CHAPTER ONE

INTRODUCTION

Sorghum (*Sorghum bicolor* (L.) Moench) is thought to have been originated in north-eastern Africa around Ethiopia, Sudan and East Africa (Dogget, 1988; De Wet and Harlan, 1971; Kimber, 2000; Acquaah, 2007). Some researchers argue for multiple centres of origin for the crop (Snowden, 1936; De Wet and Huckabay, 1967). Its distribution around the world is attributed to movement of people and its diversity to disruptive selection in different habitats, specially in northeast Africa (Kimber, 2000). Sorghum is a crop of world-wide importance, ranking fifth among the important cereal crops (Chantereau and Nicou, 1994). In the sub-Saharan Africa, it is arguably the most important cereal crop. The world production of grain sorghum amounted to 63.4 million tonne resulting from growing an area of about 47 million ha 63% of which in the African continent (FAO, 2009).

In Sudan, sorghum is the most important crop for both grain and irrigated fodder production. As grain cereal, sorghum constitutes together with millet and wheat the staple diet of the Sudanese people, ranking first in both tonnage of grain produced and acreage cultivated. According to FAO Statistics-2006, the area planted to sorghum in 2005 amounted to more than 8 million hectares with average yield of about 565 kg/ha which is far below the world average yield of 1330 kg/ha. Growing of low-yielding genotypes is believed to be one of the major factors contributing to low productivity of grain sorghum in the Sudan. As irrigated fodder, records of acreage and tonnage at the national level were difficult to trace in the literature. However, taking Khartoum State as an example, the statistics of the Ministry of Agriculture and Animal Wealth for the years 2007 through 2012 showed that the area cropped to forage sorghum (var.

Abu Sabein) ranged from 97 to 191 thousand feddans while that of Alfalfa (var. Hijazi) ranged from 35 to 45 thousand feddans (Appendix 1). Initially, sorghum grain is used primarily for food; however, its use as a feed now exceeds its use as food specially in developed countries. The use of grain as an animal feed has been an important stimulus to global use of sorghum (Dendy, 1995). Grain for feed was relatively minor until the mid 1960s when feed utilization over took that of food. Industrial uses of crop have been for feed, some for food, starch, the chemical industry and for fuel alcohol. Currently about 48% of world sorghum grain production is fed to live stock (Dowling, *et al.*, 2002) up to 97% of this use has established in many industrialized countries is likely to become more common in developing countries in which sorghum is mainly produced for human consumption (Dowling, *et al.*, 2002) .

Sorghum has great potential for fodder production under limited resource conditions, compared to other cereals, specially maize. It is more droughts tolerant, less input demanding and thrive better under harsh conditions (Mohammed, 2009). It is unique in its ability to produce under a wide array of harsh environmental conditions. Thus, it has recently witnessed an increasing importance as fodder crop in the semi arid tropics and drier parts of the world where livestock constitutes a major component of the production system. Such situation which applies to Sudan was further accentuated by global warming, water shortages, and growing demand for high quality forage resources. In view of the pressing demand for fodder coupled with the fact that grain sorghum is the staple diet of the Sudanese peoples, it is imperative to reconsider the present mono-commodity breeding strategy of sorghum. Kelly, *et al*., (1991) questioned the current strategy of strictly adopting grain-yield criteria in evaluating sorghum genotypes arguing that fodder's contribution to the total value of sorghum production has increased considerably. They reported that the grain /straw price ratio has dropped from 6:1 in 1970 to 3:1 in 1990 and is likely to decline further. Availability of feed throughout the year remains one of the major challenges to animal feed security in many countries, specially the developing ones. Crop residue contributes greatly in alleviating this problem. In Sudan, a part from the natural vegetation, the sorghum residue constitutes the bulk of the animal feed in the country (Mohammed, 2007). In India, small farmers are increasingly dependent on crop residues to feed their livestock. However, attributes relating to crop residue improvement has been largely ignored, with emphasis being placed on grain yield. Thus, dwarf high-yielding grain cultivars with fewer residue has been released in the early days of cereal improvement programs (Reddy, *et al*., 2003). The same situation exists in Sudan, where breeding objectives were set to develop short statured combinable grain cultivars (Mahmoud, 1983). Attributes contributing to high quality-stover were also ignored. This has drastically lowered the residue value of the released sorghum cultivars. Since recognition of crop residues as a viable source of feed, emphasis has been shifted to dual-purpose cultivars for grain and forage. Use of crop residues as fodder depends not only on productivity but also on quality. Sorghum, for example, continues to synthesize new vegetative material even after physiological maturity thus potentially accumulating nutrient in stubble. Also, sorghum stubble does not decrease in quality as rapidly as maize after physiological maturity (Rattunde, *et al.*, 2001). Stover traits can be easily incorporated into existing breeding programs to generate superior dual-purpose (fodder/grain) sorghum varieties suited to smallholder farmers. Such cultivars, apart from contributing in meeting the ever-rising demand for feed and food, will increase incomes of poor–resource farmers by maximizing grain and fodder yields and reducing costs of productions by saving time, labor and inputs under the constraints imposed by the environment and the prevailing production systems.

Being a possible centre of origin, Sudan is endowed with a wealth of genetic variability in sorghum (Yasin, 1978) enabling selection for most economic traits. The sorghum germplasm of Sudan has been utilized extensively all over the world specially in the USA to improve yield of both grain and fodder (Mahmoud, *et al.,* 1996). In contrast, local efforts to exploit such variability to develop dual sorghum types have been very limited and mostly directed towards developing improved grain types. Simultaneous improvement of sorghum for both fodder and grain attributes will help in meeting the demand for feed and food and allow maximum utilization of the limited farmer's resource. Research efforts of such kind were very few or lacking in the Sudan.

The ultimate objectives of this investigation were:

To develop dual purpose (fodder/grain) sorghum genotypes having the potential of combining, to the maximum possible, improved feed and food attributes.

To investigate the magnitude of variability among some local and exotic sorghum for some dual (fodder/grain) related traits.

To investigate associations between the major forage and grain attributes contributing to developing of dual purpose sorghum cultivars.

To evaluate the response of dual cultivars to different harvest options for maximizing dual (fodder/grain) production.

CHAPTER TWO

LITERATURE REVIEW

2.1 Origin and geographic distribution

It is generally agreed that cultivated sorghums arose from the wild *Sorghum bicolor* subspecies averticilliflorum (Stead.) Piper (Doggett, 1988). These wild forms were confined to Africa until recently, implying that domestication occurred in Africa. Both Doggett (1965) and Mann *et al.,* (1983) argued that the greatest variability in the crop and wild sorghums is found in the north-east quadrant of Africa (north of the equator, east of latitude 250E) and this was probably the centre of first domestication, approximately 5000 years ago. However, Harlan and De Wet (1972), using archaeological, palaeobotanical, anthropological and botanical evidence, suggested that domestication occurred at different times in an area extending from the Ethiopian border, west through Sudan and up to Lake Chad.

Recent carbon dating of carbonized sorghum seed found on the Egyptian-Sudanese border was dated at 8000 YBP (years before present) (Wendorf *et al.,* 1992). These sorghums are 3,000 years older and 10-15° latitude further north than had been previously reported and suggested. Nevertheless, more recent studies suggested domestication of sorghum within the present Sudan's territories. Fuller (2004) stated that the charred sorghum from North Sudan at Kawa, suggest a more advanced, free-threshing race cultivated sorghum, such as race caudatum (or perhaps durra). If correctly dated to the early Kushite period, before 400 BC[1], this is significantly earlier evidence for domesticated sorghum than what has been previously reported from Ibrim, or elsewhere in Africa. Moreover, this is not a primitive cultivar but more evolved one. In addition, Beldado and Costantini (2011) reported that sorghum is plausibly domesticated in North Eastern Sudan (Kasala and its environs) since the 2nd and 1st Millennium BC. Their study provided evidence from plant impressions in ceramics from the site of Mahal Teglinos and nearby survey collections confirming the presence of *Sorghum bicolor*.

Eearly domesticated sorghum spread throughout Africa and Asia. Plants were selected and dispersed throughout a broad range of environments and utilization giving rise to a widely adapted genetic base that has been further exploited throughout the agricultural process to create the current crop known as cultivated sorghum. (Poehlman, 1987).The movement of cultivated sorghum into eastern Africa is thought to have occurred with the migration of the Cushitic and Osmotic speakers from south-west and south Ethiopia in approximately 1000-2000 BC. (Maggs, 1977).

2.2 Economic importance and uses of sorghum

Sorghum is the world's fifth most important cereal globally and is the dietary staple of more than 500 million people in 30 countries. It is grown on 40 million ha in 105 countries of Africa, Asia, Oceania and the Americas. Africa and India account for the largest share (more than 70%) of global sorghum area while USA, India, Mexico, Nigeria, Sudan and Ethiopia are the major sorghum producers (Kumar *et al.*, 2011). Sorghum is the only viable food grain crop for many of the world's most food insecure people, who live in sub-Saharan Africa. Its importance to food security in Africa is crucial owing to it's uniquely drought tolerance among cereals and can withstand periods of high temperature. In most of African drought prone countries it was estimated that per capita daily food intake averaged less than 2,000 calories whereas, according to the FAO a daily intake of less than 2,400 calories is indicative of widespread hunger (Taylor, 2003). The importance of sorghum grain as animal feed has been reviewed by many workers (Subramanium and Metta, 2000; Dowling *et al.*, 2002; Reddy *et* *al.*, 2005; Kriegshauser *et al.*, 2006). Sorghum grain is a significant component of animal feed in the United States, South America, Australia and China, and is becoming important in chicken feed in India. In the Unites States it represents the second most important feed grain following maize. In the Sudan, where the second largest animal wealth in Africa exists, sorghum (forage and residue) constitutes the bulk of the animal feed in the country. Forage sorghum (cv Abu Sabein) constitutes more than 75% of the area under fodder crops. Livestock in the Sudan are traditionally fed on sorghum grain of feterita types produced under rain fed conditions.

Uses of sorghum have been discussed by (Dendy, 1995). Much of the agricultural history of sorghum has been for food, beverage, feed and building material. It has been used as an industrial crop during the last 100 years. Mechanization of its cultivation and harvesting has occurred primarily during 1960s. Industrial uses of crop have been for feed, some for food, starch, the chemical industry and for fuel alcohol. The use of grain as an animal feed has been an important stimulus to global use of sorghum (Dendy, 1995). Feed use was relatively minor until the mid 1960s when there was a rapid expansion in this use, particularly in North America. Feed utilization over took food use for the first time in 1966 after which feed use has risen from 15 to 40 million tones. Currently about 48% of the world sorghum grain production is fed to live stock (Dowling, *et al.*, 2002) up to 97% of this use was in the industrialized countries and is likely to become more common in developing countries in which sorghum is mainly produced for human consumption (Dowling, *et al.*, 2002).

Recently, sorghum also appeared to have great potential as an annual energy crop. Depending on the feedstock, the known three types of sorghum could be utilized in energy production. Forage sorghum is an energy sorghum bred for high biomass production for cellulosic ethanol conversion processes. Grain types can be used in starch to ethanol conversion processes. The juice in sweet sorghum types is directly fermented to produce ethanol (Turhollow *et al.,* 2010).

2.3 Sorghum classification

Clayton, (1961) gave historical background on sorghum classification. The first attempt was made by Linnaeus in 1753 under the name of Holcus which he subdivided into three species of cultivated sorghum viz: *Holcus sorghum, H. saccaratus* and *H. bicolor*. In 1794, Moench separated the genus Sorghum from the genus Hocus. In 1805, Person proposed the name *Sorghum vulgare* for *H. sorghum* (L.).

Doggett (1988) overviewed the present-day classification of sorghum. The current name *Sorghum bicolor* (L.) Moench was first considered by Clayton in 1961 and has since then been widely adopted. The most complete and definitive classification of cultivated sorghum (*S. bicolor* (L.) Moench) is done by (Snowden, 1936). All classifications since that time have been modifications or adaptations of the Snowden system. Snowden recognized 31 species, 157 varieties and 571 forms.

A more simplified classification was proposed by Harlan and de Wet (1972) and later developed by de Wet in 1978 to the system that presently recognized by breeders. Under this system of classification, the genus *Sorghum,* which contains all wild and cultivated sorghums, is subdivided into five sections: Spriposorghum, Parasorghum, Heterosorghum, Chaetosorghum and Sorghum. Section Sorghum contains three species *S. halepense* (L.) Person (2n=20), *S.* propinquum (Kunth) Hitchc. (2n=40) and *S. bicolor* (L.) Monech (2n=20). The species *S. bicolor* represents all annual wild, weedy and cultivated taxa. *S. bicolor* is further divided into three subspecies; *S. bicolor* subsp. bicolor, *S. bicolor* subsp. drummondii, and *S. bicolor* subsp. verticilliflorum, formally subsp. arundinaceum. The subspecies bicolo*r* contains all domesticated grain sorghums and their closest wild relatives; subspecies drummondii, includes the derivatives of crosses between domesticated grain sorghums and their closest wild relatives; and subspecies arundinaceum groups together all the wild progenitors of grain sorghum. Harlan and de Wet (1972), using comparative morphology, further divided *S. bicolor* subsp. *bicolor* into five major races and ten hybrid races based on the shape of grains, glumes, and panicles as follows:

Cultivated races

S. bicolor ssp bicolor

Basic races

Race (1) bicolor (B)

Race (2) guinea (G)

Race (3) caudatum (C)

Race (4) kafir (K)

Race (5) durra (D)

Intermediate races (all combinations of basic races)

Race (6) guinea-bicolor (GB)

Race (7) caudatum-bicolor (CB)

Race (8) kafir-bicolor (KB)

Race (9) durra-bicolor (DB)

Race (10) guinea-caudatum (GC)

Race (11) guinea-kafir (GK)

Race (12) guinea-durra (GD)

Race (13) kafir-caudatum (KC)

Race (14) durra-caudatum (DC)

Race (15) kafir-durra (KD)

Spontaneous races: *S. bicolor ssp arundinaceum*.

Race (1) arundinaceum

Race (2) aethiopicum

Race (3) virgatum

In commercial breeding programmes, there are established working groups in cultivated sorghums, namely Kafir, Milo, Feterita, Hegari, Shalu, Kaoliang and Zera-zera (Menz *et al*., 2004; Acquaah, 2007). The significance of the working groups is in differences in adaptation, yield potential and their implications to crop improvement. Researchers argue that the races are the best basis for grouping sorghum into heterotic groups for hybrid programmes (Menz *et al.,* 2004).

2.4 Morphology and physiology of sorghum

Sorghum morphology and physiology have been reviewed by number of workers (e.g. Wilson and Eastin, 1982; Peacock and Wilson, 1984; Doggett, 1988 and Paul, 1990). The growth of cereals has three distinct phases: vegetative, floral initiation and grain filling. The vegetative phase is characterized by continued leaf initiation from undifferentiated apical meristem, leaf growth and absence of internode's elongation. In the floral initiation phase the panicle begins developing, the internodes elongate by differentiation of the apical meristem and the stage ends with 50% of the plants flowering. Grain filling is characterized by the development and maturation of grain, with or without the senescence of leaves. The developmental and physiological growth phases of sorghum have been described by Vanderlip and Reeves (1972) and Eastin (1972). Ten different development stages (numbered 0 through 9) were recognized by Vanderlip and Reeves (1972) while Eastin (1972) identified three growth stages, GS 1-3. The expressions of these phenological stages of sorghum are influenced by genotype and environmental factors. The physiological changes occurring in each of the 10 developmental stages are summarized as:

Stage 0: Emergence – the seedling emerges above ground and the coleoptile leaf is visible.

Stage 1: Third leaf – The third leaf is visible in the collar of the first and second leaf. The growing point is below ground. The radicle extends and forms the seminal root.

Stage 2: Fifth leaf – The fifth leaf is visible in the collar of the fourth leaf. The seminal root has produced some lateral roots. Two or three adventitious roots begin development at the base.

Stage 3: Panicle initiation–The vegetative shoot apex differentiates into the reproductive apex, which is demarcated as an abrupt constriction. Some leaves (six to nine) are fully expanded, while the remaining leaves envelope the panicle meristem. Up to one-third of the total leaf area is fully developed. One to three lower leaves may have senesced. The stem internodes rapidly elongate after panicle initiation. Elongation begins with the basal internode, followed by the longer upper internodes. The root system is well established and the seminal root is prominent with many laterals. Adventitious roots are well extended.

Stage 4: Flag leaf visible – Flag leaf is visible at this stage, and all except for three or four leaves are fully expanded. Approximately 80% of the total leaf area is operational. The panicle meristem has undergone a series of developments: the primary and secondary branches and florets have been developed. Elongation of the stem internodes continues.

Stage 5: Boot – The panicle is fully developed and is nearly full size, but is covered by the sheath of the fully expanded flag leaf. Stem elongation is complete and the peduncle starts elongating, this helps the exertion of the panicle.

Stage 6: Half bloom – The panicle fully emerges from the sheath of the flag leaf. Flowering begins with the emergence of the anthers at the tip of the panicle and progresses downwards. Pollination and fertilization takes place. When 50% of the plants in a crop have obtained some stage of flowering the crop is said to have reached half bloom. Adventitious and nodal root growth reaches its peak. At this stage, half the total dry matter has been produced. Adverse environmental conditions at this stage directly affect fertilization and seed set thus yield.

Stage 7: Soft dough – The grains are fully visible and go through several developmental stages. The endosperm changes from a watery fluid to a milky stage. Grain formation is rapid and the culm loses dry matter. Leaves start to senescence. Eight to twelve functional leaves are present. Adventitious roots start to senescence, but nodal roots are active.

Stage 8: Hard dough – The grain is partly hard and accumulates three-quarters of final grain dry matter. More leaves and adventitious roots senescence.

Stage 9: Physiological maturity – The vascular connection and food supply to the grain is terminated, indicated by a black layer is forming in the hilar region. The black layer starts at the tip of the panicle and proceeds downwards. The grain has reached maximum total dry weight, indicating physiological maturity; grain moisture content varies from 25- 35%. The remaining functional leaves may stay green or senesce. In cereals, panicle development and productivity are the principle factors governing yield potential. The growth phase of panicle initiation and development and ultimately, the partitioning of photosynthates between grains and straw are particularly critical in determining yield outcome. The balance between the number of sinks, their size and storage capacity varies with genotype (Ratikanta Maiti, 1996).

2.4.1 Photoperiod sensitivity in sorghum

Sorghum is known as a short day plant requiring short photoperiods to flower (Ellis *et al*., 1997; Clerget *et al.*, 2004). Development of the plant being delayed by an increase in photoperiod above a critical value, between 10 and 14 h d–" depending upon cultivar. However, in field experiments based on monthly plantings, panicle initiation took place during long days as well as during short days even for highly photoperiod-sensitive varieties thought to be of the absolute type, or was particularly early for the sowings well before days were shortest (Clerget *et al.*, 2004).

Alagarswamy *et al.,* (1998) reported that the development of sorghum is influenced by genes that control sensitivity to photoperiod, and their interaction with photoperiod and temperature. While temperature influences development throughout the life cycle of plants, photoperiod influences the vegetative stage (from seedling emergence to panicle initiation).

Dingkuhn *et al*., (2008) reported that conventional models based on fixed photoperiod thresholds or additive signal accumulations are able to predict flowering for only a limited range of conditions. Recently, an alternative concept was proposed based on thresholds that vary with plant age. Using this concept, they developed a generic model of photoperiod response of sorghum called "Impatience". They reported that their model which was applied to experimental field data obtained from sowing date experiments in Mali predicted accurately the observations that: (1) panicle initiation does not occur at any genotype specific day length, but instead, on increasingly long days as the photoperiod sensitive phase is extended; (2) panicle initiation occurs predominantly when day length decreases, or after summer solstice; (3) the duration of photoperiod sensitive phase increases linearly (but not always proportionally) when crops are sown earlier in the year; (4) a genotype specific sowing date exists in winter (cool season) or spring (hot dry season) after which photoperiod sensitive phase suddenly increases by up to 160 days “break point”; (5) the largest variance of photoperiod sensitive phase occurs near the break point.

Clerget *et al., (*2007) gave some details on photoperiod in sorghum. Landraces of sorghum show very large variation for the duration of their vegetative phase, ranging from 50 to 300 days depending on the sowing date. This variation is linked with the duration of the rainy season in their place of origin. Late sorghum varieties are known to be highly photoperiod-sensitive and, for a given variety, the flowering date remains more or less constant independent of sowing dates, which in the tropical areas of the northern hemisphere occur anytime between May and July.

Clerget *et al.*, (2004) studied three tropical sorghum varieties of different photoperiod sensitivity planted monthly in Mali to investigate contradictory results reported by different workers for photoperiod sensitivity in sorghum. Their results indicated that the common concepts of a gradual (linear, or quantitative) response of photoperiod-induced phase to photoperiod at panicle initiation or a threshold-type response, could be reproduced for the sowing dates falling into the wet season (May-October), but did not describe adequately crop behaviour during the remaining months of the year. Their Modeling exercises showed that field variation in the duration to panicle initiation was better explained with rate of change of photoperiods than with absolute photoperiod observed during photoperiod-induced phase, and best with a combination of both factors in an additive model. They concluded that in tropical sorghum, floral induction is strongly associated with a negative rate of change of day length in the field, and under certain circumstances under controlled conditions, but more evidence is needed to ascertain the capability of sorghum to sense the rate of change of photoperiods before a definite model can be formulated.

2.5 Sorghum breeding in Sudan

Grain sorghum: Mahmoud (1983) gave a comprehensive review for sorghum breeding in Sudan since its inception and up to 1975. Although collection of Sudanese sorghum land races was started by Punter as early as 1914, yet varietal improvement was not started until the early thirties with the introduction of the improved types from the USA. Research work on sorghum improvement really took off in 1952 with the foundation of the Central Rain Lands Research Station at Tozi. The objectives were to develop high yielding combinable varieties to meet the growing need of the mechanized schemes. Selection within the local stocks for high yielding grain types constituted the bulk of research work at the beginning of the breeding program. Dwarf White Milo was released in the early sixties as a replacement to Wad Fahal, the popular but late maturing traditional variety. Three strains of Um Benein (T.U.B. 7, 11, and 22), one of Wad Akar (W. Akar 51/3) and one of Wad Yabis (W. Yabis 1) were distributed to the farmers. The transfer of sorghum breeding work to Wad Medani in early 1970s together with the cooperation of the international programs (ALAD, ICRISAT and INTSORMIL) gave sorghum breeding strong imputes.

Work on grain hybrid sorghum was done on a limited scale prior to the establishment of Tozi Research Station. Mahmoud (1983) attributed this to the absence of a full time sorghum breeder, limited supporting staff and shortage in research funds. However, Mahmoud (1983) reported that in 1960 he made six experimental hybrids using male-sterile 602 as a female with six local parents. Based on the results obtained, Mahmoud proposed an extended hybrid program but the proposal was rejected on the argument that farmers were too illiterate to handle hybrids. Gadam Elhamam Improved and Dabar Improved were released in 1977. Ejeta (1983) discussed the development of grain hybrid sorghum in the Sudan. The real efforts in hybrid development were started after the ICRISAT-

Sudan cooperative program was established in 1977. One of the program objectives was the development of early to medium maturing hybrids for irrigated and rain-fed environments using introduced females (A lines) and a diverse array of local and exotic pollinators. Short combinable types to meet the growing need of the mechanized sector were chosen. In 1983 one experimental hybrid (EEH-3) was officially released as the first commercial grain sorghum hybrid and renamed in Arabic 'Hageen Dura-1'.

Ibrahim (1997) and ElAhmadi (2013) gave some information about sorghum improvement during 1980s and 1990s. The period from 1985 to 1995 witnessed intensive sorghum breeding work and a number of improved open pollinated varieties were released. Some of these include El'Inqaz, Wad Ahmed, and Tabat. According to ElAhmadi (2013) Tabat is the only improved white-seeded cultivar annually produced by seed companies. The latest addition to the rather short list of improved white-seeded varieties is a striga-resistant version of Tabat, T1BC3S4, released in 2012.

Most if not all of the released cultivars developed under sorghum breeding program in the Sudan are of short combinable types with poor fodder value (Ejeta, 1983), However, ElAhmadi (2013) released what he described a dual purpose cultivar developed from the cross Wad Ahmed x Tabat. The released cultivar (given the name 'Elwafir') was said to have better straw yield than Tabat. Originally, Elwafir is not an outcome of a dual purpose breeding program but a restorer line derived from a hybrid grain sorghum breeding program.

Forage sorghum: Very few research efforts have been exerted to develop improved forage sorghum cultivars from the local stocks. The earlier work on forage sorghum breeding in the Sudan has been initiated by A. E. Kambal in the beginnings of 1970s. Kambal (1972) studied the performance of two local forage types, namely, Abu Sabein and Ankolib together with four forage varieties introduced from USA and six Abu Sabein lines derived by single plant selection. Abu Sabein was more productive than the introduced varieties which were characterized by higher tillering capacity and finer juicy-sweet stems. In another trial Kambal (1984) studied the performance of Abu Sabein , two introduced sweet sorghums, one local maize and pearl millet varieties during summer, kharif and winter seasons. He concluded that, 50% increase in yield over the present practice of growing Abu Sabein could be attained by growing the maize variety in winter, Kansas orange in summer and the millet variety in kharif. Kambal (1972) was the first to draw the attention to heterogeneity existing among Abu Sabein population pointing to the possibility of developing improved Abu Sabein versions. The ARC released some exotic forage sorghum hybrids namely: Pioneer 988 from Pioneer International (Ishag, 1989), Speed feed and Jumbo from Pacific Seed Co. (Khair *et al*., 1995), Pannar 888 from Pannar Seed Co. (Nour *et al*., 1998) and Safed Moti from Proagro Seed Co. (ElAhmadi *et al*., 2003). Mohammed (2001) in study of the agronomic performance of Abu Sabein compared to introduced hybrids Pannar 888, Speed feed and Safed Moti, stated that the introduced hybrids were superior in yield than Abu Sabein, however, Abu Sabein showed increased seedling vigor compared to introduced hybrids.

Ibrahim (1996) studied var. Abu Sabein and var. Pioneer to compare quality and quantity of different cuts and growth stages. The results showed that Pioneer yielded more than Abu Sabein. The yield was higher at the second cut for Pioneer, while it decreased significantly for Abu Sabein from the first to the third cuts. The first cut of the two cultivars showed the same quality value while Pioneer was superior for the second cut. Forage yield and crude fiber increased significantly for the two crops with age, while crude protein percent decreased. Comparison between the percent increases of forage with the percent decrease in quality indicated that the best stage of cutting was when the crops were at 25%

bloom. Ibrahim and Orfi (1996) studied variability in forage yield over two sowing dates and two locations in ten sorghum cultivars. Eight of them were grain cultivars while the other two were forage cultivars namely, Abu Sabein and the hybrid Pioneer 988. They presented data based on ranking procedure showing that Abu Sabein and some grain cultivars were superior in forage yield compared to the hybrid Pioneer 988. Among grain cultivars, Saffra and Gadam Elhamam were considered the best yielders. They noticed a wide range of variability for most characters. The effect of sowing date was most pronounced compared to that of location especially for days to flower and plant height.

The first fully dedicated forage sorghum improvement program has been initiated by Mohammed (2001) at Shambat Research Station with the objective of developing improved types by selection among local stocks and exploiting hybrid vigor to develop local x local forage sorghum hybrids. Considerable progress has been made on selection within local forage sorghums and the program succeeded in releasing some of the newly developed materials. The first improved Abu Sabein variety was released in 2004 under the name 'Kambal' (Mohammed *et al*., 2008). 'Sudan-1' the first locally improved Sudangrass (Garawi) cultivar was released in 2009 (Mohammed, 2010a). Developing of local forage sorghum hybrid has been one of the most ambitious breeding objectives. This had been achieved on March 2010 when the Variety Release Committee released the local x local hybrid SHM0022 as the first Sudan forage sorghum hybrid under the name 'Hagin Garawi' (Mohammed, 2010b). The program also succeeded in developing improved types from Ankolib (Mohammed and Mohamed, 2009) and to enhance genetic materials from Abu Sabein for the first time as local females sterilized in A3 cytoplasm (Mohammed, 2004). Some exotic sorghum materials were introduced i.e. sweet sorghum

(Mohammed *et al*, 2009) and released i.e. the hybrid forage sorghum 'Mabrouk' from Misr HiTech (Mohammed, 2013).

2.6 Dual fodder/grain sorghum

Sorghum varieties have been developed specifically for either grain, forage or stem sugar but not for dual-purpose combining grain and forage use. In the early days of cereal crop improvement, emphasis was placed on releasing dwarf, high grain yielding varieties. Since recognition of the need for crop residues as feed for livestock, the emphasis has shifted to dual-purpose cultivars for grain and forage. Dual-purpose varieties could be beneficial to the resource-poor farmers by providing grain for human consumption and forage for livestock feed (Chikuta and Okori, 2012). Residues of sorghum and other cereals are becoming important feed sources for livestock raised by resource-poor smallholders in southern Asia and sub -Saharan Africa (Mohanraj *et al.,* 2011). Although crop residues (also known as stover) have become the main source of feed for farm animals in developing countries, crop breeders have continued to focus their efforts solely on increasing grain yields and not on improving the yield and quality of stover. This situation has been recently addressed in India within a framework of partnership between National Research Centres, ICRISAT-ILRI by focusing on sorghum, as an important staple crop in India that is grown on nearly 10 million hectares throughout the country. The researchers incorporated fodder quality traits in India´s sorghum crop breeding trials and, in so doing, led breeders to identify sorghum varieties that give high yields of both grain and stover, as well as improved stover quality. The result is dual-purpose, food-plus-feed sorghum varieties that are now helping India's 208 million livestock farmers close the livestock feed gap and feed India's growing human population (CGIAR Annual Report 2009*)*.

2.6.1 Sorghum residue (Stover)

Cereal stover or straw, are the parts of the plant remaining after the grain crop has been harvested. They include the leaves and stems. Residues can be collected and removed from the field, then chopped and stored for feeding animals during periods when range grazing is unavailable or can be left standing and the livestock allowed to graze (Kristjanson and Zerbini, 1999). Sorghum possesses maximum potential for crop residue yield and quality. It continues to synthesize new vegetative material even after physiological maturity thus potentially accumulating nutrient in stubble. Also, sorghum stubble does not decrease in quality as rapidly as maize after physiological maturity (Rattunde *et al*., 2001).

Blümmel and Rao (2006) studied the economic value of sorghum stover traded as fodder for urban and peri-urban dairy production in Hyderabad, India. They explored the economic value of sorghum stover in fodder trading and the relationship between stover price and quality in Hyderabad - India. They concluded that the high monetary value of sorghum stover support the concept of simultaneously improving grain yield and stover quality traits in sorghum improvement programs arguing that improving stover digestibility is feasible without sacrificing grain yields. In the Sudan, where the second largest animal wealth in the African continent exists, sorghum straw has the greater contribution in maintaining the national herd (Mohammed and Zakaria, 2014)

Traxler and Byerlee (1993) discussed the slow adoption of modern cereal varieties with high grain yields but lower straw yields in some developing countries where straw is an important source of animal fodder for smallholders. A farmer participatory approach to select improved sorghum varieties followed by ICRISAT revealed that due to the farmers' reliance on livestock for draft power, milk and income generation, they consistently selected sorghum types that would compromise the desired fodder and grain attributes.

Considering the genetic diversity available after 20 years of breeding for increased grain yields, there is substantial opportunity for genetically increasing stover and grain biomass simultaneously (Kristjanson and Zerbini, 1999). In high-input production systems parallel increasing in grain and stover yield may be difficult to achieve, but this is not the prevailing situation in the low-input agriculture of developing countries. Research on sorghum and millet conducted at ICRISAT and elsewhere (Badve *et al.,* 1994; Lynch *et al.,* 1995; Rattunde 1998) seems to indicate that, at the present levels of grain production and with the genetic diversity available, both stover and grain biomass can be genetically increased simultaneously. Increased biomass, however, must be digestible to contribute to livestock productivity increases. Hence the need for a collaborative approach involving both crop and animal scientisis (Kristjanson and Zerbini, 1999). Straw quality and straw yields are beginning to receive attention since there is now evidence that in more marginal environment, there is low adoption of modern cultivars due to perceptions by farmers that, despite lower grain yield, their traditional varieties provide more, higher–quality straw (Kelley and Rao, 1994).

Improving the nutritional values of straw and the efficiency of their use in mixed diets is an important option for increasing livestock production. A number of technologies have been developed to address this constraint. These include biological, physical and chemical treatments of the lingo-cellulosic materials. However, in general, adoption of these technologies has been poor (Singh *et al*., 1997; Devendra *et al*., 1998). Therefore, there is a need to develop alternative technologies for crop residue improvement that are more sustainable and responsive to smallholder farmers' need. Blümmel and Reddy (2006) pointed to the importance of determining simple yet meaningful and easily measurable laboratory fodder quality traits to reliably rank cultivars for stover quality. To achieve this they compared wide range of chemical and in vitro measurements to assess organic matter digestibility, organic matter intake, nitrogen balance and digestible organic matter intake of 22 sorghum stover samples fed to sheep. They concluded that substantial variations were evident in the fodder value of sorghum stovers supporting the concept of genetic enhancement to improve dual-purpose sorghum cultivars. They identified simple laboratory traits such as nitrogen, ADF and true in vitro digestibility to predict relevant livestock responses such as digestible organic matter intake with very high accuracy.

It is possible that genetic variation in the quality of sorghum and millet stover could be exploited to develop improved crop germplasm with stover of higher nutritive value. Small increases in roughage digestibility have been reported to result in considerable increase in milk and meat (ILRI, 1995). In vitro dry-matter disappearance heritabilities for forages were found to range from 50% to 70%, and heritability estimates for fibre components and tannins were high for neutral-detergent fibre and tannin content of sorghum forage (Saini *et al.,* 1977). Such data suggest that digestibility of these species is under genetic control, indicating that improvement should be possible through breeding. Successful improvements in digestibility through selectively bred forage grasses have encouraging implications for the probability of similar research success with millet and sorghum.

2.6.2 Sorghum ratooning

Ratooning is an old cropping system, which has been practiced for many years, especially in the tropics (Africa, India, Australia) and is also practiced in USA (Arizona and California States) where the majority of studies about ratooning came from. However, few of these studies have been published on ratooning of grain sorghums, and most of them focused on management practices for intensive commercial production (Enserink, 1995). The idea behind ratooning is to avoid costs and problems involved in establishing new crop and reach maturity more quickly than direct sown crops (Doggett, 1988). In Kenya, Mburu and Alwodi (2004) reported that although yield of two main crops of improved sorghum varieties exceeded that of ratoon from the local varieties, the farmers preferences is, however, towards ratooning their local sorghum cultivars to avoid extra costs and time wastage in planting twice.

Ratooning grain sorghum has been also reviewed by Wilson (2011). It is a cultural practice to stimulate re-growth of the basal or lower epigeal buds at, or shortly after, the grains have been harvested by removing the photosynthetically active material. The fundamental basis for ratooning is the ability of the plant to behave as a perennial and continue growth beyond one fruiting or harvest cycle. The 'average' sorghum plant undergoes a sequential leaf senescence in which the older leaves at the base of the culm senesce and die. By physiological maturity, most leaves will be senescent, but the basal and lower epigeal buds are initiated, and tillers produced. These tillers will grow until either physiological maturity is reached or severe stress conditions kill them. The speed and timing of leaf senescence and tiller production varies with genotype (Plucknett *et al.*, 1970). The root system of sorghum dies after harvest and the speed and extent of the re-establishment of the new root system has a direct relationship with the performance of the ratoon crop of both grain and forage sorghums (Plucknett *et al.,* 1970). Two basic processes have been identified as of equal importance to the ratooned plant's survival and re-growth (Enserink, 1995). The first process covers the content of soluble carbohydrates in stubble ('food stocks') at the time of stover removal. Sufficient food stock is required to maintain the living stump and to support the buds, which have no roots, or leaves (Oizumi, 1977). The second process deals with the physiological activity of stumps. After the removal of the stover the stumps must maintain the ability to transport water, minerals and carbohydrates to the growing tillers until they are established (Duncan *et al*., 1981). The two processes are influenced by internal (heredity) and external (environmental) factors. One of the most important internal factors is the relative strength of the plant organ sinks. A strong head sink will 'pull' carbohydrates from the stems and roots, especially in times of stress e.g. drought, resulting in the depletion of the 'food stock' required by the plant to re-grow, thus reducing the chance of survival. Sorghum cultivars that remain green after grain maturity have been identified as retaining higher food stocks (McBee *et al*., 1983). These non-senescent cultivars can remain physiologically active longer under stress (Duncan *et al*., 1981). Non-senescent cultivars have also been shown to establish adventitious root system earlier and for the root system to decline slower after grain filling (Zartman and Woyewodzic, 1979).

Sorghum plants do not produce rhizomes or stolons, so the tiller is the organ responsible for the perenniality of the crop, and the ability of the plant to produce productive tillers determines the yield of the ratoon crop. Too early production of tillers can result in non-survival, if the soil moisture is not sufficient, while late development could result in immature tillers at harvest. In grain sorghum, a successful ratoon crop depends upon the production and development of healthy, grain-bearing tillers from the stubble of the preceding crop. The growth of tillers is supported by the main culm. Miltrope and Davidson (1966) and Williams (1966) speculated that tillers, which develop when the main culm is not established, die or become retarded in growth. Escalada and Plucknett (1975) found the first two tillers often died. This was attributed to unestablished parent shoots being unable to support tillers and that during grain filling the available nutrients are predominantly utilised in grain-filling and are therefore unavailable for tiller development.

Comparisons of the phenology of planted and ratoon crops suggest that the grain-forming ratoon tillers and the direct sown crop's primary shoot are similar (Gerik *et al*., 1990). However, the degree of tillering and the partition of above ground biomass to grain are influenced by genotype, which is significantly dependent on the environment. According to Duncan *et al*., (1980) tillers production of ratoon sorghum are quantitatively inherited with additive genetic effects. No indication of significant dominance genetic effects are evident. Thus, selecting for tillers in a ratoon sorghum crop may be rewarding. In Kenya, Mburu and Alwodi (2004) investigated breeding for improved ratoonability in sorghum by crossing local cultivars with good ratoonability, to the recommended improved varieties which are in most cases poor in ratooning. Their aim were to develop high yielding varieties of medium maturity, good ratoonability, and acceptable to farmers. They reported some progress in yield and height (tall stature) but not in earliness.

2.7 Dual purpose (fodder/grain) research in sorghum

A new dual sorghum cultivar under the name 'Sorghum-2011' was developed by Khan *et al.,* (2013) in Pakistan, Faisalabad, Ayub Agricultural Research Institute, from the cross Sugrorib (local) x Australian No.7 (exotic). It was selected through pedigree breeding method during the year 1998-99. Sorghum-2011 performed better in all these trials than the existing cultivars (Hegari, JS-263 and JS-2002). It is a dual purpose variety that produces high tonnage of green chop fresh fodder (70 t/ha) with good grain yield (2.94 t/ha). The variety Sorghum-2011 was released in 2011 for general cultivation in Pakistan.

Perez and Arevalo (1981) reported that cultivar DA-40 produced the highest grain yield but was surpassed in fodder yield by Dulpa, BK-300 and 20 DA 60. R.DA-48 was 8 days earlier than all the other varieties. Therefore it was recommended for dual purpose cultivation.

Lodhi and Bangarwa (1983) evaluated 30 sorghum lines for grain and fodder production. Six strains were found superior to local check variety in both fodder and grain yield. S-260 gave better productivity and excellent in seed production. Mohammad (1989) evaluated forage type, dual type and grain type Sorghum cultivars. He concluded that both dual and forage type sorghum were the best sources of maximum forage and stover yields.

2.7. 1 Potential for dual sorghum improvement in Sudan

There is strong evidence in the literature pointing to the great genetic diversity of sorghum spp. in the Sudan (Tahir, 1964; Yasin, 1978; Doggett, 1988). Genetic variability in forage sorghum was reported by many workers (Sindagi *et al.,* 1970; Murty *et al.*, 1987; Ibrahim and Orfi, 1996; Mohammed, 2004). The same was true for grain sorghum (Tahir, 1964; Abu-El-Gasim and Kambal, 1975; Yasin, 1978).Many of the grain sorghum varieties can be grown as forage crops. According to Harlan and de Wet's (1972) classification the most widely grown forage cultivar 'Abu Sabein' belong to the cultivated grain sorghum race Caudatum-Durra. According to Bacon (1948) the need for fodder influenced farmers to choose vigorous growing plants with finer stems which upon growing at higher seed rate produce a better forage crop. Kambal (2003) reported that the name of Abu Sabein is used for two distinct sorghum cultivars grown for grain production at Rubatab and Alyab areas in Northern Sudan. The one grown at Alyab 'Dibekri' is also cultivated as forage crop in Khartoum and Gezira States. Some heterogeneity exists within both types of Abu Sabein. Selection within such population may result in isolation of lines with better yield and quality. This had been demonstrated by Kambal (1972). 'Abu Kalleiga', a feterita type known of its ability for tillering and branching has also been reported by Bacon (1948) as another form of dual grain/forage sorghum cultivars in Sudan. Ibrahim and Orfi (1996) studied variability for forage yield in some grain and forage sorghum cultivars in Sudan. They presented data showing that some grain cultivars were superior in forage yield compared to the forage hybrid Pioneer 988. Among grain cultivars, Saffra and Gadam Elhamam were considered the best forage yielders. They noticed a wide range of variability for both grain and forage attributes.

Rao and Mengesha (1979) reported that wild sorghums, which are lacking in the present world collection, are particularly abundant in the central Sudan. According to the report of the International Board for Plant Genetic Resources 'IBPGR' (1988) a collecting mission through Sudan, Ethiopia and Kenya obtained 346 accessions of forage sorghum mainly from the cultivated dual purpose 'Sativa' and the wild loose-panicled types of *Sorghum bicolor* var. bicolor. Of these 106 were collected from Sudan and 136 from Ethiopia. The collected accessions included all available wild species and up to 15 hybrid weedy types.

2.8 Genetic diversity and genetic resources in sorghum

Genetic diversity is the cornerstone of crop improvement. Diversity provides the raw materials from which desirable or favourable alleles for improved agronomic traits of interest can be selected (Burow *et al.*, 2012). Presence of considerable genetic variability in the base material ensures better chances of evolving desired plant types. (Anup and Vijayakumar, 2000).

The genus sorghum is known for its wide genetic diversity (Mengesha and Prasada Rao, 1982). Sorghum is unique in that its genetic diversity is well-collected, and maintained. At the global level, there are approximately 168,500 sorghum accessions held in various repositories with two of the largest being the ICRISAT and USDA collections (Pederson and Dahlberg, 2008). The U.S. sorghum collection contains over 42000 accessions (Hooks *et al.*, 2006) and that of ICRISAT amounts to more than 36000 accessions. The tremendous source of genetic variability in sorghum available in the World Collection has made a significant contribution to sorghum improvement in many countries. Hageen Durra-l, the first hybrid released in the Sudan, is from introduced parents (House, 1995). Traits of global and regional importance across the sorghum growing areas are shared between ICRISAT and National Agricultural Research Systems (NARS), (Pederson and Dahlberg, 2008).

Mahmoud *et al*., (1996) reviewed the status of sorghum collection in Sudan. Of Sudan's crops, sorghum's germplasm is the most widely collected, documented and preserved. Collection started in 1914 by Punter. In the late twenties and early thirties, the collection was augmented with local types and exotic introductions, specially from U.S.A. In the early 1940s, S.Evelyn added the most to the collection and painstakingly documented it. Plant breeders from 1952 to 1980 kept adding to the collection. During this period they freely supplied this material to whoever requested it; specially to workers in the USA and India. Between 1975 and 1980, FAO sent two sorghum collection missions that covered western and southern Sudan and ICRISAT sent a mission that collected from Gedarif, Singa, Roseiris and Kurmuk areas. Researchers in Kadugli and El Obied made big collections in their respective areas. This collection well represents Sudan grain sorghums; only the southeastern corner of the country (bordering on Ethiopia and Kenya) and perhaps the Nile, Northern and Red Sea States might need further collections. In 1992, samples of the whole collection of Sudanese sorghums were sent by ICRISAT to Sudan where it was grown, described and catalogued. Samples from its harvest are kept by the Agricultural Research Corporation's (ARC) small germplasm unit at Wad medani. The World Collection at ICRISAT, India now includes some 3,000 entries of cultivated and wild Sudanese sorghums. Removing the replicates may reduce them to 2,000 - 2,500 entries.

2.9 Correlations between different characters in sorghum

Correlations among characters are of interest to the breeder because they might help in identification of easily measured characters that could be used as indicators for more important, but more complex, characters. They are also useful in pointing out the possibilities and limitations of simultaneous improvement of desirable characters (Abdalla, 1991). Correlation among traits could be utilized to enhance the rate of selection response in the primary traits (Moll and Stuber, 1974) and yield components (Grafius, 1969).Yassin (1973) attributed the association among characters to pleiotropy or linkage. Adams (1967) reported that, negative associations between different traits might be due to the competition of two developing structures of plant for limited resources like nutrients and water supply.

There is strong evidence in the literature showing significant and positive correlation between grain yield and number of grains per panicle (Kambal and Webster, 1966; Beil and Atkins, 1967; Liang *et al*., 1968; Dabholkar *et al*., 1970; Kambal and Abu-EL- Gasim, 1976; Orozco meza and Mendoza Onofre, 1983 and others). Significant positive correlation between grain yield and kernel weight was reported by Malm (1968); Sindagi *et al*., (1970); Abifarin and Pickett (1970); However, Kirby and Atking (1968); Pasha and Munshi (1974) found no correlation between the two characters. Mohammed (1988) found that the grain yield per plant was significantly and positively correlated with number of grains per panicle, panicle diameter, stem diameter, threshing percentage, leaf width and leaf area per plant, were and insignificantly correlated with plant height, 1000-grain weight, panicle length, and days to 50% flowering. Grain yield had positive and significant association with plant height and leaves per plant (Arunkumar *et al*., 2004) and also with panicle weight, harvest index, 100-seed weight and panicle length (Kumar, *et al*., 2012).

Harvest index is the ratio of grain yield to total above ground plant yield and is recognized by many plant breeders as an important criterion on the search for high yielding genotypes (Donald, 1962). Appreciably high harvest index shows the efficiency of converting biological yield into economic yield (Kusalkar, *et al*., 2003). Although harvest index is a very variable character, which is highly influenced by the environment yet it may be a useful selection criterion due to its significant correlation with grain yield (Shrotria and Singh, 1988). It has been found that harvest index had a negative correlation with plant height and there is a positive correlation with grain yield, both phenotypically and genotypically (Can and Yoshida, 1999). Contrary to harvest index forage yield is positively correlated with plant height, late maturity, tiller retention and stover yield, but negatively correlated with crude protein content and harvest index (Mohammad *et al*., 1993). Performance of sorghum even under rainfed conditions is significantly associated with green leaf area retention, plant height and maturity (Habyarimana *et al*., 2004).

Like harvest index, green fodder and dry matter yield are also variable characters both of them vary according to cultivars (Gampawar *et al*., 2002). Also there is a significant negative correlation between grain yield and physiological traits related to development and vegetative growth in *S. bicolor* genotypes (Soltani *et al*., 2001). However, there are significant positive correlations for growth rate, grain filling rate and harvest index.

Ross *et al.,* (1983) reported positive correlation between grain yield with stem and leaf yields. Generally, grain yield had no extremely strong negative phenotypic correlations with any forage residue trait. He concluded that, the correlations obtained do not suggest any formidable barriers to simultaneous improvement of agronomic, grain, and forage traits. However, the negative correlations found between grain yield with stem protein and stem invitro dry matter disappearance percentages warrant monitoring in breeding program.

Mohammed and Zakaria (2014) assessed the effect of growth stage and plant part on quality traits in forage sorghum. They reported that harvesting at boot stage will maximize the benefits gained from forage sorghum. Cultivars with improved quality traits might be developed by selecting for high leaf to stem ratio. However, these traits together with crude protein were found to be negatively correlated with forage yield. They concluded that cultivars improved in protein content, intake potential and digestibility could be developed but parallel improvement of these aspects with forage yield might be difficult to achieve. To break this adverse association, concurrent screening for quality and yield attributes in earlier stages of the breeding program has been suggested.

2.9.1 Genetics of height/biomass–yield relationship in grain sorghum

Jaeggli (2009) studied genetics and physiology of height–yield relationship in sorghum and questioned the success of the semi-dwarfing genes in wheat, but not in sorghum. She gave comprehensive review explaining why the dwarfing genes in sorghum have not brought about the same yield increases that caused in wheat. Dwarfing genes are generally employed to prevent crops from lodging and allow machine harvesting. While their introduction in wheat has brought about large yield increases, their direct effects on yield have generally been negative in sorghum. In traditional sorghum growing countries in Africa and India tall varieties predominate and harvested by hand. Their stubble is used for fodder whereas in industrialised countries, short varities that resist lodging are advantageous under mechanized system. Selection for shorter stature in sorghum began around 1880 when farmers in the US increased seed of dwarfed plants that occurred in their crops (Morgan and Finlayson, 2000). It was later found that the shorter stems of these plants were due to spontaneous mutations that affected the elongation of the internodes. Leaf size, leaf sheath length, peduncle length, number of leaves and time of flowering were unchanged, while culm diameters were greater (Graham and Lessman, 1966). Four independently inherited genes, dw1, dw2, dw3, dw4, and a modifying complex are responsible for the reduction in internode lengths (Quinby and Karper, 1954). The effect of dwarfing genes is additive, but as more dwarfing genes are added the reduction per gene is reduced (Hadley, 1957). The four dwarfing genes were recessive "loss-of-function" mutations. One single dwarfing gene can reduce total height by as much as 50 cm. Due to the effects of the modifying complex; great variability in height exists even among varieties with identical alleles at the major loci (Quinby and Karper, 1954). At least one of the four dwarfing genes is unstable and frequently reverts back to the tall allele at a frequency of about 1 in every 600 plants (Campbell and Casady 1969; Graham and Lessman 1966; Quinby and Karper 1954). Such tall plants can be haphazardly observed as off-types in most sorghum fields.

The dwarfing effects are limited to internodes and as internodal elongation usually does not start until after floral initiation, there is no reduction in size of the juvenile plants. The effects on other morphological features (leaf size, tiller number, culm diameter, and panicle size) are much smaller than effects on height (Morgan and Finlayson, 2000). The overall height of a sorghum plant is made up of internode length, peduncle length, and panicle length, with peduncle length and panicle length being under different genetic control to internodal length (Quinby and Karper, 1954). Developmental duration (i.e. maturity) of a sorghum plant influences its height through the number of nodes produced, which equates with the number of leaves produced (Doggett, 1988). There is no effect of the dwarfing genes on maturity per se (Campbell and Casady 1969; Casady 1967), but linkages between height genes and maturity genes have been postulated

(Harinarayana *et al.,* 1971; Quinby and Karper 1954; Quinby and Schertz 1970). Different pleiotropic effects have been ascribed to Dw2 and Dw3. While Dw3 has been found to have effects on number of kernels per panicle, kernel weight, tiller number and panicle size (Casady 1965; Hadley *et al.,* 1965), Dw2 is associated with pleiotropic effects on panicle length, main head yield, seed weight and leaf area (Graham and Lessman, 1966).

While the reduction in stem length provides lodging resistance and easier access with combine harvesters, the direct effect of the dwarfing genes on yield is negative (Campbell and Casady 1969; Doggett 1988; Graham and Lessman 1966; Hadley *et al*., 1965; Milach and Federizzi 2001; Morgan and Finlayson 2000). A positive correlation between plant height and yield is therefore commonly observed in sorghum studies (Ezeaku and Mohammed 2006; Arunkumar *et al.,* 2004; Borrell *et al*., 2000; Henzell *et al*., 1982). Decreases in number of heads per plant, kernel weight and kernel number per head are usually responsible for an overall yield decrease in dwarfed plants (Campbell *et al*., 1975; Casady 1965; Liang *et al*., 1969). However, the yield advantage of tall plants does not arise only from an increased number of tillers. In a comparison of semi-dwarf and dwarfed sorghum plants, differences remained even after results were adjusted for tiller and head number per plant (Hadley *et al*., 1965). Height has a direct positive effect on grain yield per plant in sorghum (Harinarayana *et al*., 1971). The negative correlation between dwarfing genes and yield components applies to true-breeding lines, as well as to sorghum hybrids (Schertz, 1973). Because culm length and grain yield are positively correlated, many dwarfing genes in cereal crops have a negative effect on grain yield (Gale and Law, 1976). The relationship between height and yield is so typical for most cereals that it is said to be intrinsic to the growth patterns and physiology of cereal plants. During the 65 million years of evolution of poaceae in the wild, taller plants would have had a competitive advantage through increased light interception and better seed dispersal (Harper, 1977). Tall plants usually have a smaller harvest index, but greater biomass. If the increase in biomass can compensate for the decline in harvest index, they will have a yield advantage (Richards, 1992). The greater biomass of tall plants provides an increased "source" and is therefore advantageous for increased yield (mainly through greater seed size) (Law *et al*., 1978). Greater biomass can be correlated with productive potential and final yields (Law *et al*., 1978) and therefore it is not changes in harvest index that matters, but changes in total dry matter production are of greater importance to final yields (Monteith and Scott, 1982).

Because many genes are involved in the positive correlation between height and yield, it is unlikely that dwarfing genes have a direct effect on yield, but rather affect yield indirectly through their effect on plant height (Law *et al*., 1978; Pinthus 1987). This complex relationship is the reason why so few dwarfing genes have successfully been used in breeding programs (Borner *et al*., 1993).

The study of Jaeggli (2009) revealed positive correlation between plant height and yield in a population that was fixed for the major dwarfing genes, but variable in peduncle and panicle length (which are under control of minor dwarfing genes). The observed reductions in plant biomass in sorghum were associated with reduced tiller number and a reduction in radiation use efficiency (RUE) in the short types. Reduction in RUE was attributed to increase in allocation of biomass to the roots, rather than differences in photosynthetic capacity or respiration, though, this assumption need to be verified by studies with greater replication. She concluded that since lodging may be controlled by means other than height reduction (e.g. stay-green), grain yield of standard sorghum types used in industrialized countries may benefit from moderate increases in plant height.

CHAPTER THREE

MATERIALS AND METHODS

3.1 The experimental site

The study was conducted in Shambat (lat.15° 39' N; Long.32° 31' E) in the Experimental Farm of the Agricultural Research Corporation (ARC) and the Research Farm of the College of Agricultural Studies, Sudan University of Science and Technology during the years 2010–2013. The physical and chemical soil properties are presented in Appendix 2. The soil is clay-silty, nonsaline, nonsodic with pH 7.8. The climatic conditions of the growing seasons are presented in Appendices 3, 4 and 5. The average min-max temperature during the growing season in 2011 was 14°C and 40°C. The summer season of 2012 has short rainy period extending from July to September with scant and fluctuating precipitation. The mean min-max temp during summer averaged 26°C–39°C whereas the respective temperature during the winter season were 16°C– 35°C.

3.2 The plant materials

The source population of this study was based on a breeding nursery established in 2010 in the Experimental Farm of ARC. The material grown consisted of 122 sorghum genotypes comprising 34 Sudangrass, 33 Abu Sabein, 29 grain sorghum, 17 sweet sorghum and 9 Ankolib genotypes (Appendix 6). All materials other than grain sorghum were developed or kept by the Forage Improvement Programme (FIP) at Shambat Research Station (Sh.R.S.). The grain sorghum genotypes were collected from different parts of the country, or provided by other research programs as shown in Appendix 6.

The materials were evaluated for some characters including (but not limited to) days to flower, plant height (cm), stem diameter (cm), tillering, leafiness, stay green and sugar content (Brix^{O}). Panicle and grain characteristics were evaluated in the laboratory from five heads, randomly chosen from each genotype. Based on the above attributes, 21 genotypes comprising 7 Sudangrass, 5 each Abu Sabein and grain sorghum and 2 each Ankolib and sweet sorghum were selected. These were tested against 3 checks in a preliminary yield trial (PYT). The 24 entries comprised the PYT (Table 1) were further evaluated for dual fodder/grain yield and related traits. Based on the results obtained 6 genotypes were selected for testing in advanced yield trial (AYT) against one dual purpose check. The 7 entries comprised the AYT are presented in Table 2.

3.3 The experiments

3.3.1 Management

Management practices were the same for the breeding nursery, preliminarily yield trial (PYT) and advanced yield trial (AYT). The land was disc ploughed, disc harrowed and leveled by scraper to obtain fine seed bed. Ridging was done at 0.75 m spacing. The plots were watered before sowing to ensure fine seed bed. Nitrogen fertilizer, urea was added at the second irrigation at rate of 55 kg N/ha, The insecticide Sevin 85 WP (Carbaryl) was sprayed against stem borers one month after sowing at rate of 0.98 kg/fed. Irrigation water was applied at 10-12 days interval. Weed population was kept at minimum by hand weeding.

3.3.2 The breeding nursery

The 122 sorghum genotypes were sown on 25/11/2010. Each genotype was represented by one 5m - ridge replicated twice. Sowing was done manually on the eastern side of the ridge by placing 5 seeds in holes spaced at 20 cm. Thinning was done to 1-2 plant per hole as appropriate.

Table1.The selected forage sorghum genotypes evaluated in the preliminary yield trial (PYT) (Shambat, 2011)

Entry	Genotype	Group/Type
1	SG33	Sudangrass
2	SG08	Sudangrass
3	SG54	Sudangrass
4	SG53-1	Sudangrass
5	SG12-1	Sudangrass
6	SG51	Sudangrass
7	SG32-1	Sudangrass
8	S.25Abu70	Abu Sabein
9	S.24Abu70	Abu Sabein
10	S.26Abu70	Abu Sabein
11	S.134Abu70	Abu Sabein
12	S.03Abu70	Abu Sabein
13	ANKSenar	Ankolib
14	ANKNyala	Ankolib
15	E-35-1	Sweet sorghum
16	Atlas	Sweet sorghum
17	ArfaaGadamek	Grain sorghum
18	HagaBanat	Grain sorghum
19	FakiMustahi	Grain sorghum
20	Hemasi	Grain sorghum
21	Abjaro	Grain sorghum
22	Abnaffain	Grain sorghum(dual check)
23	SG32-2A	Sudangrass (forage check)
24	WadAhmed	Grain sorghum(grain check)

Table 2. The selected forage sorghum genotypes evaluated in the advanced yield trial (AYT) (Shambat summer, 2012 and winter, 2012/2013)

Entry	Genotype	Group/Type
1	Abjaro	Grain sorghum
2	Abnaffain	Grain sorghum (dual check)
3	S.25Abu70	Abu Sabein
4	S.03Abu70	Abu Sabein
5	E-35-1	Sweat sorghum
6	SG51	Sudangrass
7	SG08	Sudangrass

3.3.3 Preliminary yield trial (PYT)

The experimental layout is shown in Appendix 7. The 21 selected genotypes plus the three standard checks (totaling 24) were arranged in alpha-lattice design (Patterson and Williams, 1976) with 12 incomplete (iblock) and 4 complete blocks. The iblock composed of two plots each having two 5m ridges. The iblocks were separated by 1m from each other. The blocks were separated by 2m road and watered by a separate canal. Planting date was effected on 11/10/2011. Sowing method and planting density were similar to those of the breeding nursery. The two outer rows of each incomplete block were used to estimate grain yield and the inner rows were used to estimate forage yield.

3.3.4 Advanced yield trial (AYT)

The experimental layout was shown in Appendix 8. The AYT was grown during the summer and winter seasons. The summer sowing was effected on 13 July 2012 whereas the winter sowing was on 15 October 2012. The performance of the 7 genotypes was assessed under two harvest options viz.:

Harvest Option One (HOP1) The crop was cut at heading time to evaluate forage yield and the ratoon (regenerated crop) was left to grow up to maturity stage to evaluate grain yield.

Harvest Option Two (HOP2) The crop was left to grow up to seed maturity to evaluate grain and stover yield.

The treatments were replicated 4 times in split plot design with the harvest options assigned to the main plot and genotypes to the sub plot. The plot consisted of 4 ridges 6m long spaced at 0.75 m. Sowing method and planting density were similar to those of the breeding nursery.

4.0 Data Taken

Unless otherwise specified the following data were recorded for both PYT and AYT trials:

4.1 Agronomic data

4.1.1 Forage yields and related traits

The green matter yield (GMY, t/ha): In the PYT, the GMY was recorded at flowering from 4 m row randomly chosen from each plot leaving the edge of the ridges whereas in the AYT, the whole plot was harvested at heading time to estimate the GMY. Cutting was done at 5 to 7 cm above the ground level.

The dry matter yield (DMY, t/ha): Estimated from a random sample of 0.5 kg taken from the GMY of the harvested plot and air dried to a constant weight. The dry weight of the sample was then used to convert the GMY of the corresponding plot to DMY

Regrowth (gm): Evaluated in the PYT on dry weight basis 15 days after the date of cutting of each entry. New immerging shoots from 5 competitive plants randomly chosen from each harvested plot were collected and air dried and the dry weight was determined.

Days to booting: Taken when 50% of the plants in each plot were at booting stage.

Days to heading: Taken when 50% of the plants in each plot reached the stage of panicle emergence.

Days to flowering: Estimated in the preliminary yield trial (PYT) when 50% of the plants in the whole plot started to shed pollens.

The following three growth traits, namely: plant height, stem diameter and leaf to stem ratio were estimated from 3 plants randomly chosen from each plots:

Plant height (cm): Measured at harvest from ground level to the tip of the head.

Stem diameter (cm): Taken as the thickness of the stalk at the middle of the fourth internode from the plant base using a vernier calliper.

Leaf to stem ratio: Measured on dry weight basis. Leaves were detached from stems and were separately air dried. Average dry weights of leaves and stems were determined. The ratio of leaf to stem was calculated by dividing the weight of the leaves by the total weight of leaves and stems.

4.1.2 Grain yield and related traits

Grain yield/plant (gm): The panicles were left to dry in the laboratory, threshed in bulk and the average weight was determined.

In the PYT, 5 panicles were randomly chosen in each plot and bagged. The panicles were harvested at physiological maturity and taken to the laboratory to assess grain yield and related traits as follows:

Grain yield (kg/ha): Estimated in the AYT by harvesting heads representing 25% of the area of each plot omitting the edge plants. The panicles were covered by cloth bags prior to seed setting to avoid bird damage. At grain maturity, the panicles were harvested, left to dry in the lab, threshed in bulk and weighted. The grain yield per plot thus obtained was transformed to grain yield kg/ha

Stover yield t/ha: Evaluated in the AYT following grain harvest in each plot. The plants left were cut 5 to 7 cm above ground level to evaluate the stover yield per plot which was then transformed to ton/ha.

Panicle length (cm): Measured from the base to the tip of the panicle.

Panicle circumference (cm): Taken as the maximum circumference of the panicle using a measuring tape.

Seed number/panicle: calculated by dividing seed weight per panicle over the corresponding1000 seed weight and then multiplied by 1000.

1000 seeds weight (gm): The weight of 1000 grain taken as a random sample from the bulked seeds of each plot.

4.2 Proximate quality traits

Evaluated in the AYT. For forage material, the following three quality traits were studied on dry basis; using bulked material from the AYT conducted in the summer season.

1. Neutral detergent fiber (NDF)
2. Acid detergent fiber (ADF)
3. Crude protein (CP)

With regard to grain material, the crude protein was evaluated alone in each season and for both harvest options. The analysis was done following the standard procedure of the AOAC (1980). Crude protein was analyzed using micro-kjeldhal method. The CP in each sample was estimated from total nitrogen using the numerical conversion factor = 6.25. The chemical analysis was carried out in the Laboratory of the Faculty of Animal Production, Shambat, University of Khartoum.

5.0 Statistical analysis

In the PYT the data was subjected to analysis of variance (ANOVA) following the procedure of alpha lattice design (Patterson and Williams, 1976). Correlation between different characters was also worked out. Table 3. Shows source of variation and partitioning of degrees of freedom used in the alpha lattice analysis. In the AYT the data of each harvest option in each season was subjected to single ANOVA of (RCBD) before performing the combined ANOVA which was carried out across seasons for each harvest option. Only characters that showed homogeneous error variance (namely: plant height, forage yield and leaf to stem ratio) were combined following Snedecor and Cochran, (1967). ANOVA of split plot in (RCBD) (Cochran and Cox, 1957) was used to analyze the data of the characters evaluated at both harvest options, namely: grain yield, days to boot and plant height. Tables 4 and 5 show source of variations and partitioning of degrees of freedom used in the combined and split plot analysis, respectively.

Least Significant Difference (LSD) and Duncan's Multiple Range Test (DMRT) were used to separate means in AYT and PYT, respectively. Tables 3 and 5 show source of variations and partitioning of degrees of freedom used in the analysis of alpha lattice and split plot in (RCBD), respectively. The statistical software packages Agrobase Gen II (2008) was used to run alpha lattice design whereas GenStat (2011) was used to run split plot ANOVA and correlation analysis.

Table 3. Source of variations and partitioning of degrees of freedom used in the alpha lattice analysis

Source of variation	Degrees of freedom
Reps (complete blocks) (R)	r-1
Entry (T)	t-1
Residual (RCBD)	(r-1)(t-1)
iBlock (incomplete block) (S)	rs-r
Error (Intra rep)	rt-rs-t+1
Total	n-1

Table 4. Source of variations and partitioning of degrees of freedom used in the combined analysis

Source of variation	Degrees of freedom
Season (E)	e-1
Residual	e(r-1)
Entry (G)	g-1
G*E	(g-1)(e-1)
Error	e(r-1) (g-1)

Table 5. Source of variations and partitioning of degrees of freedom used in the split plot analysis

Source of variation	Degrees of freedom
Blocks (r)	r-1
Main plot (Factor A)	a-1
Error (a)	(r-1)(a-1)
Sub plot (Factor B)	b-1
Interaction A*B	(a-1)(b-1)
Error (b)	a(r-1)(b-1)
Total	n-1

CHAPTER FOUR

RESULTS

4.1 The Preliminary yield trial (PYT)

4.1.1 Analysis of variance

Mean squares from ANOVA for different yield and related traits of 24 sorghum genotypes tested in the preliminary yield trial are shown in Tables 6, 7, 8 and 9. The analysis of variance revealed highly significant differences among genotypes for all studied traits. The magnitudes of mean squares due to genotypes were in most cases were 10 folds greater than that of the error. Mean squares due to incomplete blocks (iblocks) were not significant for all traits; however, in some cases they were specifically larger than those due to blocks e.g. regrowth weight (Table 6) and number of seed/panicle (Table 9).

4.1.2 Agronomic performance

4.1.2.1 Forage yield

Tables 10 and 11 show dry (DMY) and green (GMY) matter yields obtained by different cultivars in the PYT. The overall mean for DMY was 7.34 t/ha. The Sudangrass genotype SG33 gave the highest DMY (11.4 t/ha) followed by Abjaro (9.85 t/ha), S.25Abu70 (9.80 t/ha), SG08 (9.74 t/ha) and S.03Abu70 (9.19 t/ha). The grain types (WadAhmed, ArfaaGadamak, FakiMustahi) and Ankolib types gave low DMY ranging from 4.26 to 5.43 t/ha. The lowest DMY was shown by Abnaffain (3.78 t/ha)

The overall mean for GMY was 33.8 t/ha (Table 11). Generally, the genotypes kept similar trend as in DMY. The highest GMY was shown by S.25Abu70 (48.0 t/ha) and SG33 (47.7 t/ha) whereas the lowest GMY was shown by Abnaffain (18.0 t/ha).

4.1.2.2 Grain yield per plant

Table 12 shows grain yield per plant obtained by different genotypes in the PYT. The overall mean for grain yield per plant was 31.6 gm. Abjaro showed the highest grain yield (72.5 gm) followed by S.134Abu70 (57.5 gm), S.26Abu70 (49.1 gm), Hemasi (45.6 gm) and S.25Abu70 (44.1gm). S.03Abu70 and E-35-1 averaged 41.9 and 36.9 gm, respectively. SG53-1 and SG51 gave the best grain yield among Sudangrass group averaging 30.1 and 28.8 gm, respectively. Abnaffain, ArfaaGadamak and WadAhmed gave below average grain yield amounting to 25.7, 23.6 and 21.7 gm, respectively. The lowest grain yield was shown by the Sudangrass genotypes SG33 (18.4 gm), SG32-2A (13.7 gm) and SG32-1 (12.9 gm).

Table 6. Mean squares from ANOVA for different yield and related traits of 24 sorghum genotypes tested in the PYT (Shambat, 2011)

Source of variation	**DF**	**Green matter yield (t/ha)**	**Dry matter yield (t/ha)**	**Grain yield/plant (gm)**	**Regrowth weight (gm)**
Block	3	113.00*	4.845	86.856	6.394
Genotype	23	275.862**	15.254**	815.573**	70.534**
Residual†	69	30.428	2.004	67.697	13.352
iBlock ♣	44	36.190	2.014	78.527	15.933
Error ‡	25	20.285	1.987	48.63777	8.810

***, ** = significant and highly significant at 0.01 probability level, respectively**
† = RCBD residual
♣ = Incomplete block
‡ = Intra block error

Table 7. Mean squares from ANOVA for yield-related traits of 24 sorghum genotypes tested in the PYT (Shambat, 2011)

Source of variation	DF	Days to booting	Days to flower
Block	3	20.427**	20.427**
Genotype	23	97.521**	75.565**
Residual†	69	4.195	4.007
iBlock ♣	44	5.211	5.009
Error ‡	25	2.407	2.244

****= highly significant at 0.01probability level**
† = RCBD residual
♣ = Incomplete block
‡ = Intra block error

Table 8. Mean squares from ANOVA for yield-related traits of 24 sorghum genotypes tested in the PYT (Shambat, 2011)

Source of variation	DF	Plant height (cm)	Stem diam. (cm)	Leaf /stem ratio
Block	3	700.260**	0.013	0.000
Genotype	23	2757.597**	0.104**	0.004**
Residual†	69	129.311	0.009	0.001
iBlock ♣	44	157.543	0.010	0.001
Error ‡	25	79.623	0.007	0.001

**** = highly significant at 0.01 probability level**
† = RCBD residual
♣ = Incomplete block
‡ = Intra block error

Table 9. Mean squares from ANOVA for yield-related traits of sorghum genotypes tested in the PYT (Shambat, 2011)

Source of variation	DF	Panicle length (cm)	Panicle circumference (cm)	Number of seed/panicle	1000 seed weight (gm)
Block	3	6.372	1.541	26354.111	53.349*
Genotype	23	52.248**	32.898**	440505.304**	238.050**
Residual†	69	2.384	1.306	38651.300	18.012
iBlock ♣	44	2.562	1.438	40529.697	19.574
Error ‡	25	2.071	1.075	35345.320	15.286

***, **= significant and highly significant at 0.05 and 0.01 probability level, respectively**
† = RCBD residual
♣ = Incomplete block
‡ = Intra block error

Table 10. Dry matter yield (DMY) of sorghum genotypes evaluated in the PYT (Shambat, 2011)

Entry	Genotype	DMY (t/ha)		Rank
1	SG33	11.4	A	1
21	Abjaro	9.85	A B	2
8	S.25Abu70	9.80	A B	3
2	SG08	9.74	A B	4
12	S.03Abu70	9.19	A B C	5
11	S.134Abu70	8.86	B C D	6
3	SG54	8.85	B C D	7
10	S.26Abu70	8.19	B C D	8
7	SG32-1	7.71	B C D E	9
18	HagaBanet	7.67	B C D E	10
9	S.24Abu70	7.64	B C D E	11
15	E-35-1	7.39	B C D E	12
23	SG32-2A	7.18	C D E	13
16	Atlas	7.12	C D E	14
6	SG51	7.08	C D E	15
20	Hemasi	6.79	C D E	16
4	SG53-1	6.73	D E	17
5	SG12-1	6.66	D E	18
14	ANKNiyala	5.43	E	19
24	WadAhmed	5.35	E	20
13	ANKSenar	5.25		21
17	ArfaaGadamak	4.32		22
19	FakiMustahi	4.26		23
22	Abnaffain	3.78		24
	Mean	7.34		
	S.E±	0.7079		
	C.V (%)	19.28		

Means with letter in common are not significantly different at 0.05 probability level according to Duncan's Multiple Range Test

Table 11. Green matter yield (GMY) of sorghum genotypes evaluated in the PYT (Shambat, 2011)

Entry	Genotype	GMY (t/ha)		Rank
8	S.25Abu70	48.0	A	1
1	SG33	47.7	A	2
11	S.134Abu70	45.1	A B	3
12	S.03Abu70	43.7	A B	4
10	S.26Abu70	42.4	A B C	5
21	Abjaro	42.1	A B C D	6
2	SG08	41.1	A B C D E	7
9	S.24Abu70	39.3	A B C D E F	8
3	SG54	36.9	B C D E F	9
7	SG32-1	36.8	B C D E F	10
23	SG32-2A	34.0	C D E F	11
16	Atlas	33.1	C D E F	12
5	SG12-1	32.7	D E F	13
15	E-35-1	32.7	D E F	14
6	SG51	31.8	E F	15
4	SG53-1	30.8	F	16
13	HagaBanet	30.1	F	17
20	Hemasi	28.6		18
13	ANKSennar	27.8		19
14	ANKNiyala	26.6		20
24	WadAhmed	23.4		21
17	ArfaaGadamak	20.4		22
19	FakiMustahi	19.0		23
22	Abnaffain	18.0		24
	Mean	33.8		
	S.E±	2.6240		
	C.V (%)	15.51		

Means with letter in common are not significantly different at 0.05 probability level according to Duncan's Multiple Range Test

Table 12. Grain yield of sorghum genotypes evaluated in the PYT (Shambat, 2011)

Entry	Genotype	Grain yield/plant (gm)		Rank
21	Abjaro	72.5	A	1
11	S.134Abu70	57.5	A	2
10	S.26Abu70	49.1	A B	3
20	Hemasi	45.6	A B	4
8	S.25Abu70	44.1	A B C	5
12	S.03Abu70	41.9	B C D	6
9	S.24Abu70	37.9	B C D	7
15	E-35-1	36.9	B C D	8
4	SG53-1	30.1	C D	9
6	SG51	28.8	D	10
19	FakiMustahi	28.2	D	11
16	Atlas	27.7	D	12
3	SG54	27.1		13
13	ANKSennar	25.7		14
22	Abnaffain	25.7		15
2	SG08	24.0		16
5	SG12-1	23.9		17
17	ArfaaGadamak	23.6		18
18	HagaBanat	22.5		19
24	WadAhmed	21.7		20
14	ANKNiyala	19.1		21
1	SG33	18.4		22
23	SG32-2A	13.7		23
7	SG32-1	12.9		24
	Mean	31.6		
	S.E±	3.9725		
	C.V (%)	25.14		

Means with letter in common are not significantly different at 0.05 probability level according to Duncan's Multiple Range Test

4.1.2.3 Forage yield related traits

The results obtained for the following yield related traits by different sorghum genotypes grown in the PYT are presented in Table 13.

Booting and flowering: The average performance for days to booting and flowering were 49.9 and 58.9 days, respectively. The genotypes SG12-1 and Abnaffain were the earliest to flower. The former took 39.1 day to boot and 52.3 day to flower whereas the respective days for Abnaffain were 42.3 and 53.2. In contrast, Abjaro and E-35–1 were the latest to flower taking 71.3 and 66.0 days. Their respective days to boot were 61.3 and 58.7. The flowering time for Abu Sabein genotypes ranged from 55.9 to 58.7 days. ArfaaGadamak and Wad Ahmed took 57.7 and 59.5 days to flower, respectively. FakiMustahi was comparable in flowering time to most of Abu Sabein genotypes.

Plant height: The average performance for plant height was 182 cm. Abjaro was the tallest (217 cm) whereas ArfaaGadamak and WadAhmed showed the shortest stature (122 cm). The plant height of Sudangrass genotypes ranged from 178 and 214 cm whereas that of Abu Sabein group ranged from 187 to 201 cm. The plant heights of SG32-2A and Abnaffain were 211 and 171 cm, respectively. The latter was significantly taller than ArfaaGadamak, WadAhmed and FakiMustahi.

Stem diameter: The average performance for stem diameter was 0.95 cm. (Table 13). Abjaro was the thickest (1.57 cm) whereas SG32-2A was the thinnest (0.65 cm) in stem diameter. The genotypes SG33 and SG51 were the thickest among Sudangrass group showing stem diameter of 1.02 and 1.00 cm, respectively. All of Abu Sabein genotypes, apart from S.24Abu70 showed above average stem diameter (0.97 to 0.98 cm) whereas Abnaffain, ArfaaGadamak, WadAhmed and FakiMustahi showed below average stem diameter ranging from 0.82 to 0.92 cm.

Leaf to stem ratio: The average performance for leaf to stem ratio was 0.39. The highest ratio was shown by ArfaaGadamak (0.45), WadAhmed (0.44), FakiMustahi (0.44), Abjaro (0.43) and Atlas (0.43). The Sudangrass genotypes, Abu Sabein genotypes (apart from S.26Abu70) and Abnaffain, all showed below average leaf to stem ratio. The lowest leaf to stem ratio was shown by SG08 (0.34) and SG33 (0.35).

Regrowth weight: The average performance for regrowth weight per plant was 21.9 gm/plant. The highest regrowth weight was given by the Sudangrass genotypes SG32-2A (33.6 gm/plant) and SG08 (30.6 gm/plant). Abnaffain Fakimustahi and All of the Abu Sabein genotypes gave below average regrowth weight ranging from 17.0 to 19.6 gm/plant. Some of Sudangrass genotypes (SG54 and SG53-1) also gave below average regrowth weight. In contrast ArfaaGadamak and Abjaro gave above average regrowth weight of about 23.9 and 22.3 gm/plant, respectively.

4.1.2.4 Grain yield components

The following grain yield components obtained by different sorghum genotypes grown in the PYT are presented in Table14.

Number of seeds per panicle: Mean performance for number of seeds per panicle was 1098 seeds. Abjaro gave the greater number of seed per panicle (1879) whereas SG32-1 showed the lowest number (458 seed/panicle). The genotypes Atlas and E-35-1 ranked second to Abjaro. Number of seed per panicle obtained by Abu Sabein genotypes ranged from 1159 to 1465 seed. ArfaaGadamak and WadAhmed gave 1234 and 1216 seed/panicle, respectively. Abnaffain showed below average seeds per panicle (719). Apart from SG51 and SG53-1, all of the Sudangrass genotypes showed below average number of seed per panicle.

1000 seed weight: Mean performance for 1000 seed weight was 28.5 gm. The greater seed weight was expressed by the genotypes: Hemasi, S.26Abu70, S.134Abu70, S.25Abu70, Abjaro and Abnaffain showing seed weight ranging from 36.8 gm (for Abnaffain) to 38.5 gm (for Abjaro). The lowest value for seed weight was shown by SG32-2A (16.2 gm) and WadAhmed (16.5 gm) ArfaaGadamak also showed low seed weight (19.5 gm). Apart from SG12-1 and SG32-1, all of the Sudangrass genotypes showed below average seed weight.

Panicle length: Mean performance for panicle length was 20.5 cm. the largest value for panicle length was shown by ArfaaGadamak (26.9 cm) and FakiMustahi (25.0 cm) whereas the smallest value was shown by Abjaro (15.7 cm) and E-35-1 (15.8 cm). Most of the Sudangrass genotypes showed above average panicle length. In contrast all of the Abu Sabein genotypes and Abnaffain have below average panicle length ranging from 16.4 to 18.9 cm.

Panicle circumference: Mean performance for panicle circumference was 14.9 cm (Table 14). Abjaro gave the largest panicle circumference (24.2 cm) whereas the smallest value was shown by SG32-2A (10.9 cm). All of the Abu Sabein genotypes and Abnaffain showed above average panicle circumference ranging from 15.8 to 17.3 cm. in contrast ArfaaGadamak, WadAhmed and all of the Sudangrass genotypes, gave below average panicle circumference ranging from 11.8 (for ArfaaGadamak) and 14.8 cm (for SG53-1).

Table 13. Performance of 24 sorghum genotypes for forage yield related traits evaluated in the PYT (Shambat, 2011)

Entry	Genotype	Days to booting	Days to flower	Plant ht. (cm)	Stem diam. (cm)	Regrowth Wt. (gm/plant)	Leaf /stem ratio
1	SG33	47.4	60.2	206	1.02	27.8	0.35
2	SG08	48.2	59.3	201	0.96	30.6	0.34
3	SG54	52.5	61.0	214	0.97	19.3	0.38
4	SG53-1	47.7	56.6	178	0.94	20.3	0.38
5	SG12-1	39.1	52.3	191	0.82	22.1	0.36
6	SG51	52.9	62.5	206	1.00	23.1	0.36
7	SG32-1	45.4	56.2	202	0.94	23.5	0.36
8	S.25Abu70	49.8	57.4	195	0.97	18.3	0.38
9	S.24Abu70	49.0	55.9	189	0.93	17.0	0.37
10	S.26Abu70	47.4	56.4	187	0.97	19.5	0.40
11	S.134Abu70	50.3	57.8	201	0.98	17.8	0.37
12	S.03Abu70	51.8	58.7	187	0.97	19.6	0.38
13	ANKSenar	45.0	54.1	167	0.80	19.5	0.40
14	ANKNiyala	48.7	56.9	167	0.88	18.9	0.40
15	E-35-1	58.7	66.0	154	1.10	22.7	0.41
16	Atlas	55.8	62.3	177	0.95	18.5	0.43
17	ArfaaGadamak	50.0	57.7	122	0.85	23.9	0.45
18	HagaBanet	54.5	64.0	176	0.87	28.0	0.38
19	FakiMustahi	46.3	55.3	154	0.82	19.4	0.44
20	Hemasi	48.8	58.2	178	1.01	19.1	0.38
21	Abjaro	61.3	71.3	217	1.57	22.3	0.43
22	Abnaffain	42.3	53.2	171	0.89	18.2	0.38
23	SG32-2A	51.9	60.7	211	0.65	33.6	0.38
24	WadAhmed	52.7	59.5	123	0.92	21.8	0.44
	Mean	49.9	58.9	182	0.95	21.9	0.39
	SE±	0.9409	0.9139	5.3147	0.0465	1.7344	0.0121
	LSD (5%)	2.7406	2.6620	15.4796	0.1356	5.0517	0.0351
	CV%	3.77	3.10	5.83	9.81	15.87	6.19

Table 14. Performance of 24 sorghum genotypes for grain yield related traits evaluated in the PYT (Shambat, 2011).

Entry	Genotype	Panicle length (cm)	Panicle circumference (cm)	Number of seed/panicle	1000 seed wt.(gm)
1	SG33	24.5	12.7	731	26.7
2	SG08	19.2	14.1	850	28.0
3	SG54	25.8	13.9	1058	25.8
4	SG53-1	21.6	14.8	1116	27.3
5	SG12-1	22.9	13.8	731	33.7
6	SG51	24.2	14.1	1223	23.8
7	SG32-1	19.0	14.4	458	30.4
8	S.25Abu70	18.0	16.9	1159	38.6
9	S.24Abu70	18.6	15.8	1253	31.2
10	S.26Abu70	16.4	16.1	1232	39.2
11	S.134Abu70	16.8	17.3	1465	38.7
12	S.03Abu70	18.9	17.2	1267	33.3
13	ANKSenar	22.6	11.6	988	25.6
14	ANkNiyala	24.6	11.1	788	23.3
15	E-35-1	15.8	15.9	1595	22.7
16	Atlas	21.4	14.1	1615	17.1
17	ArfaaGadamak	26.9	11.8	1234	19.5
18	HagaBanet	16.1	13.9	977	21.6
19	FakiMustahi	25.0	13.9	931	30.0
20	Hemasi	17.2	19.1	1127	39.8
21	Abjaro	15.7	24.2	1879	38.5
22	Abnaffain	16.7	15.3	719	36.8
23	SG32-2A	24.1	10.9	744	16.2
24	WadAhmed	20.9	13.8	1216	16.5
	Mean	20.5	14.7	1098	28.5
	SE±	0.7663	0.5638	97.9926	2.1016
	LSD (5%)	2.2320	1.6421	285.4157	6.1212
	CV%	7.46	7.59	17.85	14.75

4.2 Advanced yield trial (AYT)

4.2.1 Harvest Option 1 (HOP1)

4.2.1.1 Analysis of variance

Mean squares from single ANOVA for forage and grain attributes in the summer season are presented in Tables 15 and 16. Differences among genotypes for forage yield and related traits were highly significant for all characters including forage yields, days to booting and heading, leaf to stem ratio, plant height and stem diameter (Table 15). Highly significant differences among genotypes were also detected for ratoon grain yield, ratoon plant height and ratoon days to boot (Table 16).

Mean squares in the winter season are presented in Tables 17 and 18 for forage yield and ratoon grain yield and their related traits, respectively. Highly significant differences among genotypes have been also encountered for all studied traits.

Tables 19 and 20 show mean squares from combined ANOVA for forage yield and some yield related traits, respectively. Differences among genotypes were highly significant for green (GMY) and dry (DMY) matter yields. The interaction between genotype and season was highly significant for DMY but it was insignificant for GMY (Table 19). Highly significant differences among genotypes were also detected for leaf to stem ratio and plant height (Table 20). The genotype by season interaction was highly significant for plant height and leaf to stem ratio. In most traits blocking over season has removed significant portions of variability.

Table 15. Mean squares from single ANOVA for forage yield and related traits of 7 sorghum genotypes obtained for HOP1* (Shambat, summer 2012)

Source of variation	Df	GMY (t/ha)	DMY (t/ha)	Days to boot	Days to head	Leaf /stem ratio	Plant ht.(cm)	Stem diam.cm)
Block	3	161.22	12.982	37.655	29.571	0.000356	69.0	0.04238
Genotype	6	198.73**	18.749**	2012.119**	1957.810**	0.006873**	41283**	0.43405**
Residual	18	17.59	1.173	8.849	7.349	0.001250	208.6	0.04405

**** = Highly significant at 0.01 probability level**
*** HOP1 = (Harvest Option 1) = Forage crop harvested at heading time followed by grain crop harvested from ratoon**

Table 16. Mean squares from single ANOVA for ratoon grain yield and related traits of 7 sorghum genotypes obtained for HOP1* (Shambat, summer 2012)

Source of variation	Df	Ratoon grain yield(kg/ha)	Ratoon plant height(cm)	Df #	Ratoon days to boot
Block	2	15930	3268.9	3	39.94
Genotype	6	233791**	1974.3**	6	222.79**
Residual	12	22880	340.7	18	29.47

**** = Highly significant at 0.01 probability level**

*** HOP1 = (Harvest Option 1) = Forage crop harvested at heading time followed by grain crop harvested from ratoon**
 # = Df for Ratoon days to boot

Table 17. Mean squares from single ANOVA for forage yield and related traits of 7 sorghum genotypes obtained for HOP1* (Shambat, winter 2012/2013)

Source of variation	Df	GMY (t/ha)	DMY (t/ha)	Days to boot	Days to head	Leaf /stem ratio	Plant ht. (cm)	Stem diam. (cm)
Block	3	46.27	3.025	1.952	2.988	0.0014762	284.3	0.004167
Genotype	6	302.54**	17.628**	240.167**	186.452**	0.0027167**	6361.1**	0.048333**
Residual	18	37.68	1.350	1.897	2.294	0.0006484	123.1	0.006111

**** = Highly significant at 0.01 probability level**
*** HOP1 = (Harvest Option 1) = Forage crop harvested at heading time followed by grain crop harvested from ratoon**

Table 18. Mean squares from single ANOVA for ratoon grain yield and related traits of 7 sorghum genotypes obtained for HOP1* (Shambat, winter 2012/2013)

Source of variation	Df	Ratoon grain yield(kg/ha)	Ratoon plant ht. (cm)	Df	Ratoon days to boot
Block	2	78101	205.19	3	5.27
Genotype	6	659802**	1051.62**	6	91.45**
Residual	12	38790	89.86	18	16.13

** = Highly significant at 0.01 probability level
* HOP1 = (Harvest Option 1) = Forage crop harvested at heading time followed by grain crop harvested from ratoon
# = Df for Ratoon days to boot

Table 19. Mean squares from combined ANOVA for forage yield of 7 sorghum genotypes obtained for HOP1† (Shambat, 2012)

Source of variation	Df	GMY(t/ha)	DMY (t/ha)
Season (S)	1	621.11*	6.231
Residual	6	103.68	8.004
Genotype (G)	6	447.93**	30.684**
G x S	6	52.63	5.693**
Residual	36	27.67	1.262

****, * = highly significant and significant at 0.01 and 0.05 probability level, respectively**
† HOP1 = (Harvest Option 1) = Forage crop harvested at heading time followed by grain crop harvested from ratoon

Table 20. Mean squares from combined ANOVA for yield- related traits of 7 sorghum genotypes obtained for HOP1* (Shambat, 2012)

Source of variation	Df	Leaf /stem ratio	Plant height (cm)
Season(S)	1	0.0375446**	23370.3**
Residual	6	0.0009161	176.7
Genotype(G)	6	0.0058863**	9471.2**
G×S	6	0.0037030**	1018.3**
Residual	36	0.0009494	165.9

**** = highly significant at 0.01 probability level.**
*** HOP1 = (Harvest Option 1) = Forage crop harvested at heading time followed by grain crop harvested from ratoon**

Mean performance of sorghum genotypes for green (GMY) and dry (DMY) matter yields obtained in each and both seasons combined for HOP1 are presented in Tables 21 and 22, respectively.

Green matter yield (GMY t/ha): The overall average for GMY was 37.2 and 30.5 t/ha in winter and summer seasons, respectively. Abjaro significantly outyielded all of the other genotypes in GMY averaging 45.2 t/ha. Abnaffain showed the lowest GMY (21.5 t/ha). The Abu Sabein genotypes S.25Abu70 and S.03Abu70 ranked second to Abjaro averaging 39.0 and 37.0 t/ha, respectively. Their GMY in the winter season was not significantly different than that of Abjaro.

Dry matter yield (DMY t/ha): The overall average for DMY was 7.10 and 7.76 t/ha in winter and summer seasons, respectively. Apart from E-35-1 in the summer season, the genotypes kept the same trend as in GMY. Abjaro was leading averaging 10.9 t/ha followed by S.25Abu70 (8.14 t/ha) and E-35-1 (8.00 t/ha).

Yield related traits Table 23 shows the performance of genotypes during summer and winter seasons for number of days taken to heading, plant height and stem diameter. Table 24 shows performance of genotypes for leaf to stem ratio in each and both season combined.

Days to heading: The overall averages of days taken to heading in winter and summer seasons were 53.0 and 72.9 days, respectively. Abjaro was significantly the latest among the material tested taking 65.5 and 115 days to heading in winter and summer seasons, respectively. Abnaffain was the earliest in winter season with 43.5 days to heading. E-35-1, like Abjaro, showed wide range between days to heading in winter (54.5 day) and that of summer (91.3 day). The respective range for Abu Sabein genotypes was 52.8 to 59.5 days.

Plant height (cm): The overall average for plant height in winter and summer seasons were 220 and 179 cm, respectively. Abjaro was significantly the tallest in both seasons with plant height of 289 and 217 cm in winter and summer seasons, respectively. Abnaffain showed the shortest stature with respective plant height of 153 and 124 cm.

Stem diameter (cm): The overall average for stem diameter in winter and summer seasons were 1.23 and 1.56 cm, respectively. Abjaro showed the thickest stem in both seasons with stem diameter of 1.38 and 2.18 cm in winter and summer seasons, respectively. Sudangrass genotypes showed below average stem diameter ranging from 1.08 cm in winter to 1.38 cm in summer season.

Leaf to stem ratio: The overall average for leaf to stem ratio across both seasons was 0.396. The highest value for leaf to stem ratio was obtained by Abnaffain (0.435) and E-35-1(0.430). The Sudangrass genotypes gave the lowest values for leaf to stem ratio. All of the genotypes showed higher leaf to stem ratio in summer than winter season.

Table 21. Performance of sorghum genotypes for green matter yield obtained in each and both seasons combined for HOP1* (Shambat, 2012)

Genotype	Green matter yield (t/ha)		
	Winter	**Summer**	**Combined**
Abjaro	47.9	42.5	45.2
Abnaffain	21.2	21.9	21.5
E-35-1	32.6	32.1	32.3
S.25Abu70	43.8	34.1	39.0
S.03Abu70	41.5	32.6	37.0
SG51	36.9	23.8	30.3
SG08	36.5	26.8	31.6
Mean	37.2	30.5	33.9
SE±	3.07	2.101	1.860
LSD (5%)	9.12	6.241	5.334
CV (%)	16.5	13.8	15.5

*** HOP1 = (Harvest Option 1) = Forage crop harvested at heading time followed by grain crop harvested from ratoon**

Table 22. Performance of sorghum genotypes for dry matter yields obtained in HOP1* (Shambat, 2012)

Genotype	Dry matter yield (t/ha)		
	Winter	**Summer**	**Combined**
Abjaro	10.5	11.4	10.9
Abnaffain	3.61	5.53	4.57
E-35-1	6.09	9.91	8.00
S.25Abu70	8.29	8.00	8.14
S.03Abu70	7.58	7.13	7.35
SG51	6.77	6.10	6.44
SG08	6.86	6.29	6.57
Mean	7.10	7.76	7.43
SE±	0.581	0.542	0.397
LSD (5%)	1.726	1.609	1.139
CV (%)	16.4	14.0	15.1

*** HOP1 = (Harvest Option 1) = Forage crop harvested at heading time followed by grain crop harvested from ratoon**

Table 23. Performance of sorghum genotypes for 3 yield related traits taken in each season for HOP1* (Shambat, 2012)

	Days to head		Plant ht.(cm)		Stem diam.(cm)	
Genotype	**Winter**	**Summer**	**Winter**	**Summer**	**Winter**	**Summer**
Abjaro	65.5	115	289	217	1.38	2.18
Abnaffain	43.5	70.5	153	124	1.10	1.75
E-35-1	54.5	91.3	222	147	1.25	1.55
S.25Abu70	52.8	56.8	226	198	1.33	1.38
S.03Abu70	53.8	59.5	217	196	1.20	1.58
SG51	53.3	56.8	226	187	1.25	1.15
SG08	47.5	61.0	207	183	1.08	1.38
Mean	53.0	72.9	220	179	1.23	1.56
SE±	0.757	1.355	5.55	7.22	0.0391	0.1049
LSD (5%)	2.250	4.027	16.48	21.46	0.1161	0.3118
CV (%)	2.90	3.70	5.10	8.10	6.4	13.4

***HOP1 = (Harvest Option 1) = Forage crop harvested at heading time followed by grain crop harvested from ratoon**

Table 24. Performance of sorghum genotypes for leaf to stem ratio in HOP1* (Shambat, 2012)

Genotype	Leaf /stem ratio		
	Winter	**Summer**	**Combined**
Abjaro	0.380	0.415	0.398
Abnaffain	0.423	0.448	0.435
E-35-1	0.358	0.503	0.430
S.25Abu70	0.363	0.413	0.388
S.03Abu70	0.360	0.405	0.383
SG51	0.340	0.388	0.364
SG08	0.368	0.383	0.375
Mean	0.370	0.422	0.396
SE±	0.01273	0.01768	0.01089
LSD (5%)	0.03783	0.05253	0.03125
CV (%)	6.90	8.40	7.80

*** HOP1 = (Harvest Option 1) = Forage crop harvested at heading time followed by grain crop harvested from ratoon**

4.2.1.2 Ratoon grain yield and related traits

Table 25 shows grain yield of ratoon crop (HOP1) obtained in the winter and summer seasons. Days to booting and plant height of the ratoon crop obtained by different genotypes in each season are presented in Table 26.

Ratoon grain yield (winter season): The overall average grain yield in the winter season was 621 kg/ha. Abjaro significantly outyielded all of the studied genotypes with grain yield amounting to 1504 kg/ha. Its grain yield was more than twice greater than that obtained by S.03Abu70 (the 2nd best genotype) which yielded 668 kg/ha. Abnaffain yielded 474 kg/ha. The lowest grain yield was shown by E-35-1 (332 kg/ha)

Ratoon grain yield (summer season): The overall average grain yield in the summer season was 505 kg/ha. Abjaro and the Abu Sabein genotype S.25Abu70 significantly out yielded all of the studied genotypes with respective grain yield amounting to 890 and 849 kg/ha. The lowest grain yield was shown by the Sudangrass genotype SG08 (301 kg/ha) and Abnaffain (319 kg/ha)

Ratoon days to boot: The overall average for number of days to boot was 28.5 and 29 days in the winter and summer seasons, respectively. The ratoon plants of Abjaro were the latest to boot in the winter (36.3 day) and summer (43.5 day) season. Abu Sabein genotype S.25Abu70 ranked second to Abjaro in the summer season taking 34.0 days to boot in the ratoon stage. Abnaffain was the earliest taking 22.3 and 23.5 days to boot in the winter and the summer season, respectively.

Ratoon plant height: The overall average plant height was 147 and 129 cm in the winter and summer seasons, respectively. The ratoon plants of Abjaro showed the tallest stature in winter (168 cm) and the summer (156 cm) season. E-35-1 and Abnaffain displayed the shortest ratoon stature with respective values of 130 and 132 cm in winter and 98.0 and 98.3 cm in summer.

Table 25. Performance of sorghum genotypes for ratoon grain yield in HOP1* (Shambat, 2012)

	Ratoon grain yield (kg/ha)	
Genotype	**Winter**	**Summer**
Abjaro	1504	890
Abnaffain	474	319
E-35-1	332	379
S.25Abu70	575	849
S.03Abu70	668	578
SG51	421	536
SG08	376	301
Mean	621	550
SE±	98.5	75.6
LSD (5%)	303.4	233.0
CV (%)	31.7	27.5

*** HOP1 = (Harvest Option 1) = Forage crop harvested at heading time followed by grain crop harvested from ratoon**

Table 26. Performance of sorghum genotypes for ratoon booting and plant height in HOP1* (Shambat, 2012)

Genotype	Days to booting		Plant height(cm)	
	Winter	**Summer**	**Winter**	**Summer**
Abjaro	36.3	43.5	168	156
Abnaffain	22.3	23.5	132	98.3
E-35-1	27.5	23.0	130	98.0
S.25Abu70	29.5	34.0	137	143
S.03Abu70	25.5	23.8	137	134
SG51	32.8	26.8	162	142
SG08	25.5	28.8	160	135
Mean	28.5	29.0	147	129
SE±	2.008	2.71	4.74	9.23
LSD (5%)	5.967	8.06	14.60	28.44
CV (%)	14.10	18.70	6.50	14.30

*** HOP1 = (Harvest Option 1) = Forage crop harvested at heading time followed by grain crop harvested from ratoon**

4.2.2 Harvest option 2 (HOP2)

4.2.2.1 Analysis of variance

Mean squares from single ANOVA for grain and stover yields and related traits in the winter and summer seasons are presented in Tables 27, 28 and 29.

Differences among genotypes for grain yield obtained under HOP2 were highly significant in both winter and summer seasons whereas that for stover yield were only significant in the summer seasons (Table 27).

Differences among genotypes for number of days to boot, plant height and stem diameter were highly significant in both winter and summer seasons (Tables, 28 and 29).

4.2.2.2 Grain and stover yields

Table 30 shows performance of genotypes for grain and stover yields obtained in winter and summer season under HOP2.

Main crop grain yield: The overall average of grain yield of the main crop was 2748 and 2174 kg/ha in the winter and summer seasons, respectively. The grain yields obtained by Abjaro in the winter (4139 kg/ha) and summer (3086 kg/ha) seasons were significantly higher than all entries other than Abu Sabein genotypes that showed respective grain yield of 3670 and 2825 kg/ha. Abnaffain and Sudangrass genotypes gave below average grain yield.

Stover yield: The overall average of stover yield was 49.1 and 29.6 t/ha in the winter and summer seasons, respectively. Abjaro was leading in stover yield in both seasons. Its yield in the summer season (39.8 t/ha) was significantly different than all other genotypes whereas its yield in the winter season (58.6 t/ha) was not significantly different than that obtained by the Abu Sabein genotypes (51.7 - 52.6 t/ha) and E-35-1 (50.6 t/ha). Abnaffain gave the lowest stover yield in the winter (36.6 t/ha) and summer (22.5 t/ha) seasons.

4.2.2.3 Yield related traits

Table 31 shows performance of sorghum genotypes under HOP2 for days to boot, plant height and stem diameter during summer and winter seasons.

Days to boot: The overall average for days to boot was 43.8 and 63.2 days in the winter and summer seasons, respectively. Abjaro was the latest in both seasons with respective booting time of 58.5 and 105 days. Abnaffain was the earliest to boot in winter (33.3 days) but was among the latest to boot in summer (64.0 days). The Abu Sabein genotypes showed close booting time in winter (45.8 -46.8 days) and the summer (48.5 – 50.8 days) seasons.

Plant height: The overall average for plant height was 226 and 180 cm in the winter and summer seasons, respectively. Abjaro was the tallest showing plant height of 288 and 226 cm in the winter and the summer season, receptively. Abnaffain exhibited the shortest stature with respective plant height of 181 and 140 cm. Abu Sabein and Sudangrass genotypes gave above average plant height.

Stem diameter: The overall average for stem diameter was 1.14 and 1.39 cm in the winter and summer seasons, respectively. Abjaro showed the thickest stem of 1.53 and 2.05 cm in the winter and the summer season, receptively. The Sudangrass genotypes showed the thinnest stem with respective values of 1.03 and 1.08 cm for both genotypes.

Table 27. Mean squares from single ANOVA for grain and stover yields of 7 sorghum genotypes obtained in HOP2* (Shambat, summer and winter 2012/2013)

Source of variation	Grain yield(kg/ha)			Stover yield(ton/ha)		
	Df	Summer	Winter	Df	Summer	Winter
Block	2	565366	69748	3	59.392	85.91
Genotype	6	2172298**	3272436**	6	111.969**	190.60
Residual	12	244100	248228	18	7.782	74.42

****= highly significant at 0.01 probability level**
***HOP2= (Harvest Option 2) Grain crop harvested at seed maturity and the stover crop evaluated thereafter**

Table 28. Mean squares from single ANOVA for yield- related traits of 7 sorghum genotypes obtained in HOP2* (Shambat, summer 2012)

Source of variation	Df	Day to boot	Plant ht.(cm)	Stem diam. (cm)
Block	3	21.655	561.3	0.05429
Genotype	6	2035.476**	3251.7**	0.43238**
Residual	18	1.905	188.9	0.02762

**** = Highly significant at 0.01 probability level**
***HOP2= (Harvest Option 2) Grain crop harvested at seed maturity and the stover crop evaluated thereafter**

Table 29. Mean squares from single ANONA for yield related traits of 7 sorghum genotypes obtained in HOP2* (Shambat, winter 2012/2013)

Source of variation	Df	Days to boot	Plant ht.(cm)	Stem diam. (cm)
Block	3	9.179	249.8	0.014643
Genotype	6	256.417**	4267.0**	0.122024**
Residual	18	3.179	346.4	0.006310

**** = Highly significant at 0.01probability level**
***HOP2= (Harvest Option 2) Grain crop harvested at seed maturity and the stover crop evaluated thereafter**

Table 30. Performance of sorghum genotypes for grain and stover yields in HOP2* (Shambat, 2012/2013)

Genotype	Grain yield(kg/ha)		Stover yield (t/ha)	
	Winter	Summer	Winter	Summer
Abjaro	4139	3086	58.6	39.8
Abnaffain	1908	1362	36.6	22.5
E-35-1	2363	1641	50.6	28.2
S.25Abu70	3678	2825	51.7	31.3
S.03Abu70	3670	3293	52.6	29.9
SG51	1680	1505	48.5	28.5
SG08	1798	1508	44.8	26.8
Mean	2748	2174	49.1	29.6
SE±	287.7	285.2	4.31	1.395
LSD (5%)	886.3	878.9	12.82	4.144
CV (%)	18.1	22.7	17.6	9.4

***HOP2= (Harvest Option 2) Grain crop harvested at seed maturity and the stover crop evaluated thereafter**

Table 31. Performance of sorghum genotypes for 3 yield related traits obtained under HOP2* (Shambat, 2012/2013)

	Days to boot		Plant height(cm)		Stem diam.(cm)	
Genotype	**Winter**	**Summer**	**Winter**	**Summer**	**Winter**	**Summer**
Abjaro	58.5	105	288	226	1.53	2.05
Abnaffain	33.3	64.0	181	140	1.05	1.40
E-35-1	43.3	81.8	221	150	1.13	1.43
S.25Abu70	45.8	48.5	216	183	1.15	1.40
S.03Abu70	46.8	50.8	228	190	1.13	1.28
SG51	41.0	44.3	240	194	1.03	1.08
SG08	37.8	48.0	211	179	1.03	1.08
Mean	43.8	63.2	226	180	1.14	1.39
SE±	0.891	0.690	9.31	6.87	0.0397	0.0831
LSD (5%)	2.649	2.050	27.65	20.42	0.1180	0.2469
CV (%)	4.10	2.20	8.20	7.60	6.90	12.00

***HOP2= (Harvest Option 2) Grain crop harvested at seed maturity and the stover crop evaluated thereafter**

4.2.2 Main and Interaction effects of genotypes and harvest options

Tables 32 and 33 show mean squares of the main and interaction effects of harvest options and genotypes for grain yield and related traits in the summer and winter seasons, respectively. Differences among main effects of harvest options and genotypes for grain yield, plant height and days to boot were significant in both seasons. With the exception of plant height in the summer season, the interaction effects between harvest options and genotypes were highly significant for the three traits in both seasons.

4.2.2.1 Main effects

Tables 34 and 35 show the main effect`s of genotypes and harvest options on grain yield and related traits in the summer and the winter seasons, respectively. In the summer season (Table 34), grain yield of the main crop (2174 kg/ha) was almost 4 times greater than that of ratoon crop (550 kg/ha). Days to boot were about a month earlier in ratoon than in the main crop. The plant height in the ratoon (134 cm) was shorter than in the main crop (180 cm). In the winter season (Table 35) the effect of the harvest option on grain yield, days to boot and plant height generally kept the same trend as in the summer season.

Table 32. Mean squares of the main and interaction effects of harvest options and genotypes for grain yield and related traits in sorghum (Shambat summer, 2012)

		Mean of Squares		
Source of variation	Df	Grain yield (kg/ha)	Plant height (cm)	Days to boot
Harvest option (HOP)	1	27692448**	29683.0*	1632029**
Residual	2 (3)	201585	431.2	3.00
Genotype (G)	6	1669009**	6205.6**	1481.60**
G x HOP	6	678620**	231.6	776.66**
Residual	30 (36)	133490	172.7	15.69

***, ** = significant and highly significant at 0.05and 0.01 probability level,**
Figures in brackets in the DF column indicate degree of freedom for plant height and days to boot

Table 33. Mean squares of the main and interaction effects of harvest options and genotypes for grain yield and related traits in sorghum (Shambat, winter 2012/2013)

Source of variation	Df	Mean of Squares		
		Grain yield (kg/ha)	Plant height (cm)	Days to boot
Harvest option (HOP)	1	47314941**	95120.4**	3271.143**
Residual	2 (3)	54690	142.4	7.095
Genotype (G)	6	2832419**	4116.4**	293.768**
G x HOP	6	925038**	1201.7**	54.101**
Residual	30 (36)	143138	243.8	9.657

**** = highly significant at 0.01 probability level.**
Figures in brackets in the DF column indicate degree of freedom for plant height and days to boot

Table 34. Main effects of variety and harvest options for yield and related traits in sorghum (Shambat, summer 2012)

Genotype	Grain yield (kg/ha)	Days to boot (No)	Plant height (cm)
Abjaro	1988	74.3	195
Abnaffain	840	43.8	117
E-35-1	1010	52.4	122
S.25Abu70	1837	41.3	165
S.03Abu70	1936	37.3	164
SG51	1020	35.5	174
SG08	904	38.4	162
Mean	1362	46.1	157
SE±	149.2	1.4000	4.65
Harvest options:			
Ratoon Crop	550	29.0	134
Main crop	2174	63.2	180
Mean	1362	46.1	157
SE±	98.0	0.327	3.92

Table 35. Main effects of variety and harvest options for yield and related traits in sorghum (Shambat, winter 2012/2013)

Genotype	Grain yield (kg/ha)	Days to boot (No)	Plant height (cm)
Abjaro	2818	47.4	227
Abnaffain	1190	27.8	155
E-35-1	1346	35.4	174
S.25Abu70	2124	37.6	175
S.03Abu70	2166	36.1	181
SG51	1049	36.9	200
SG08	1086	31.6	184
Mean	1683	36.1	185
SE±	154.5	1.099	5.52
Harvest options:			
Ratoon Crop	621	28.5	142
Main crop	2 744	43.8	226
Mean	1683	36.1	185
SE±	51.0	0.503	2.25

4.2.2.2 Interaction effects (summer season)

Table 36 shows interaction effect of harvest option and genotype on grain yield in the summer season. Ratoon cropping in summer has resulted in reduced grain yield in all genotypes. The least reduction in grain yield in the ratoon crop was shown by the Sudangrass genotype SG51 (64.4%) followed by the Abu Sabein genotype S.25Abu70 (70.0%) and Abjaro (71.2%). The largest reduction in ratoon grain yield (82.5%) was shown by S.03Abu70. The ratoon grain yield obtained by Abjaro (890 kg/ha) was not significantly different than that of the main crop of Abnaffain (1362 kg/ha) and Sudangrass genotypes (1505-1508 kg/ha).

Table 37 shows interaction effect of harvest option and genotype on number of days to boot in the summer season. Time taken to boot was reduced in the ratoon crop for all genotypes. The largest percent reduction in days to boot was depicted by E-35-1 (71.9%) and Abnaffain (63.3%). The least reduction in days to boot was shown by SG08 (19.3%). The ratoon days to boot of Abjaro (43.5 day) was comparable to that of the main crop of SG51 (44.3 day).

Table 38 shows interaction effect of harvest option and genotype on plant height in the summer season. Plant height was reduced in the ratoon crop in all genotypes. Reduction in plant height ranged from 19.0% to 37.2%. The least percent reduction in plant height was shown by the Sudangrass genotypes and S.25Abu70. The largest reduction was shown by E-35-1. The ratoon height of Abjaro (164 cm) was significantly taller than that of the main crop of Abnaffain (140 cm).

Table 36. Interaction effect of harvest options with genotypes for grain yield (kg/ha) in sorghum (Shambat, summer 2012)

Genotype	Harvest options* Main crop	Ratoon crop	Difference	Reduction in grain yield in ratoon crop (percentage)
Abjaro	3086	890	2196	71.2
Abnaffain	1362	319	1043	76.6
E-35-1	1641	379	1262	76.9
S.25Abu70	2825	849	1976	70.0
S.03Abu70	3293	578	2715	82.5
SG51	1505	536	969	64.4
SG08	1508	301	1207	80.0
SE±	218.5			
LSD (0.5%)	641.9			
CV (%)	26.8			

***: Ratoon crop = regenerated crop after being cut at heading time to evaluate forage yield**
Main crop = crop left to grow until grain maturity to evaluate grain and stover yields

Table 37 Interaction effect of harvest options with variety for number of day to boot in sorghum (Shambat, summer 2012)

Genotype	Harvest options* Main crop	Ratoon crop	Difference	Reduction in days to boot in ratoon crop (percentage)
Abjaro	105	43.5	61.5	58.6
Abnaffain	64.0	23.5	40.5	63.3
E-35-1	81.8	23.0	58.8	71.9
S.25Abu70	48.5	34.0	14.5	29.9
S.03Abu70	50.8	23.8	27.0	53.2
SG51	44.3	26.8	17.5	39.5
SG08	48.0	28.8	19.3	19.3
SE±	1.862			
LSD (0.5%)	5.333			
CV (%)	8.6			

***: Ratoon crop = regenerated crop after being cut at heading to evaluate forage yield**
Main crop = crop left to grow until grain maturity to evaluate grain and stover yields

Table 38. Interaction effect of harvest options with variety for plant height (cm) in sorghum (Shambat, summer 2012)

	Harvest options*			Reduction in plant
	Main	Ratoon		height in ratoon crop
Genotype	**crop**	**crop**	**Difference**	**(percentage)**
Abjaro	226	164	61.9	27.5
Abnaffain	140	94.6	44.9	32.2
E-35-1	150	94.3	55.9	37.2
S.25Abu70	183	147	35.7	19.5
S.03Abu70	190	138	51.6	27.2
SG51	194	155	38.2	19.7
SG08	179	145	34.0	19.0
SE±	7.24			
LSD (0.5%)	21.63			
CV (%)	8.4			

***: Ratoon crop = regenerated crop after being cut at heading to evaluate forage yield**
Main crop = crop left to grow until grain maturity to evaluate grain and stover yields

4.2.2.3 Interaction effects (winter season)

Ratoon cropping in winter has also resulted in reduced grain yield, plant height and number of days taken to booting in all genotypes.

Table 39 shows interaction effect of harvest option and genotype on grain yield in the winter season. The least percent reduction in grain yield due to ratoon cropping was exhibited by Abjaro (63.6%) whereas the largest reduction was shown by E-35-1 (85.9 %) and Abu Sabein genotypes (81.8 % - 84.3%). The ratoon grain yield of Abjaro (1504 kg/ha) was not significantly different than the main crop grain yield of Abnaffain (1906 kg/ha) and Sudangrass genotypes (1678-1795 kg/ha)

The interaction effects of harvest option and genotype on days to boot in the winter season are shown in Table 40. The largest reduction (45.5 %) was exhibited by S.03Abu70 and the least one by SG51 (20.1%). Days to boot shown by Abjaro ratoon was not significantly different than that of the main crop of Abnaffain (41.0 day) and SG08 (37.8 day)

Table 41 shows interaction effect of harvest option and genotype on plant height in the winter season. The least reduction in plant height due to ratoon cropping was displayed by SG08 (25.6 %) and Abnaffain (28.7 %) whereas the largest reduction was experienced by Abjaro (42.7 %) and E-35-1 (42.5 %). The ratoon plant height of Abjaro (165 cm) was not significantly different than that of the main crop of Abnaffain (181 cm)

Table 39. Interaction effect of harvest options with variety for grain yield (kg/ha) in sorghum (Shambat, winter 2012/2013)

Genotype	Harvest options: Main crop	Ratoon crop	Difference	Reduction in grain yield(kg/ha) in ratoon crop (percentage)
Abjaro	4133	1504	2629	63.6
Abnaffain	1906	474	1432	75.1
E-35-1	2360	332	2028	85.9
S25Abu70	3672	575	3097	84.3
S.03Abu70	3665	668	2997	81.8
SG51	1678	421	1257	74.9
SG08	1795	376	1419	79.1
SE±	208.6			
LSD (0.5%)	606.4			
CV (%)	22.5			

***: Ratoon crop = regenerated crop after being cut at heading to evaluate forage yield**
Main crop = crop left to grow until grain maturity to evaluate grain and stover yields

Table 40. Interaction effect of harvest options with variety for number of days to boot in sorghum (Shambat, winter 2012/2013)

Genotype	Harvest options* Main crop	Ratoon crop	Difference	Reduction in days to boot in ratoon crop (percentage)
Abjaro	58.5	36.3	22.3	38.0
Abnaffain	33.3	22.3	11	33.1
E-35-1	43.3	27.5	15.8	36.4
S.25Abu70	45.8	29.5	16.3	35.5
S.03Abu70	46.8	25.5	21.3	45.5
SG51	41.0	32.8	8.3	20.1
SG08	37.8	25.5	12.3	32.5
SE±	1.524			
LSD (0.5%)	4.362			
CV (%)	8.6			

***: Ratoon crop = regenerated crop after being cut at heading to evaluate forage yield**
Main crop = crop left to grow until grain maturity to evaluate grain and stover yields

Table 41. Interaction effect of harvest options with variety for plant height (cm) in sorghum (Shambat, winter 2012/2013)

Genotype	Harvest options* Main crop	Ratoon crop	Difference	Reduction in plant height in ratoon crop (percentage)
Abjaro	288	165	123	42.7
Abnaffain	181	129	52	28.7
E-35-1	221	127	94	42.5
S.25Abu70	216	134	82	38.0
S.03Abu70	228	134	94	41.2
SG51	240	159	81	33.8
SG08	211	157	54	25.6
SE±		7.57		
LSD (0.5%)		21.82		
CV (%)		8.4		

***: Ratoon crop = regenerated crop after being cut at heading to evaluate forage yield**
Main crop = crop left to grow until grain maturity to evaluate grain and stover yield

4.3 Associations

Table 42 shows correlation among different grain and forage attributes in sorghum based on preliminary yield trial data.

Correlation between green matter yield (GMY) and grain yield were positive and highly significant (r=0.4018). Positive highly significant correlations were also observed between GMY and each of 1000 seed weight, head circumference, plant height and stem diameter. Negative highly significant correlations were detected between GMY and each of head length and leaf to stem ratio. Correlations were weak and insignificant between GMY with seed No/ head, days to flowering, and regrowth

Correlation were positive and highly significant between grain yield and each of plant height, stem diameter, 1000 seed weight, seed No/ head and head circumference. Regrowth and head length were negatively and highly significantly correlated with grain yield. Correlations were weak and insignificant between grain yield and each of days to flowering and leaf to stem ratio.

Plant height was positively and highly significantly correlated with 1000 seed weight and head circumference but has insignificant correlation with days to flower, regrowth and seed No/ head. Plant height has negative highly significant correlation with leaf to stem ratio.

Days to flowering has highly significant positive correlation with seed No/ head, stem diameter, head circumference and positive significant correlation with leaf to stem ratio, but has negative significant correlations with 1000 seed weight and head length. Weak and insignificant correlation was observed between days to flowering and regrowth.

Table 42. Correlation among different grain and forage attributes in sorghum (Shambat, 2011)

1	Regrowth										
2	Seed No/ head	-0.2173*									
3	Seed_yield	-0.3118**	0.7541**								
4	Stem diameter	-0.1078	0.5252**	0.5900**							
5	Plan height	0.1456	-0.0381	0.2765**	0.2593*						
6	1000 seed wt	-0.3134**	0.0998	0.6994**	0.3063**	0.3949**					
7	Days to flowering	0.1359	0.4322**	0.1893	0.4936**	0.0772	-0.2536*				
8	Green matter yield	0.0894	0.1725	0.4018**	0.3506**	0.6901**	0.3732**	0.1038			
9	Head circumiference	-0.3068**	0.6098**	0.8569**	0.6820**	0.2997**	0.6650**	0.3309**	0.3340**		
10	Head length	0.1589	-0.2666**	-0.4711**	-0.3559**	-0.1455	-0.4453**	-0.2226*	-0.2850**	-0.5969**	
11	Leaf to stem ratio	-0.1432	0.2666**	0.0153	0.0436	-0.6258**	-0.2480*	0.2157*	-0.4521**	-0.0087	0.1042
		1	2	3	4	5	6	7	8	9	10

***, ** = significantly different from zero at 0.05 and 0.01 probability level, respectively**

4.4 Quality traits

Table 43 shows proximate grain crude protein (CP) for different sorghum genotypes obtained for ratoon and main crop in both seasons. The average grain CP in the summer season was 11.2 % for the ratoon and 11.3 % for the main crop, whereas the respective averages in the winter season were 11.6% and 11.8%.

Above average grain CP was generally observed for SG08 and S.03Abu70. Abjaro was among genotypes showing below average crude protein with values ranging from 10.3% to 11.5% whereas the CP of Abnaffain ranged from 11.0 % to 12.2%. Below average CP was also observed for S.25Abu70 ranging from 10.6 % and 11.6%.

Table 44 shows percentage neutral detergent fiber (NDF), crude protein (CP) and acid detergent fiber (ADF) of forage sorghum (HOP1). The overall averages were 72.5% for NDF, 11.6 % for forage CP and 46.5% for ADF. The genotypes S.03Abu70 and Abjaro scored the highest forage CP of 15.4% and 14.4%, respectively. The lowest forage CP was shown by SG51 (7.81%) and E-35-1 (9.06%). For NDF, Abjaro scored the best (lowest) value (56.5%) followed by E-35-1 (67.5%). The genotypes S.25Abu70 and Abnaffain scored the highest NDF values of 78.9% and 78.4%, respectively. For ADF, Abjaro exhibited the best (lowest) value (36.7 %) followed by E-35-1 (38.9 %). The highest value for ADF (57.4 %) was shown by S.25Abu70.

Table 43. Percentages of grain crude protein of ratoon and main crop in sorghum (Shambat 2012-2013)

	Summer		Winter	
Genotype	**Ratoon crop**	**Main crop**	**Ratoon crop**	**Main crop**
Abjaro	10.9	10.7	10.3	11.5
Abnaffain	11.0	11.4	11.8	12.2
E-35-1	10.1	11.5	11.5	12.2
S.25Abu70	10.9	10.6	11.6	11.6
S.03Abu70	12.0	11.6	12.3	11.2
SG51	12.4	11.6	11.4	11.3
SG08	11.3	11.7	12.5	12.5
Mean	11.2	11.3	11.6	11.8
SE±	0.1644	0.1563	0.1781	0.313

Table 44. Percentage neutral detergent fiber (NDF), crude protein (CP) and acid detergent fiber (ADF) in sorghum for HOP1* (Shambat summer, 2012)

Genotype	NDF	CP	ADF
Abjaro	56.5	14.4	36.7
Abnaffain	78.4	12.3	46.6
E-35-1	67.5	9.06	38.9
S.25Abu70	78.9	8.60	57.4
S.03Abu70	74.7	15.4	45.9
SG51	78.2	7.81	51.8
SG08	73.4	13.7	48.4
Mean	72.5	11.6	46.5
SE±	0.0632	0.1997	0.1241

*** HOP1 = (Harvest Option 1) Forage crop harvested at heading time followed by grain crop harvested from ratoon**

CHAPTER FIVE

DISCUSSION

5.1 The Preliminary Yield Trial (PYT)

Analysis of variance in the PYT revealed highly significant differences among genotypes for all studied characters suggesting that the greater part of the observed variability was due to genetic differences among genotypes. The presence of such high variability will help greatly in simultaneous selection for forage and grain attributes.

Selection was firstly based on high dual grain / forage yield then on related attributes with more emphasis given to earliness, regrowth and leaf to stem ratio. Abjaro and the Abu Sabein selections: S.25Abu70, S.134Abu70, S.26Abu70 and S.03Abu70 were the best genotypes simultaneously top ranking in forage and grain yields. However, of the 4 Abu Sabein genotypes, only S.25Abu70 and S.03Abu70 were advanced due to their good performance in one or more of other attributes including regrowth, earliness and leaf to stem ratio.

The Sudangrass genotype SG08 was among the top forage yielders yet showing below average grain yield. It was advanced mainly due to its good performance in regrowth and earliness. The genotype SG33, showed similar performance to SG08, unfortunately it has got brown seed color which is undesirable for food consumption. In contrast, SG51 which has been advanced, showed medium performance in grain and forage yields, earliness, good grain characteristics and has known agronomic and botanical stability (Mohammed, 2010a). E-35-1 was the best among sweet sorghum group showing desirable performance in dual purpose attributes.

Abnaffain is a traditional cultivar grown widely under rain-fed conditions in the White Nile districts for dual production of grain and fodder. The literal translation of the Arabic name "Abnaffain" (Father of two benefits) implies the dual utility of this cultivar. It was included here as a check for dual fodder / grain production. In this study, all of the advanced materials outperformed the check Abnaffain in dual forage and grain yields. Its low fodder and grain yields could be attributed to its reduced plant height and seed number / head (Tables 13 and 14). However, none of the studied materials was earlier in flowering than Abnaffain. Earliness is a key factor under limited moisture conditions allowing completion of the main cycle of the production (grain + stover) or even permitting another cycle of ratoon cropping. A variety similar to Abnaffain in earliness with improved grain and fodder yields might be a good alternative.

ArfaaGadamak and WadAhmed exhibited below average performance in both grain and fodder yields. Their low forage yield could be attributed to their short plant stature. Being grown out of their production zone might explain their low grain yield. Both cultivars are the outcome of the national breeding program which emphasizes developing of high grain yielding types at the expense of fodder yield i.e. dwarf combinable types suitable for mechanized harvesting (Mahmoud, 1983). All of the recommended grain sorghum cultivars in the Sudan are specifically released to suit the conditions and production systems of the Central Clay Plains. Both cultivar are leading in leaf to stem ratio, however, their improved performance in this aspect is attributable to their reduced stem weight (resulting from short stature). Abjaro belongs to landraces of Northern Sudan like Hemasi, and Abu Sabein that originally grown alongside the banks of the River Nile and lower Atbara river. Abjaro seemed to be the best genotype combining the highest fodder and grain yields (Tables 10 and 12). Its high fodder yield could be explained by its unique tallness and stem thickness (Table 13) whereas the high grain yield is attributable to the high number of seeds per head coupled with high weight of the seed (Table 14). Unexpectedly, Abjaro was among the best genotypes in leaf to stem ratio (Table 14). Usually leaf to stem ratio correlates unfavourably with forage yield and plant height as proved by this study (Table 42) or reported by other workers (Rashida and Mohammed, 2012). This trait represents a good measure for fodder quality as the greater part of the nutritive value is stored in leaves which also have better intake potential and digestibility (Mohammed and Zakaria, 2014). Unfortunately, Abjaro was the latest to flower (Table 14). However, being highly productive along with leafiness justify its advancement as a candidate for dual fodder/grain production.

Some of Abu Sabein genotypes i.e. S.25Abu70 and S.03Abu70 were comparable to Abjaro in high fodder/grain productivity. Though less leafy, they were however, excelling Abjaro in earliness. Abu Sabein is basically a grain cultivar more probably derived from the palatable 'Dibekri' a land race widely grown in Northern Sudan (Kambal, 2003). Driven by the need for fodder, the farmers around cities opted to Abu Sabein as a dual fodder/grain cultivar. However, Abu Sabein was gradually devoted for forage production in response to the increasing demand for fodder.

5.2 The advanced yield trial (AYT)

The material chosen from the preliminary yield trial were further tested under two harvest options across summer and winter seasons. In HOP1 the main crop was harvested for forage and the ratoon crop was harvested for grain whereas in the second harvest option (HOP2) the main crop was harvested for both grain and stover. Considerable portion of the variability observed under different options and seasons was due to genotypes as indicated by the highly significant differences encountered among genotypes for mostly all studied traits. However, the significant genotype x season interaction noticed for forage yield, plant height and leaf to stem ratio indicated that the genotypes performed inconsistently across season implying the need for testing across different growing seasons.

5.2.1 Main crop and ratoon option

When harvesting the main crop for forage and grain from ratoon crop, Abjaro gave the best forage yield and ratoon grain yield specially during winter season (Tables 21, 22 and 25). The winter ratoon grain yield of Abjaro was strikingly high exceeding that of S.03Abu70 (the 2nd best genotype) by more than twice and that of Abnaffain by more than 3 folds. The Abu Sabein genotypes (S.03Abu70 in winter and S.25Abu70 in summer) ranked second to Abjaro. In spite of that the choice of farmers may go for Abu Sabein since it was remarkably earlier than Abjaro specially in the summer season. This is specially true for S.25Abu70 in summer season which was 58 day earlier in heading, time (Table 23) while keeping comparable ratoon grain yield to Abjaro (Table 25). The benefits gained from increased forage yield of Abjaro over that of Abu Sabein may not be enough to justify affording the additional costs and other implications imposed by delaying harvest for about nearly 2 months. On the other hand the Abu Sabein genotype S.25Abu70 may represent a good replacement for Abnaffain when used for producing forage and grain from main and ratoon crop, respectively.

All genotypes headed earlier in winter than summer (Table 23). However, Abjaro and E-35-1 showed contrasting difference in heading time between the two seasons with respective ranges amounting to 50 and 37 days. Hence both cultivars could be regarded as photoperiod sensitive. Sorghum is a short day plant requiring short photoperiods to flower, with some variability among varieties (Clerget *et al*., 2004). Late tropical land races (like Abjaro) are known to be highly photoperiod-sensitive (Clerget *et al*., 2007). On the other hand, Abu Sabein genotypes could be considered as neutral or slightly photoperiod sensitive with seasonal difference in heading time of 4 to 6 days.

These results may explain the farmers' practice of growing Abu Sabein during most of the year (Feb to Nov) while restricting Abjaro cultivation to winter sowings. As pointed above earliness is a key factor under limited moisture conditions. It could be noted (Table 23) that by growing Abu Sabein in summer instead of Abjaro, the farmers can spare 55 day, enough to allow them maximizing the benefits of their crop by harvesting both grain and fodder. Since, in summer, the ratoon grain yield of Abu Sabein (S.25Abu70) is comparable to that of Abjaro (Table 25), growing of this cultivar in summer is suggested for harvesting fodder from the main crop and grain from the ratoon. In contrast, in the winter season Abjaro could be regarded as the right choice for a dual fodder/grain production since it gave ratoon grain yield of more than twice of that of the best Abu Sabein genotype (Table 25) while only being 13 day later in heading time (Table 23). The above suggestions will not be affected by the difference in ratoon days to boot as it almost followed the same trend of days to heading in the main crop (Table 26). This is in agreement with the finding of Gerik *et al*., (1990) that suggests similar phenology of planted and ratoon crops.

Ratooning is a cultural practice to stimulate regrowth of the basal or lower epigeal buds after removal of the photo-synthetically active material. A successful grain sorghum ratoon crop depends upon the production and development of healthy, grain-bearing tillers from these buds in the stubble of the preceding crop (Wilson, 2011). In the present study tiller development has not been evaluated, however, the large stem diameter (Table 23) might be one of the reasons behind the high ratoon grain yield of Abjaro. Thicker stems contribute to increased content of soluble carbohydrates in the stubble which has been considered essential to the ratooned plant's survival and re-growth in the absence of roots and leaves (Enserink, 1995; Oizumi, 1977). Retaining of food stocks in the stubble is also found to be enhanced in sorghum cultivars that stay green after grain maturity (McBee *et al*., 1983). Stay green has been monitored in the nursery and Abjaro scored medium value for this trait whereas all of the Abu Sabein materials scored low values.

5.2.2 Main crop option (HOP2)

When harvesting grain and stover from the main crop, Abjaro also kept top ranking in both attributes in winter as well as summer seasons (Table 30). However, Abjaro yields were not significantly different from that of Abu Sabein genotypes except for stover in the summer season. Considering the lateness of Abjaro farmers may favour to grow Abu Sabein for grain / stover production in both seasons unless the stover value of the summer season is high enough to justify growing Abjaro, or if quality aspects of the stover were considered. Abjaro was apparently leafier than Abu Sabein with reduced NDF and ADF values (Table 44). Both stover yield and quality are of equal importance. Increased biomass, however, must be digestible to contribute to improvement of livestock productivity (Kristjanson and Zerbini, 1999). in Hyderabad- India, Blümmel and Reddy, (2006) found considerable variations in the value of sorghum stover supporting the concept of genetic enhancement to improve dual-purpose sorghum cultivars arguing that improving stover digestibility is feasible without sacrificing grain yields. In the Sudan, sorghum stover has the greater contribution in maintaining the national herd (Mohammed and Zakaria, 2014). Although fodder trading and monetary value of sorghum stover in the Sudan are not explored, yet substantial evidences exist pointing to the growing importance of stover value over that of grain. High stover yielding cultivars are becoming increasingly valued over high grain but lower stover yielding ones in irrigated schemes and Gash and Tokar Deltas. Similar trends were reported in developed countries (Traxler and Byerlee, 1993) where farmers consistently select sorghum types that would compromise the desired fodder and grain attributes due to their reliance on livestock for draft power, milk and income generation.

5.2.3 Main and interactions effects of genotype and harvest options

In both seasons the interaction effects between genotype and harvest option were highly significant (Tables 32 and 33) indicating differential response of genotypes to harvest options. This implies that a genotype showing the best or worst performance in one option may not behave the same in the other. Therefore, when breeding for dual fodder/grain sorghum cultivars, the harvest option should be seriously considered.

Irrespective of harvest option, Abjaro followed by the Abu Sabein genotypes kept the top rank in grain yield in both seasons (Tables 34 and 35). Grain yield of the main crop was about 4 times greater than that of ratoon crop option. This is well expected due to limited ratoon growth that leads to reduction in both photosynthetates and sink (panicle). However, due to the sizable reduction in grain yield caused by ratooning, dual fodder/grain production will not be validated unless the stover value of the ratoon crop is large enough to offset the negative impact of reduction in ratoon grain yield. Ratoon stover was not evaluated in this study. However, the ratoon plant height displayed by some genotypes like Abjaro was high (164 cm) pointing to high potential of stover yield (Tables 36 and 37).

The results obtained for reduction in grain yield caused by ratooning indicated that Abjaro was among the least affected specially in the winter season (Tables 36 and 37). This confirms our previous suggestion that, Abjaro is the right choice in the winter season for a dual fodder/grain production by ratooning. In contrast, grain yield of Abu Sabein genotypes was the most affected by ratooning specially in the winter season. The summer and winter ratoon of Abjaro kept almost the same rank of the main crop for grain yield and other studied traits. It could be noted that the ratoon performance of Abjaro was not significantly different from the main crop performance of some genotypes for the studied traits. Such results point to the stability of Abjaro performance across the main and ratoon crops.

5.3 Association

The study revealed positive highly significant correlation between green matter yield (GMY) and grain yield (Table 42). This result points to the possibility of simultaneously combining high levels of grain and fodder yields in one cultivar. Similar results (but between grain and stover) were reported by a number of workers (i.e. Ross *et al.,* 1983; Blümmel *et al.,* 2009; Reddy *et al***.,** 2005). Ross *et al*., (1983) reported that grain yield had no extremely strong negative phenotypic correlations with any forage residue trait. They concluded that, the correlations obtained do not suggest any formidable barriers to simultaneous improvement of agronomic, grain, and forage traits. Their results go well with our finding that GMY was positively or favourably correlated with 1000 seed weight, head circumference and seed number per head. Furthermore, this was strongly supported by the positive and highly significant correlation shown in this study between plant height and each of grain and fodder yields. Positive significant association between grain yield and plant height was also reported by Kumar *et al*., (2012).

Correlations of days to flower with each of forage and grain yield in this study were weak and insignificant permitting development of early and improved dual grain fodder cultivars. Results supporting weak correlation between grain yield and days to flower were reported by Mohammed, (1988) whereas disagreeing results were reported by Patil *et al*., (1995).

Cultivars showing high dual grain and fodder yields in this study were represented by Abjaro and AbuSabein genotypes: S.25Abu70 and S.03Abu70.

5.4 Proximate quality traits

The data presented for protein content of the grain (Table 43) revealed that ratooning has no negative impact on protein content as no major differences between main and ratoon crops could be noted in both season. The below average level of protein content noticed for Abjaro could be attributed to the well established negative yield – protein relationship known to exist in many crops.

The data presented (Table 44) indicated clearly the superiority of Abjaro over other genotypes in fodder quality showing protein content of 14.4% coupled with the lowest NDF and ADF values. Low NDF value indicates high intake potential. Dry matter intake is negatively related to NDF content in high producing dairy cows (Mertens, 1987) and was also found to be negatively related to digestibility (Argillier *et al.*, 2000). Similarly, the lower the ADF value the better the digestibility and energy value of the fodder (Steve and Marble, 1997). Positive correlations of fodder yield with both total ADF and NDF were found in the literature (Moyer *et al*., 2003) but relationship between forage yield and crude protein was reported to be significantly negative by many workers (Muhammed, 1990; Sanderson *et al*., 1994; Moyer *et al*., 2003; Mohammed and Zakaria, 2014). Abjaro seems to represent one of the rare cases combining high quality fodder (protein content) with high fodder yield. This could be explained by the ability of Abjaro to combine high leaf to stem ratio with high fodder yield. Protein content of the leaves was found to be higher than that of the stem (Mohammed and Zakaria, 2014).

Outlook

Attributes relating to improvement of sorghum biomass have been largely ignored by breeders with emphasis being placed on grain yield. Thus, dwarf combinable grain types have been developed in Sudan and other developing countries at the expense of stover yield and quality. The huge genetic diversity available Worldwide for sorghum, and that untapped in a country like Sudan will enable simultaneous selection for both food and fodder attributes. The results shown by this study support the previous calls for reconsidering the present mono-commodity breeding strategy of sorghum.

The future sorghum cultivars in the developing World must provide both food and feed for the millions of resource-poor smallholders and their animals. To develop such cultivars, feed and food attributes need to be incorporated in the early stages of the breeding program. Increased biomass, however, must also be digestible to contribute to livestock productivity increases. Hence, the need for assessing both yield and quality attributes. When selecting for grain yield, sorghum breeder should simultaneously keep an eye on characters like plant height (medium to tall stature), earliness, ratoonability (regrowth ability), stay green, leafiness (leaf to stem ratio, leaf area index) and stem diameter (thick stem). Selection should firstly be based on populations having edible sorghum grain. In Sudan, most of the above traits are largely met by land races along the main course of the River Nile, Atbara River, and eastern States of Sudan (Gedarif, Kassala and Red Sea). Such germplasm are somewhat lacking in the present Sudan Sorghum Collection (Mahmoud *et al.*, 1996) therefore, collection expeditions in the above mentioned areas need to be undertaken.

Studies to maximize the benefits gained from dual cultivars should explore different harvest options to determine variety choice for each option. Optimization of husbandry practices for dual cultivars should include population density, fertilization and planting time. Sorghum breeders should work in close collaboration with animal nutrition scientists to identify materials with high stover digestibility. Economic studies to investigate the feasibility of dual fodder/grain sorghum should be carried out under different harvest options. The economic and monetary value of grain and stover harvested from the main crop should be explored relative to that of ratoon cropping.

CHAPTER SIX

CONCLUSIONS

The study revealed the possibility of selecting sorghum cultivars with high capacity for dual fodder/grain production. This has been enhanced by the high significant differences encountered among genotypes for all studied traits. Six genotypes were identified as having the best dual fodder/grain excelling the standard dual check Abnaffain. Of these, Abjaro seemed to be the best genotype combining the highest fodder and grain yields and was among the best in leaf to stem ratio. The Abu Sabein selections S.25Abu70 and S.03Abu70, though less leafy, ranked second to Abjaro in high fodder/grain productivity and excelled it in earliness. ArfaaGadamak and WadAhmed, the short statured standard grain checks, exhibited below average performance in both grain and fodder yields but were among the best in leaf to stem ratio. Abnaffain gave lowest dry matter yield with below average grain yield.

The association study suggested that high levels of grain and fodder yields coupled with some desirable traits could be incorporated in one sorghum cultivar.

The study revealed that performance of dual sorghum cultivars differ across harvest options and seasons. To maximize grain and fodder yields from dual sorghum cultivars, different genotypes were suggested for different harvest options in different seasons. When harvesting the main crop for forage and grain from ratoon crop, the best choice is to grow the cultivar Abjaro during winter and S.25Abu70 during summer. Ratoon cropping has resulted in reduced grain yield, time taken to boot and plant height in winter and summer sowings. Reduction in grain yield due to ratoon cropping ranged from 64% to 86%.When harvesting grain and stover from the main crop, Abjaro also kept the top rank in both attributes in winter and summer seasons however, considering the lateness of Abjaro, farmers may favour growing Abu Sabein unless the stover value of the summer season is high enough to justify growing Abjaro, or if quality aspects of the stover were considered.

The data presented for protein content of the grain revealed that ratooning has no negative impact on protein content. Abjaro was the best in forage quality in terms of protein content, NDF and ADF but it showed below average protein content of the grain.

Future studies in collaboration with animal nutrition specialists should focus on developing dual sorghum cultivars having high stover quality with special emphasis on improved digestibility. Studies to maximize the benefits gained from dual cultivars should explore variety choice and cultural practices (Population density, fertilization and planting time) for different harvest options.

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APPENDICES

Appendix 1. Total area (fed) cropped to forage sorghum (var. Abu Sabein and Berseam) in Khartoum State

Year	Berseam (Alfalfa)	Abu Sabein
2007-2008	35091	173549
2008-2009	41657	191345
2009-2010	38290	141946
2010-2011	42157	85009
2011-2012	43640	137935
2012-2013	44934	97268

Source: The statistics of the Ministry of Agriculture and Animal Wealth

Appendix 2. Chemical and Physical soil properties of the experimental site at Shambat

Depth (Cm)	Chemical properties				Physical properties		
	pH	E Ce (ds/m)	Na (m mol+I)	SAR	Clay (%)	Silt (%)	Sand (%)
0-15	7.79	1.4	5.1	2.4	42.1	15.9	42.0
15-35	7.88	1.0	4.3	2.5	39.6	15.8	44.6
35-51	7.87	1.2	7.1	4.5	44.1	16.4	39.5
51-75	7.91	2. 0	12.5	6.3	51.4	16.6	32.0
75-120	7.71	2.2	16.0	9.2	50.0	16.6	33.4

Appendix 3. Monthly mean temperature (°C), rainfall (mm) and relative humidity (R.H %) during the growing season of the breeding nursery (Shambat, 2010 - 2011).

Month	Mean Temperature		R.H. (%)	Total rain fall (mm)
	Max.	Min.		
November 2010	37.0	23.1	29	0.0
December	32.2	17.4	30	0.0
January 2011	29.0	14.1	29	0.0
February	34.5	17.3	21	0.0
March	35.0	18.7	18	0.0

Source: Meteorological Authority, Ministry of environment Forestry and Physical Development (2012).

Appendix 4. Monthly mean temperature (°C), rainfall (mm) and relative humidity (R.H %) during the growing season of the preliminary yield trial (Shambat, 2011-2012).

Month	Mean Temperature		R.H. (%)	Total rain fall(mm)
	Max.	Min.		
October	39.9	25.1	29	2.2
November	32.7	16.7	25	10.1
December	31.8	17.2	33	0.0
January	29.5	14.1	29	0.0
February	34.4	18.5	26	0.0
March	35.4	17.7	19	0.0

Source: Meteorological Authority, Ministry of environment Forestry and Physical Development (2012).

Appendix 5. Monthly mean temperature (°C), rainfall (mm) and relative humidity (R.H %) during the growing season of the advanced yield trial (Shambat, summer winter, 2012-2013)

Month	Mean Temperature		R.H. (%)	Total rain fall (mm)
	Max.	Min.		
July 2012	38.2	26.8	45	33.1
August	35.9	25.7	55	69.2
September	39.3	26.2	41	TR
October	39.0	24.3	32	40.5
November	35.5	20.3	25	TR
December	31.3	16.4	30	0.0
January 2013	31.9	16.5	28	0.0
February	35.0	17.5	24	0.0
March	38.0	18.3	17	0.0

Source: Meteorological Authority, Ministry of environment Forestry and Physical Development 2012-2013
TR = Trace

Appendix 6. Dual sorghum breeding nursery (Shambat, 2010)

Entry	Genotype	Source	Group/Type	Grain color
1	SG44	FIP-Shambat*	SudanGrass	White
2	SG33	FIP-Shambat	SudanGrass	White
3	SG23	FIP-Shambat	SudanGrass	White
4	SG44(4)	FIP-Shambat	SudanGrass	White
5	SG26	FIP-Shambat	SudanGrass	White
6	SG04	FIP-Shambat	SudanGrass	White
7	SG08	FIP-Shambat	SudanGrass	White
8	SG9	FIP-Shambat	SudanGrass	White
9	SG54	FIP-Shambat	SudanGrass	White
10	SG51	FIP-Shambat	SudanGrass	White
11	SG40	FIP-Shambat	SudanGrass	White
12	SG21	FIP-Shambat	SudanGrass	White
13	SG03	FIP-Shambat	SudanGrass	White
14	SG53-1	FIP-Shambat	SudanGrass	White
15	SG12-2	FIP-Shambat	SudanGrass	White
16	SG50-1	FIP-Shambat	SudanGrass	Brown
17	SG32-1	FIP-Shambat	SudanGrass	White
18	SG53	FIP-Shambat	SudanGrass	White
19	SG27	FIP-Shambat	SudanGrass	Brown
20	SG34-1	FIP-Shambat	SudanGrass	Brown
21	SG18	FIP-Shambat	SudanGrass	Brown
22	SG12-1	FIP-Shambat	SudanGrass	White
23	SG18-1	FIP-Shambat	SudanGrass	Brown
24	SG27-1	FIP-Shambat	SudanGrass	Brown
25	SG34-2	FIP-Shambat	SudanGrass	Brown
26	SG11	FIP-Shambat	SudanGrass	Brown
27	SG36	FIP-Shambat	SudanGrass	brown
28	SG51(28)	FIP-Shambat	SudanGrass	White
29	SG10-1	FIP-Shambat	SudanGrass	White
30	SG18(30)	FIP-Shambat	SudanGrass	Brown
31	SG32-2A	FIP-Shambat	SudanGrass	Brown
32	SG32-1	FIP-Shambat	SudanGrass	White
33	SG34	FIP-Shambat	SudanGrass	brown
34	SG32-2A (34)	FIP-Shambat	SudanGrass	brown
35	S.85	FIP-Shambat	Abu Sabein	White
36	S.126	FIP-Shambat	Abu Sabein	White
37	S.152	FIP-Shambat	Abu Sabein	White
38	S.140	FIP-Shambat	Abu Sabein	White
39	S.107	FIP-Shambat	Abu Sabein	White
40	S.117	FIP-Shambat	Abu Sabein	White
41	S.25	FIP-Shambat	Abu Sabein	White
42	S.143	FIP-Shambat	Abu Sabein	White
43	S.179	FIP-Shambat	Abu Sabein	White
44	S.24	FIP-Shambat	Abu Sabein	White
45	S.89	FIP-Shambat	Abu Sabein	White

46	S.120	FIP-Shambat	Abu Sabein	White
47	S.22	FIP-Shambat	Abu Sabein	White
48	S.80	FIP-Shambat	Abu Sabein	White
49	S.119	FIP-Shambat	Abu Sabein	White
50	S.26	FIP-Shambat	Abu Sabein	White
51	S.51	FIP-Shambat	Abu Sabein	White
52	S.155	FIP-Shambat	Abu Sabein	White
53	S.63	FIP-Shambat	Abu Sabein	White
54	S.170	FIP-Shambat	Abu Sabein	White
55	S.47	FIP-Shambat	Abu Sabein	White
56	S.81	FIP-Shambat	Abu Sabein	White
57	S.134	FIP-Shambat	Abu Sabein	White
58	S.94	FIP-Shambat	Abu Sabein	White
59	S.41	FIP-Shambat	Abu Sabein	White
60	S.19 (Kambal)	FIP-Shambat	Abu Sabein	White
61	S.134	FIP-Shambat	Abu Sabein	White
62	S.79	FIP-Shambat	Abu Sabein	White
63	S.03	FIP-Shambat	Abu Sabein	White
64	S.148	FIP-Shambat	Abu Sabein	White
65	S.93	FIP-Shambat	Abu Sabein	White
66	Abu70	FIP-Shambat	Abu Sabein	White
67	S.31	FIP-Shambat	Abu Sabein	White
68	S.S.S.Exp	FIP-Shambat	Ankolib	Brown
69	ANKS.43	FIP-Shambat	Ankolib	Brown
70	ANKS.16	FIP-Shambat	Ankolib	Brown
71	ANKS.40	FIP-Shambat	Ankolib	Brown
72	ANK.CHK	FIP-Shambat	Ankolib	Brown
73	ANKS.36	FIP-Shambat	Ankolib	Brown
74	ANKS.42	FIP-Shambat	Ankolib	Brown
75	ANKNyala	Dr. Abdulrahman Nyala Res. St.	Ankolib	Brown
76	ANKSennar	Sennar	Ankolib	Brown
77	K.S.5	USDA-ARS U. of Nebraska	Sweet sorghum	White
78	N111	USDA-ARS U. of Nebraska	Sweet sorghum	Brown
79	BlueRibbon	USDA-ARS U. of Nebraska	Sweet sorghum	Brown
80	Brawly	USDA-ARS U. of Nebraska	Sweet sorghum	Brown
81	Kensas Collis	USDA-ARS U. of Nebraska	Sweet sorghum	Brown
82	N99	USDA-ARS U. of Nebraska	Sweet sorghum	Brown
83	N110	USDA-ARS U. of Nebraska	Sweet sorghum	Brown
84	Atlas	USDA-ARS U. of Nebraska	Sweet sorghum	White
85	Hastings	USDA-ARS U. of Nebraska	Sweet sorghum	Brown
86	Red-x	USDA-ARS U. of Nebraska	Sweet sorghum	Brown
87	N98	USDA-ARS U. of Nebraska	Sweet sorghum	Brown
88	Fremont	USDA-ARS U. of Nebraska	Sweet sorghum	Brown
89	Waconia	USDA-ARS U. of Nebraska	Sweet sorghum	Brown
90	Colman	USDA-ARS U. of Nebraska	Sweet sorghum	Brown
91	Sugardrip	USDA-ARS U. of Nebraska	Sweet sorghum	Brown
92	N109	USDA-ARS U. of Nebraska	Sweet sorghum	White
93	N100	USDA-ARS U. of Nebraska	Sweet sorghum	Brown

94	WadAhmed	ARC-National Program Abu Assar	Grain sorghum	White
95	ArfaaGadamak	ARC-National Program Abu Assar	Grain sorghum	White
96	Tabat	Faculty of Agric. U. of K.	Grain sorghum	White
97	Aklamoi	Kasala	Grain sorghum	White
98	Haga Banet	Dr. Abdulrahman Nyala Res. St.	Grain sorghum	White
99	Butana	ARC-National Program Abu Assar	Grain sorghum	White
100	Umbinen-7	ARC-National Program Abu Assar	Grain sorghum	White
101	Umbinen-22	ARC-National Program Abu Assar	Grain sorghum	White
102	GadamElhamam	ARC-National Program Abu Assar	Grain sorghum	White
103	Bashir	ARC-National Program Abu Assar	Grain sorghum	White
104	Milo	ARC-National Program Abu Assar	Grain sorghum	White
105	AjabSido	ARC-National Program Abu Assar	Grain sorghum	White
106	FakiMustahi	ARC-National Program Abu Assar	Grain sorghum	White
107	Aklamoi UK	Dept of Botany Fac. of Agric. U. of K.	Grain sorghum	White
108	DwarfWhiteMilo	Dept of Botany Fac. of Agric. U. of K.	Grain sorghum	White
109	Geshesh	Dept of Botany Fac. of Agric. U. of K.	Grain sorghum	White
110	ArossElremal	Ahmad Ismail El Diwaem	Grain sorghum	White
111	FatretaBaladi	Ahmad Ismail El Diwaem	Grain sorghum	White
112	Ahmadi 1	Prof. ElAhmadi	Grain sorghum	White
113	Ahmadi 2	Prof. ElAhmadi	Grain sorghum	White
114	HemasiAbiad	Shendi Turus RiverNileState	Grain sorghum	White
115	Mugud/Hemasi Ahmar	Shendi River Nile State	Grain sorghum	Creamy
116	MaregBaladi Asfar	Karima Northern State	Grain sorghum	Yellow
117	DebakaryNile	Shendi - Zeidab Area	Grain sorghum	White
118	Debakary Atbra	Ed Damar Upper Atbara	Grain sorghum	White
119	Mugud Tengasi	Merowi Tengasi Northern State	Grain sorghum	Creamy
120	Abjaro	Ed Damar RiverNileState	Grain sorghum	White
121	DuraAbu70	Merowi Manasir Northern State	Grain sorghum	White
122	Abjaro Atbra	Shendi Upper Atbara	Grain sorghum	White

***FIP Shambat = Forage improvement program, Shambat Research Station, Sudan**

Appendix 7. Layout of the preliminary yield trial (Shambat, 2012)

Rep 1				Rep 11				Rep 111				Rep 1V		
6	**C**	10	**R**	21	**C**	4	**R**	8	**C**	13	**R**	4	**C**	24
6	**A**	10	**O**	21	**A**	4	**O**	8	**A**	13	**O**	4	**A**	24
21	**N**	18	**A**	24	**N**	11	**A**	4	**N**	12	**A**	14	**N**	18
21	**A**	18	**D**	24	**A**	11	**D**	4	**A**	12	**D**	14	**A**	18
3	**L**	17		3	**L**	6		1	**L**	24		21	**L**	8
3		17		3		6		1		24		21		8
8		24		23		16		20		22		15		2
8		24		23		16		20		22		15		2
2		12		1		10		5		23		11		6
2		12		1		10		5		23		11		6
11		4		2		22		14		2		20		22
11		4		2		22		14		2		20		22
7		16		5		17		7		6		3		9
7		16		5		17		7		6		3		9
22		5		12		19		21		9		12		5
22		5		12		19		21		9		12		5
1		20		15		20		11		15		13		1
1		20		15		20		11		15		13		1
19		23		14		18		3		16		16		10
19		23		14		18		3		16		16		10
13		9		9		13		17		19		23		7
13		9		9		13		17		19		23		7
14		15		7		8		10		18		19		17
14		15		7		8		10		18		19		17

Appendix 8. Layout of the advanced yield trial (Shambat, 2012/2013)

Block1				Block11				Block111				Block 1V		
Main Plot	C	Main Plot	R	Main Plot	C	Main Plot	R	Main Plot	C	Main Plot	R	Main Plot	C	Main Plot
GF S.03 Ab70	A N A	FG SG51	O A D	FG Abjaro	A N A	GF SG08	O A D	FG Abjaro	A N A	GF SG51	O A D	FG Abnaffain	A N A	GF SG08
GF Abjaro	L	FG Abjaro		FG SG08	L	GF Abnaffain		FG E-35-1	L	GF SG08		FG E-35-1	L	GF Abjaro
GF SG08		FG Abnaffain		FG E-35-1		GF SG51		FG S.25Ab7		GF E-35-1		FG Abjaro		GF Abnaffain
GF E-35-1		FG S.03Ab70		FG SG51		GF S.03		FG SG08		GF Abjaro		FG SG08		GF E-35-1
GF SG51		FG SG08		FG Abnaffain		GF E-35-1		FG SG51		GF S.03		FG SG51		GF S.03Ab70
GF Abnaffain		FG S.25Ab70		FG S.03Ab70		GF Abjaro		FG S.03		GF Abnaffain		FG S.03Ab70		GF SG51
GF S.25Ab70		FG E-35-1		FG S.25Ab70		GF S.25Ab70		FG Abnaffain		GF S.25Ab70		FG S.25Ab70		GF S.25Ab70

FIGURES

Figure 1. General view of the nursery (Shambat, 2010/2011)

Figure 2. General view of the PYT (Shambat, 2011)

Figure 3. General view of the AYT (Shambat, 2012/2013)

Figure 4. General view of Abjaro

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Figure 5. General view of S.25Abu70

Figure 6. General view of the dual check (Abnaffain)

Figure 7. Showing different stages of harvest options, Abjaro (middle), S.25Abu70 (left) and Abnaffain (right)

Figure 8. Showing ratoon growth during the AYT