
<td>2295</td>
<td>2155</td>
<td>2720.143</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>2050</td>
<td>2385</td>
<td>3120</td>
<td>2819</td>
<td>2610</td>
<td>2347</td>
<td>1535</td>
<td>2409.429</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>2046</td>
<td>2035</td>
<td>3125</td>
<td>3630</td>
<td>3850</td>
<td>2440</td>
<td>1250</td>
<td>2625.143</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td>2082.0</td>
<td>2262</td>
<td>3225</td>
<td>3283</td>
<td>3235</td>
<td>2360.667</td>
<td>1646.667</td>
<td></td>
</tr>
</tbody>
</table>

LSD at P (5%) = 597  
C.V % = 12.98

Table (5.26): Mean number of seeds per panicle for the seven cultivars of sweet sorghum grown at Towawa (Gedarif) in the rainy season (2009).

<table>
<thead>
<tr>
<th>Cultivars</th>
<th>Rep</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
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<td>1</td>
<td>2012</td>
<td>2540</td>
<td>3027</td>
<td>2172</td>
<td>3049</td>
<td>2262</td>
<td>1256</td>
<td>2331.143</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>1935</td>
<td>2118</td>
<td>3190</td>
<td>2245</td>
<td>2585</td>
<td>1890</td>
<td>1272</td>
<td>2176.429</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>1515</td>
<td>2316</td>
<td>2885</td>
<td>1831</td>
<td>2353</td>
<td>2275</td>
<td>1782</td>
<td>2136.714</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td>1820.667</td>
<td>2324.667</td>
<td>3034.00</td>
<td>2082.667</td>
<td>2662.333</td>
<td>2142.333</td>
<td>1436.667</td>
<td></td>
</tr>
</tbody>
</table>

LSD at P (5%) = 446.343  
C.V % = 11.32

Table (5.27): Mean number of seeds per panicle for the two combined seasons.

<table>
<thead>
<tr>
<th>Cultivars</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>1951.333</td>
<td>2293.333</td>
<td>3129.5</td>
<td>2682.88</td>
<td>2948.667</td>
<td>2251.5</td>
<td>1541.667</td>
</tr>
</tbody>
</table>

LSD at P (5%) = 491.545  
C.V % = 12.1
Table (5.28): Mean 100 seeds weight (g) for the seven cultivars of sweet sorghum grown at Towawa (Gedarif) in the rainy season (2008).

<table>
<thead>
<tr>
<th>Cultivars</th>
<th>Rep</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td>1.47</td>
<td>1.41</td>
<td>1.03</td>
<td>1.83</td>
<td>1.23</td>
<td>1.55</td>
<td>2.56</td>
<td>1.583</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>1.50</td>
<td>1.38</td>
<td>1.04</td>
<td>1.70</td>
<td>1.33</td>
<td>1.59</td>
<td>2.37</td>
<td>1.559</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>1.34</td>
<td>1.47</td>
<td>0.99</td>
<td>1.61</td>
<td>1.41</td>
<td>1.60</td>
<td>2.50</td>
<td>1.560</td>
</tr>
<tr>
<td><strong>Mean</strong></td>
<td></td>
<td><strong>1.437</strong></td>
<td><strong>1.42</strong></td>
<td><strong>1.02</strong></td>
<td><strong>1.713</strong></td>
<td><strong>1.323</strong></td>
<td><strong>1.58</strong></td>
<td><strong>2.477</strong></td>
<td></td>
</tr>
</tbody>
</table>

LSD at P (5%) = 0.154  
C.V % = 5.16

Table (5.29): Mean 100 seeds weight (g) for the seven cultivars of sweet sorghum grown at Towawa (Gedarif) in the rainy season (2009).

<table>
<thead>
<tr>
<th>Cultivars</th>
<th>Rep</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td>1.79</td>
<td>1.78</td>
<td>1.23</td>
<td>1.81</td>
<td>1.14</td>
<td>1.96</td>
<td>2.51</td>
<td>1.746</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>1.66</td>
<td>1.75</td>
<td>1.28</td>
<td>1.78</td>
<td>1.16</td>
<td>2.04</td>
<td>2.54</td>
<td>1.744</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>1.64</td>
<td>1.78</td>
<td>1.30</td>
<td>1.84</td>
<td>1.07</td>
<td>2.06</td>
<td>2.43</td>
<td>1.731</td>
</tr>
<tr>
<td><strong>Mean</strong></td>
<td></td>
<td><strong>1.697</strong></td>
<td><strong>1.77</strong></td>
<td><strong>1.27</strong></td>
<td><strong>1.81</strong></td>
<td><strong>1.123</strong></td>
<td><strong>2.02</strong></td>
<td><strong>2.493</strong></td>
<td></td>
</tr>
</tbody>
</table>

LSD at P (5%) = 0.097  
C.V % = 3.06

Table (5.30): Mean 100 seeds weight (g) for the two combined seasons.

<table>
<thead>
<tr>
<th>Cultivars</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mean</strong></td>
<td>1.567</td>
<td>1.595</td>
<td>1.145</td>
<td>1.762</td>
<td>1.223</td>
<td>1.800</td>
<td>2.485</td>
</tr>
</tbody>
</table>

LSD at P (5%) = 0.106  
C.V % = 3.99
the season 2009 cultivar "6" reached a weight of 2.02 g for 100 seeds and 1.8 "g" for the combined seasons. Cultivar "5" had the second smallest figure for the 100 seeds weight g prior to cultivar "3". These results were supported by that of Balole (2001) who reported that the weights of 100 seeds ranged between 1.45g for L7 and 2.29 g for L6. The number of seeds is important in determining grain yield.

5-1-11 Glume colors:

The glume color was the main morphological character selected by the researcher to differentiate between the seven cultivars of sweet sorghum chosen for cultivation in this study. This morphological trait is usually used to differentiate between the cultivars of sweet sorghum at Gedarif among the traditional farmers, since the grains are enclosed inside the glumes tightly and are not shattered easily. The heads were well exerted in all of the "7" cultivars studied. The glume colors were illustrated in (Table 5.44) for the seven cultivars grown at Towawa. Cultivar "1" had light red glumes while cultivar "6" had dark red (liver color) glumes on reaching full physiological maturity. It was difficult to differentiate between these two cultivars "1" and "6" on the basis of glume color only. The size of the panicle was important too, as cultivar "6" possesses large panicles compared to cultivar "1". Glumes of cultivar "3" and cultivar "4" had a mixture of white and black colors but in cultivar "4", the proportion of the black color is more and the seed is bigger than that of cultivar "3". Cultivar "2" was characterized by black reddish glumes. Cultivar "5" had almost white glume with red or dark spots at the bottom. The pink glumes which were easily shattered were observed in cultivar "7". Balole (2001) reported several colors of the glumes for the 10 landraces studied in Botswana. These colors were grey, purple, white, black and red.
5-1-12 Grain colors:

The grain colors of the "7" cultivars of sweet sorghum grown at Towawa (Gedarif State) were shown in (Table 5.44). Almost all the grains were brown in color, however, yellowish brown grains were observed in cultivar "3" and white grains, which look like grain sorghum, were observed in cultivar "7".

Balole (2001) reported yellow, orange, red and white grain colors for the ten landraces of sweet sorghum grown at Botswana. He also reported that there was no variation of seed and glume color within a landrace. This suggests that during breeding programs, glume color could be used as a marker for selection. Illustrations of the grain colors were presented in Figure (5.2) for the "7" cultivars of sweet sorghum grown at Towawa in Gedarif for the two seasons 2008/2009.

Table (5.44) **Glume color** and **grain color** of the "7" cultivars of sweet sorghum grown at Towawa (Gedarif) in the rainy seasons 2008/2009:

<table>
<thead>
<tr>
<th>Cultivars</th>
<th>Glume color</th>
<th>Grain color</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Light reddish</td>
<td>Pale brown</td>
</tr>
<tr>
<td>2</td>
<td>Black reddish</td>
<td>Dark brown</td>
</tr>
<tr>
<td>3</td>
<td>½ white ½ black</td>
<td>Yellowish brown</td>
</tr>
<tr>
<td>4</td>
<td>¼ white ¾ brownish black</td>
<td>Dark brown</td>
</tr>
<tr>
<td>5</td>
<td>White with bottom red or black</td>
<td>Pale brown</td>
</tr>
<tr>
<td>6</td>
<td>Dark reddish (Liver color)</td>
<td>Dark brown</td>
</tr>
<tr>
<td>7</td>
<td>Pink or black</td>
<td>white</td>
</tr>
</tbody>
</table>

**Key to cultivars of Sorghum bicolor (L.) Moench. based on morphological characters:**

A : Stem height < 200cm ; number of internodes <11; leaf area < 5000cm² :

B: Stem diameter <1.9cm ; panicle length < 25cm ; glume color pale red(orange) .

BB: Stem diameter > 1.9cm; panicle length > 25cm; glume color not as
above: 

C: leaf area ca 4859.3 cm$^2$; peduncle length ca 39.5 cm; panicle length ca 31.5 cm; panicle width ca 6.4 cm; glumes black reddish.

CC: Leaf area ca 4571.9 cm$^2$; peduncle length ca 35 cm; panicle length ca 26.5 cm; panicle width ca 7.5 cm; glumes dark red (liver color).

AA: Stem height > 200 cm; number of internodes > 11; leaf area > 5000 cm$^2$.

D: Number of seeds/panicle > 3000; peduncle length < 38 cm; glumes black-white.

DD: Number of seeds/panicle < 3000; peduncle length > 38 cm.

E: 100 seeds weight > 2 (g); number of seeds/panicle < 2000; glumes pink; grains white.

EE: 100 seeds weight < 2 (g); number of seeds/panicle > 2000; glumes not as above; grains not as above.

F: 100 seeds weight ca 1.9 (g); number of seeds/panicle ca 2600; glumes white-brownish-black; grain dark brown.

FF: 100 seeds weight ca 1.2 (g); number of seeds/panicle ca 2950; glumes white-dotted with black or orange; grain pale-brown.
Figure (5.2) Grains and glumes of the 7 cultivars of sweet sorghum grown at Towawa (Gedarif) for the two rainy seasons 2008-2009.
Morphological characters and the chemical components of stem juice for the 7 cultivars of sweet sorghum grown at Towawa for the combined seasons were presented on Appendix (3) Table (5.45).

5-2 Chemical studies:
The study also included the chemical components of the juice which were brix %, pol % (sucrose %), purity % and reducing sugars %.

5-2-1 Brix %:
Total soluble solids are usually expressed in brix degrees. There is a positive correlation between sugar content and brix degrees in the juice of sweet sorghum stalks (FAO, 1989). Significant differences were observed in brix% among the cultivars for the combined seasons (Table 5.33) on one hand and the seasons 2008, and 2009 on the other hand. The range of brix % was 14.503- 18.273 for the season 2008 (Table 5.31). In the season 2009 the range of brix % was 14.033 - 16.453 (Table 5.32). This reduction in brix % may be due to low water rainfall during the flowering stage till maturity in the autumn season (2009) Appendix (1). In the combined seasons cultivar "1" had a brix % of 17.363 and cultivar "3" had the lowest brix % value (14.963). These findings were in line with Balole (2001) who reported a range of brix % 8.2 -15.1 for the ten landraces of sweet sorghum grown at Botswana. The results were also supported by Reddy et al. (2007) who reported a brix % range of 9.5 - 21.5 for 42 varieties and hybrids grown at ICRISAT center in Patancheru (India ). In the promising varieties identified for ethanol production in India national programs the birx % ranged between 14.2 and 17.7 (Reddy et al. 2004). The results were supported with those found by Reddy et al. (2007) in India for 7 hybrids grown at ICRISAT in the year 2005 in which the brix % ranged between 9.3 and 18.1. In 2009 at Patancheru (India) 5 hybrids had a range of brix % 15.65 - 20.32. The results were also in agreement with those reported by Anderson et al. (1995) for the "6" American varieties grown at
Table (5.31): Mean Brix % for the seven cultivars of sweet sorghum grown at Towawa (Gedarif) in the rainy season (2008).

<table>
<thead>
<tr>
<th>Cultivars</th>
<th>Rep</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>17.7</td>
<td>15.98</td>
<td>14.75</td>
<td>16.54</td>
<td>15.39</td>
<td>16.86</td>
<td>15.98</td>
<td>16.171</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>19.01</td>
<td>15.41</td>
<td>15.09</td>
<td>15.18</td>
<td>15.51</td>
<td>15.46</td>
<td>15.49</td>
<td>15.879</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>18.11</td>
<td>17.62</td>
<td>13.67</td>
<td>15.6</td>
<td>17.0</td>
<td>17.73</td>
<td>17.38</td>
<td>16.73</td>
</tr>
</tbody>
</table>

LSD at P (5%) = 1.552
C.V % = 5.37

Table (5.32): Mean Brix % for the seven cultivars of sweet sorghum grown at Towawa (Gedarif) in the rainy season (2009).

<table>
<thead>
<tr>
<th>Cultivars</th>
<th>Rep</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>16.49</td>
<td>13.64</td>
<td>15.89</td>
<td>14.52</td>
<td>14.95</td>
<td>13.66</td>
<td>15.19</td>
<td>14.906</td>
</tr>
</tbody>
</table>

LSD at P (5%) = 1.292
C.V % = 4.88

Table (5.33): Mean Brix % for the two combined seasons.

<table>
<thead>
<tr>
<th>Cultivars</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>17.363</td>
<td>15.233</td>
<td>14.963</td>
<td>15.437</td>
<td>15.26</td>
<td>15.358</td>
<td>15.283</td>
</tr>
</tbody>
</table>

LSD at P (5%) = 1.322
C.V % = 5.05
Ames with brix % of 14.107 for (Sugar Drip) and 16.25 for (Grassi) cultivars. The results also coincided with those reported by FAO (1989) in a study conducted at China for 5 varieties of sweet sorghum in which brix % ranged between 11.4 for Jitian "2" and 18.20 for longshi "1" cultivars. The findings of Alsharief (1993) with a range of brix % 17.1 – 21.3 for the cultivars of sweet sorghum grown at Shambat also supported these results. Schaffert and Gourley (1982) reported that brix % for the different sweet sorghum varieties in USA were between 17 -21 and between 10.5 -17.7 respectively.

5-2-2 Pol % (sucrose %):

Significant differences were observed in pol % (sucrose%) among the cultivars in both seasons 2008, 2009 (Tables 5.34, 5.35) and also for the combined seasons (Table 5.36). Cultivar "1" and "7" had the highest sucrose % with values of 10.627, 11.397, 9.857 for cultivar "1" and 10.9, 12.9, 8.9 for cultivar "7" in combined seasons and the seasons 2008, 2009 respectively. The lowest pol % (2.983) obtained by cultivar "5" in the season 2009, compared to a value of (10.070) in 2008, may be due to the low water rainfall that occurred prior to the flowering stage in the season 2009 Appendix (1).

The effect of low level of rainfall was observed clearly in cultivar "5" which was classified as late maturing cultivar. The results were in contrast with that found by Seetharma et al. (1988), Saif (1984) who concluded that water stress increases sugar percentage in sweet sorghum. The average sucrose % (pol %) ranged between 6.527 to 10.9 for the combined seasons, and between 6.607 to 12.9 in the season 2008, and between 2.983 to 9.857 for the season 2009.

These results were supported by Alsharief (1993) who reported an average of 11.6 - 14.75 in season 1990 and 12.9 - 16.2 in season 1991 for "5" cultivars of sweet sorghum. The results were also in agreement with those obtained by Webster et al. (1953) for the eight varieties grown at Oklahoma.
Table (5.34): Mean Pol % (sucrose %) for the seven cultivars of sweet sorghum grown at Towawa (Gedarif) in the rainy season (2008).

<table>
<thead>
<tr>
<th>Cultivars</th>
<th>Rep</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2</td>
<td>13.28</td>
<td>9.92</td>
<td>8.61</td>
<td>9.87</td>
<td>8.34</td>
<td>8.34</td>
<td>12.25</td>
<td>10.087</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>10.44</td>
<td>12.44</td>
<td>6.22</td>
<td>10.06</td>
<td>10.96</td>
<td>10.49</td>
<td>13.01</td>
<td>10.517</td>
</tr>
<tr>
<td><strong>Mean</strong></td>
<td></td>
<td><strong>11.397</strong></td>
<td><strong>9.737</strong></td>
<td><strong>6.607</strong></td>
<td><strong>10.42</strong></td>
<td><strong>10.07</strong></td>
<td><strong>9.32</strong></td>
<td><strong>12.9</strong></td>
<td></td>
</tr>
</tbody>
</table>

LSD at P (5%) = 2.978  
C.V % = 16.62

Table (5.35): Mean Pol % (sucrose %) for the seven cultivars of sweet sorghum grown at Towawa (Gedarif) in the rainy season (2009).

<table>
<thead>
<tr>
<th>Cultivars</th>
<th>Rep</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>10.43</td>
<td>7.48</td>
<td>6.28</td>
<td>4.51</td>
<td>2.07</td>
<td>7.09</td>
<td>9.48</td>
<td>6.763</td>
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<tr>
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<td>2</td>
<td>9.25</td>
<td>6.69</td>
<td>8.86</td>
<td>8.82</td>
<td>3.28</td>
<td>6.50</td>
<td>8.86</td>
<td>7.766</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>9.89</td>
<td>10.41</td>
<td>6.30</td>
<td>3.67</td>
<td>3.60</td>
<td>7.77</td>
<td>8.36</td>
<td>7.143</td>
</tr>
<tr>
<td><strong>Mean</strong></td>
<td></td>
<td><strong>9.857</strong></td>
<td><strong>8.193</strong></td>
<td><strong>7.147</strong></td>
<td><strong>5.667</strong></td>
<td><strong>2.983</strong></td>
<td><strong>7.12</strong></td>
<td><strong>8.90</strong></td>
<td></td>
</tr>
</tbody>
</table>

LSD at P (5%) = 2.77  
C.V % = 21.84

Table (5.36): Mean Pol % (sucrose %) for the two combined seasons.

<table>
<thead>
<tr>
<th>Cultivars</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mean</strong></td>
<td>10.627</td>
<td>8.965</td>
<td>6.877</td>
<td>8.043</td>
<td>6.527</td>
<td>8.22</td>
<td>10.9</td>
</tr>
</tbody>
</table>

LSD at P (5%) = 2.633  
C.V % = 18.21
(USA) in which pol % ranged between 5.49 and 12.77. The results also coincided with that reported by "FAO" in a study conducted in China for 5 cultivars of sweet sorghum with an average ranging between 4.43 for Gitian "2" and 7.91 for Longshi "1". The results were also supported by those found by Reddy et al. (2004) with a range between 9.5 and 13.6 for the 15 promising varieties identified for ethanol production in India national programs grown at ICRISAT center (Patancheru).

Balole (2001) reported values of pol % ranging between 2.36 and 5.82 for the 10 landraces of sweet sorghum. These findings were in line with the results of the current study. Balole added that deheaded plants produced much higher brix values and pol% (up to 30% more) when panicle were removed at 100% flowering. Similar results were also reported by Broadhead (1972) and Ferraris (1981) who found higher brix values, sucrose and starch from deheaded plants. Traditional farmers in Gedarif used to cut panicles at the flowering stage to increase the sucrose % in the stalks of their sweet sorghum crop. They keep part of the heads (panicles) intact for seed production. The local cultivars of sweet sorghum grown at Gedarif State can be considered as good varieties when compared with those grown throughout the world with respect to their pol % and brix % (Figures 5.3, 5.4).

5-2-3 Purity %:

Purity is a measure of sugar content. It is a proportion of sucrose to all soluble solids (brix % in the juice).

There were significant differences in purity % among the cultivars in both seasons 2008, 2009 and the combined seasons, (Tables 5.37, 5.38,). Cultivar "7" had the highest value (70.827) and cultivar "5" had the lowest (41.813) (Table 5.39). In the season 2008 the range was between 79.343 for cultivar "7" and 45.46 for cultivar "3". Cultivar "7" also was observed to have the biggest purity % while cultivars "5" was the smallest in purity % in
the season 2009. The results were in agreement with those of Balole (2001) who found that the purity % for 10 landraces of sweet sorghum was between 16.6 and 38.8. Sweet sorghum juice for syrup production have low purity below 70%, compared to the required purity of at least 75 % for sugar production (Coleman, 1970). The results were also supported with the findings of Venture et al. (1948) who reported a range of purity % between 63.65 – 80.62 for Red X, Early Floger, Sugar Drip, Tracy and Honey varieties of sweet sorghum in the USA. Similarly Dempsey and Broadhead (1979) found purity for "Rio" sweet sorghum to be 73.7%. Again, Alsharief (1993) reported a range of purity% between 66.6 -72.2% in the first season and between 71.8 – 76.4 in the second season for "5" cultivars of sweet sorghum grown at Shambat (Khartoum).

5-2-4 Reducing sugar % (RSS %) :

Significant differences were observed among the cultivars in the seasons 2008, 2009 and the combined seasons in the percentage of reducing sugar in the juice. The average ranged between 0.99 for cultivar "7" and 1.437 for cultivar "2" in the season 2008 (Table 5.40), and between 2.023 for cultivar "5" and 1.607 for cultivar "6" in the season 2009 (Table 5.41) and between 1.652 for cultivar "2" and 1.353 for cultivar "6" in the combined seasons (Table 5.42). It was found that cultivar "2" had the highest % of reducing sugars while cultivar "6" had the lowest % for the combined seasons. The results were in accordance with those reported by Alsharief (1993) whose results ranged between 1.7 -2.7 for "5" cultivars of sweet sorghum studied at Khartoum. Also the results were within the range demonstrated by Krishnaveni et al. (1990), who found that the reducing sugars content of sweet sorghum juice varied between 0.81% and 4.2%. The results were in agreement with that reported by Venture et al. (1948) who found that the average reducing sugars
Figure (5.3) Brix% of cultivar "I" from Sudan compared with varieties from different parts of the world

Figure (5.4) Pol (sucrose %) of cultivar "I" from Sudan compared with varieties from different parts of the world
Table (5.37): Mean purity % for the seven cultivars of sweet sorghum grown at Towawa (Gedarif) in the rainy season (2008).

<table>
<thead>
<tr>
<th>Cultivars</th>
<th>Rep</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>59.15</td>
<td>42.86</td>
<td>33.83</td>
<td>67.89</td>
<td>70.89</td>
<td>54.15</td>
<td>84.10</td>
<td>58.981</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>69.85</td>
<td>64.37</td>
<td>57.05</td>
<td>65.01</td>
<td>53.77</td>
<td>53.94</td>
<td>79.08</td>
<td>63.296</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>57.64</td>
<td>70.43</td>
<td>45.50</td>
<td>64.48</td>
<td>64.47</td>
<td>59.16</td>
<td>74.85</td>
<td>62.381</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td>62.213</td>
<td>59.22</td>
<td>45.46</td>
<td>65.793</td>
<td>63.043</td>
<td>55.75</td>
<td>79.343</td>
<td></td>
</tr>
</tbody>
</table>

LSD at P (5%) = 15.607
C.V % = 14.25

Table (5.38): Mean purity % for the seven cultivars of sweet sorghum grown at Towawa (Gedarif) in the rainy season (2009).

<table>
<thead>
<tr>
<th>Cultivars</th>
<th>Rep</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>63.25</td>
<td>54.83</td>
<td>39.52</td>
<td>31.06</td>
<td>13.84</td>
<td>51.9</td>
<td>62.40</td>
<td>45.257</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>56.92</td>
<td>49.22</td>
<td>61.14</td>
<td>55.26</td>
<td>22.90</td>
<td>49.16</td>
<td>61.87</td>
<td>50.924</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>59.50</td>
<td>68.66</td>
<td>39.64</td>
<td>24.76</td>
<td>25.01</td>
<td>53.0</td>
<td>62.66</td>
<td>47.604</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td>59.890</td>
<td>57.27</td>
<td>46.767</td>
<td>37.022</td>
<td>20.583</td>
<td>51.353</td>
<td>62.31</td>
<td></td>
</tr>
</tbody>
</table>

LSD at P (5%) = 16.362
C.V % = 19.18

Table (5.39): Mean purity % for the two combined seasons.

<table>
<thead>
<tr>
<th>Cultivars</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>61.052</td>
<td>58.395</td>
<td>46.113</td>
<td>51.41</td>
<td>41.813</td>
<td>53.552</td>
<td>70.827</td>
</tr>
</tbody>
</table>

LSD at P (5%) = 14.554
C.V % = 15.81
% for 18 sweet sorghum varieties was 2.3%. Reddy et al. (2007) reported a reducing sugars% between 1.3 and 2.2 for 15 of sweet sorghum varieties identified for ethanol production at ICRISAT center in India. Schaffert and Gourley (1982) found that reducing sugars percentage for sweet sorghum in national trials ranged between 0.7 and 7.3 in the USA.

FAO (1989) reported a range of reducing sugars % between 2.92% for Rio cultivar and 6.17% for Jitian 2 in a study conducted at China for 5 cultivars of sweet sorghum.

Key to the cultivars of sweet sorghum (*Sorghum bicolor* (L.)Moench.) based on chemical components of stem juice (sugars).

A: Late maturing types (≥90 days to physiological maturity):

- \( \text{Purity } > 40\% \) \( \text{and reducing sugars } < 1.5\% \)

B: Pol (sucrose) % ca 8; purity 51.4% ; days to physiological maturity ca 92 days

BB: Pol (sucrose)% ca 6.5 ; purity ca 42% ; days to physiological maturity ca 120

AA: Early maturing cultivars (< 90 days to physiological maturity):

- \( \text{Pol (sucrose)} > 10\% \) \( \text{and purity } > 60\% \)

C. Pol (sucrose) > 10% purity > 60% : .................... 1, 7

D : Brix ca 17.3%; days to physiological maturity ca 84

DD: Brix ca 15.3%; days to physiological maturity ca 87

CC : Pol (sucrose)< 10% ; purity < 60% : ............2 , 3 , 6

E : Brix < 15%, Pol (sucrose) < 8 % ; purity < 50%

EE : Brix > 15%; Pol (sucrose) > 8% ; purity > 50%: ...2, 6

F : Pol ca 9%; purity 50.4% ; reducing sugars ca 1.6% ; days to physiological maturity ca 87

FF: Pol ca 8%; purity ca 53.3% ; reducing sugars ca 1.35 ; days to physiological maturity ca 83
Table (5.40): Mean **reducing sugars %** for the seven cultivars of sweet sorghum grown at Towawa (Gedarif) in the rainy season (2008).

<table>
<thead>
<tr>
<th>Cultivars</th>
<th>Rep 1</th>
<th>Rep 2</th>
<th>Rep 3</th>
<th>Rep 4</th>
<th>Rep 5</th>
<th>Rep 6</th>
<th>Rep 7</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.17</td>
<td>1.73</td>
<td>1.01</td>
<td>1.08</td>
<td>1.21</td>
<td>1.05</td>
<td>1.03</td>
<td>1.183</td>
</tr>
<tr>
<td>2</td>
<td>1.24</td>
<td>1.31</td>
<td>1.31</td>
<td>1.14</td>
<td>1.11</td>
<td>1.17</td>
<td>0.95</td>
<td>1.176</td>
</tr>
<tr>
<td>3</td>
<td>1.21</td>
<td>1.27</td>
<td>1.11</td>
<td>1.08</td>
<td>1.11</td>
<td>1.08</td>
<td>0.99</td>
<td>1.121</td>
</tr>
<tr>
<td><strong>Mean</strong></td>
<td><strong>1.207</strong></td>
<td><strong>1.437</strong></td>
<td><strong>1.143</strong></td>
<td><strong>1.100</strong></td>
<td><strong>1.143</strong></td>
<td><strong>1.100</strong></td>
<td><strong>0.990</strong></td>
<td></td>
</tr>
</tbody>
</table>

LSD at P (5%) = 0.218  
C.V % = 10.65

Table (5.41): Mean **reducing sugars %** for the seven cultivars of sweet sorghum grown at Towawa (Gedarif) in the rainy season (2009).

<table>
<thead>
<tr>
<th>Cultivars</th>
<th>Rep 1</th>
<th>Rep 2</th>
<th>Rep 3</th>
<th>Rep 4</th>
<th>Rep 5</th>
<th>Rep 6</th>
<th>Rep 7</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.76</td>
<td>1.98</td>
<td>1.86</td>
<td>1.98</td>
<td>2.11</td>
<td>1.50</td>
<td>1.98</td>
<td>1.881</td>
</tr>
<tr>
<td>2</td>
<td>1.98</td>
<td>1.76</td>
<td>1.86</td>
<td>1.86</td>
<td>1.98</td>
<td>1.66</td>
<td>1.98</td>
<td>1.869</td>
</tr>
<tr>
<td>3</td>
<td>1.76</td>
<td>1.86</td>
<td>1.76</td>
<td>1.76</td>
<td>1.98</td>
<td>1.66</td>
<td>1.98</td>
<td>1.823</td>
</tr>
<tr>
<td><strong>Mean</strong></td>
<td><strong>1.833</strong></td>
<td><strong>1.867</strong></td>
<td><strong>1.827</strong></td>
<td><strong>1.867</strong></td>
<td><strong>2.023</strong></td>
<td><strong>1.607</strong></td>
<td><strong>1.98</strong></td>
<td></td>
</tr>
</tbody>
</table>

LSD at P (5%) = 0.169  
C.V % = 4.98

Table (5.42): Mean **reducing sugars %** for the two combined seasons.

<table>
<thead>
<tr>
<th>Cultivars</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>3</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mean</strong></td>
<td><strong>1.520</strong></td>
<td><strong>1.652</strong></td>
<td><strong>1.485</strong></td>
<td><strong>1.483</strong></td>
<td><strong>1.583</strong></td>
<td><strong>1.353</strong></td>
<td><strong>1.485</strong></td>
</tr>
</tbody>
</table>

LSD at P (5%) = 0.176  
C.V % = 6.95
Chapter (6)

6-3 Conclusions:
- The results showed significant variations among the "7" cultivars in (12) characters out of 16 Appendix (3).
- These characters included stem height, number of internodes, leaf area, peduncle length, glume color, 100 seeds weight (g), number of seeds per panicle, days to 50% physiological maturity, brix %, pol% (sucrose %), purity % and reducing sugars %.
- Prominent variations were observed among the cultivars in glume colors. This character could be considered as the major trait used by Gedaref traditional farmers and the researcher to differentiate between the cultivars of sweet sorghum cultivated in Gedaref area.
- No significant variations were observed among the cultivars in stem diameter, panicle length, panicle width and grain color.
- Variations in stem height were observed among the cultivars for the two seasons in which cultivar "7" had the highest value (238.6cm) while cultivar "6" was the shortest (187.183cm).
- Cultivar "5" reached physiological maturity in more than 120 days for combined seasons 2008 and 2009 while cultivar "4" reached physiological maturity in more than 90 days. Therefore, these cultivars could be considered as late maturing types while the others (1, 2, 3, 6, and 7) were the early maturing ones.
- From the 16 traits studied it was observed that there were no variations in 13 of these characters between cultivar "1" and cultivar "6". Even the degree of glume color was slightly different. Therefore, more studies should be carried out for these two cultivars to determine whether they were the same variety or not.
- Cultivars "3" and "5" had the lowest weight of seeds, but both cultivars showed a large number of seeds per panicle (3000 or more). Cultivar "7" had white grain which resemble as those of grain sorghum varieties (100 seeds wt over 2g) but it had the least number of seeds per panicle (less than 2000).
- The sucrose % (pol %) was higher (>10%) in cultivars "1" and "7" as compared to the other cultivars, however, the two cultivars had almost the same % of reducing sugars. Cultivars "7" had purity % above 70 which is an advantage for production of jaggery or crystalline sugar.

6-4 Recommendations:

(1) Comparing sucrose % and brix % of the "7" cultivars of sweet sorghum studied, cultivars "1" and "7" were superior to the rest of cultivars. Cultivars "4", "2" and "6" were promising too. So it is recommended to grow these cultivars for jaggery or ethanol production for commercial utilization in the future at Gedarif State.

(2) These local cultivars can be crossed with the Indian or American lines to produce hybrids characterized by high juice quality (rich in sugars), high productivity and high adaptability to environmental factors.

(3) Glume color could be used as the main character to differentiate between the cultivars in Gedarif area as this character was the same within each landrace.

(4) Cultivar "7" should be widely cultivated because it is the most promising cultivar, which is characterized by high % of sugar contents in the juice and grains that could be used for feeding animals (as a forage) as well as humans.
(5) The researcher suggests that more studies should be carried out on accessions of cultivar "7" (Abumaksaben), since this cultivar has more than one type which differ in morphological characters, and may be in the chemical components of the juice too.

(6) Mixed varieties (late and early maturing types) should be planted for commercial processing of extracted sugars of sweet sorghum juice for jaggery and ethanol production at Gedarif State in the future.
References


Bitzer M. J. (2009). Production of sweet sorghum for syrup in Kentucky, report at file:///c:\Documents and Settings\Huda\Desktop\AGR-122.


Stokes, I. E., Coleman, O. H. and Dean, J. L. (1957). Culture of sorgo for


Wikipedia (2006). Sweet sorghum from wikipedia. (cited in file //c:\documents and settings\huda\mdocument\sweetsorghum.htm)


### Table (46) An average of rainfall at Towawa (Gedarif) for the two seasons 2008-2009

<table>
<thead>
<tr>
<th>Seasons</th>
<th>Months</th>
<th>rainfall in mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>2008</td>
<td>May</td>
<td>10.5</td>
</tr>
<tr>
<td></td>
<td>June</td>
<td>14.6</td>
</tr>
<tr>
<td></td>
<td>July</td>
<td>179.7</td>
</tr>
<tr>
<td></td>
<td>August</td>
<td>116.5</td>
</tr>
<tr>
<td></td>
<td>September</td>
<td>188.0</td>
</tr>
<tr>
<td></td>
<td>Sum</td>
<td>509.3</td>
</tr>
<tr>
<td>2009</td>
<td>May</td>
<td>21.3</td>
</tr>
<tr>
<td></td>
<td>June</td>
<td>46.0</td>
</tr>
<tr>
<td></td>
<td>July</td>
<td>88.5</td>
</tr>
<tr>
<td></td>
<td>August</td>
<td>168.8</td>
</tr>
<tr>
<td></td>
<td>September</td>
<td>65.3</td>
</tr>
<tr>
<td></td>
<td>Sum</td>
<td>389.9</td>
</tr>
</tbody>
</table>
Appendix (2)

Figure (7 a-b)
Sweet Sorghum grown at Towawa (Gederif) for the rainy season 2008 at different stages of growth
### Appendix(3)

Table (5.45) Morphological characters and chemical (Sugar contents) of the 7 cultivars of sweet sorghum grown at Towawa (Gedarif) for the combined seasons 2008-2009.

<table>
<thead>
<tr>
<th>Cultivars Characters</th>
<th>cv.1</th>
<th>cv.2</th>
<th>cv.3</th>
<th>cv.4</th>
<th>cv.5</th>
<th>cv.6</th>
<th>cv.7</th>
<th>C.V%</th>
<th>LSD</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Days to 50% maturity</td>
<td>84.2</td>
<td>86.7</td>
<td>84.0</td>
<td>92.0</td>
<td>119.8</td>
<td>83.0</td>
<td>86.5</td>
<td>S</td>
<td>1.54</td>
</tr>
<tr>
<td>2. Stem height</td>
<td>193.7</td>
<td>199.933</td>
<td>215.05</td>
<td>212.6</td>
<td>214.233</td>
<td>187.183</td>
<td>238.6</td>
<td>S</td>
<td>5.35%</td>
</tr>
<tr>
<td>3. Stem diameter</td>
<td>1.863</td>
<td>1.937</td>
<td>2.057</td>
<td>1.913</td>
<td>2.067</td>
<td>1.938</td>
<td>2.095</td>
<td>NS</td>
<td>6.91%</td>
</tr>
<tr>
<td>4. No. of internodes</td>
<td>10.8</td>
<td>10.548</td>
<td>12.04</td>
<td>11.6</td>
<td>12.533</td>
<td>10.5</td>
<td>10.858</td>
<td>S</td>
<td>4.25%</td>
</tr>
<tr>
<td>5. Leaf area</td>
<td>4408.088</td>
<td>4859.673</td>
<td>6311.242</td>
<td>6067.9</td>
<td>6496.633</td>
<td>4571.97</td>
<td>5621.978</td>
<td>S</td>
<td>9.16</td>
</tr>
<tr>
<td>6. Peduncle length</td>
<td>35.233</td>
<td>39.533</td>
<td>37.567</td>
<td>38.5</td>
<td>39.5</td>
<td>35.017</td>
<td>50.958</td>
<td>S</td>
<td>7.85</td>
</tr>
<tr>
<td>7. Panicle length</td>
<td>24.967</td>
<td>31.467</td>
<td>28.983</td>
<td>31.0</td>
<td>27.067</td>
<td>26.567</td>
<td>29.5</td>
<td>NS</td>
<td>9.80</td>
</tr>
<tr>
<td>8. Panicle width</td>
<td>6.817</td>
<td>6.433</td>
<td>6.942</td>
<td>6.5</td>
<td>6.717</td>
<td>7.533</td>
<td>7.312</td>
<td>NS</td>
<td>7.96</td>
</tr>
<tr>
<td>9. Glume color</td>
<td>Light red</td>
<td>Black</td>
<td>Reddish</td>
<td>½white</td>
<td>½ black</td>
<td>½white</td>
<td>½brownish</td>
<td>black</td>
<td>White with bottom or black</td>
</tr>
<tr>
<td>10. Grain color</td>
<td>Brown</td>
<td>Dark brown</td>
<td>Yellowish brown</td>
<td>Dark brown</td>
<td>Pale brown</td>
<td>Brown</td>
<td>White</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>11. 100 seeds wt/g</td>
<td>1.567</td>
<td>1.595</td>
<td>1.145</td>
<td>1.762</td>
<td>1.223</td>
<td>1.800</td>
<td>2.485</td>
<td>S</td>
<td>3.99</td>
</tr>
<tr>
<td>12. Number of seeds/panicle</td>
<td>1951.333</td>
<td>2293.333</td>
<td>3129.5</td>
<td>2602.833</td>
<td>2948.667</td>
<td>2251.5</td>
<td>1541.667</td>
<td>S</td>
<td>12.18</td>
</tr>
<tr>
<td>15. Purity %</td>
<td>61.952</td>
<td>58.395</td>
<td>46.113</td>
<td>51.41</td>
<td>41.813</td>
<td>53.552</td>
<td>70.827</td>
<td>S</td>
<td>15.81</td>
</tr>
<tr>
<td>16. Reducing Sugars %</td>
<td>1.520</td>
<td>1.652</td>
<td>1.485</td>
<td>1.483</td>
<td>1.583</td>
<td>1.353</td>
<td>1.485</td>
<td>S</td>
<td>6.95</td>
</tr>
</tbody>
</table>