ASSESSMENT OF DROUGHT TOLERANCE, EARLINESS AND GRAIN YIELD IN SOUTH SUDAN SORGHUM GERMPLASM AND ICRISAT LINES

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DECLARATION

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

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DEDICATION

I dedicate this thesis to my family. first of all to my beloved wife, Philis Mutoro whose care and contribution led to the writing, compilation and completion of this research thesis. To my son Morgan Ayak, who always woke me up to take to the table towrite the thesis. May God bless them all.

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CONTENTS

LIST OF TABLES

ABSTRACT

Sorghum production is highly constrained by drought stress in semi-arid tropics leading to grain deficit, higher consumer food-commodity prices, food insecurity and malnutrition. The goal of the current study was to identify sorghum genotypes exhibiting genes for earliness and yield under drought stress conditions that could be utilized in the development of superior sorghum synthetics for improved food and nutritional security in drought prone areas of South Sudan. This study used sorghum germplasm comprising 47 genotypes from South Sudan collection and 34 elite lines drawn from ICRISAT-Nairobi's sorghum germplasm repository. The trails were laid out in a 9 x 9 alpha square lattice in a well irrigated and non-irrigated conditions Genotypes and water regimes had effects on days to flowering, staygreen scores, dry leaf scores, waxy bloom, leaf area, leaf rolling, total leaf count and lodging implying genetic diversity for the sorghum genotypes evaluated in this study. The superior lines that outperformed the check variety (Kiboko local2) for earliness were Wote collection1 (56 days), IESV 23010 DL (58 days), ZSV3 (60 days), Bizany (61 days) and Tabat (61 days). However, there were yield penalties recorded among the accessions wote collection1, Bizany, ZSV3 and Tabat. Thus, the accessions IESV 23010 DL would best serve as an ideal drought evading candidate with better performance for grain yield. The sorghum genotype Olerere (12.82%) exhibited staygreen trait while Omuhathi (76.23%) showed the highest senescence. Reduced total leaf counts and net leaf area were observed among improved drought tolerant lines namely IESV 92028 DL IESV 91111 DL, Mahube, IESV 92172 DL, Gwada and IESV 23010 DL. The accessions that scored dense wax load under drought stress condition were Gwada, ICSR 161, Mahube, AG8, IESV 91131 DL, IESV 91111 DL, IESV 92028 DL and IESV 92172 DL and comprised of inbred lines drawn from

ICRISAT- Nairobi gene bank. The genotypes Lobuheti (50.65g), IESV 91131 DL (46.52g), Lodoka1 (47.08g) and IESV 92172 DL (46.69g) showed superior field weights as opposed to the check variety (Kiboko local1). Accession IESV 91131 DL and IESV 92172 DL recorded high harvest index (3.13% and 6.86%) and threshing percentage of 73.94% and 67.34%. Results of correlation analysis revealed that panicle weight showed positive correlation with grain yield, harvest index, and panicle width suggesting that these traits could be used as the basis for indirect selection for high grain yield in sorghum breeding programs. There were significant differences among the maternal and non-maternal effects implying that maternal genes play a greater role in regulating maturity. There were higher predictability ratios for days to flowering, panicle weight and grain weight suggesting that additive genes play a bigger role than non-additive genes in conferring such traits. Negative significant general combining ability effects (GCA) were noted for days to flowering for parents ICSV 111 IN, B35 and Macia suggesting that these parents can be utilized as donor parents when introgressing earliness triat. The parental lines Lodoka, Okabir and Akuorachot with positive days to flowering implied lateness thus conferring the late physiological maturity. The study identified parental lines, Macia and ICSV 111 IN as exhibiting positive and high GCA effects indicating that they are good combiners for grain yield compared to parental lines B35, Okabir and Akuorachot which showed inferiority with regards to grain weight. Parental lines Macia and ICSV 111 IN also showed positive GCA for 100-seed weight, suggesting that they are good combiners for this trait and would therefore serve as good parental lines for the development of commercial synthetics.

CHAPTER ONE

INTRODUCTON

1.1 Background

Sorghum (Sorghum Bicolor L Moench) is the fifth most important cereal crop globally and the second most important staple cereal crop after maize in Africa and Asia (Blum, 2011). Farmers' preference for sorghum comes from its ability to yield high in the face of severe abiotic and biotic stresses relative to crops such as maize (*Zea mays*), rice (*Oryza sativa*) and wheat (*Triticum aestivum*)(Grenier et al., 2004). The importance of sorghum lies on its ability to withstand drought stress as well as being a cheap source of carbohydrate, protein, fibre, and vitamins to both human and animals (Blum, 2011). Sorghum is native to Ethiopia- Sudan region, an area characterised by poorly distributed, unpredictable and erratic rainfall. Selection and cultivation by rural African farmers has led to the development of wider genotypic variation for tolerance to drought stress (Martin, 2016).

South Sudan falls within the centre of sorghum domestication and cultivation (FAO, 2017) Sorghum accounts for 70% of the total acreage for cereal crops productivity followed by maize (27%) and millet (3%).indicating that sorghum is an indispensable staple cereal food crop in the country (FAO, 2017). In all the agro-ecologies, sorghum is wholly utilized with little or no waste (Gamar and Mohamed, 2013). Grain sorghum is processed in many traditional ways across the country but the methods vary from one locality to another depending on local custom, culture as well as food habit. Sorghum is consumed mostly as a solid porridge or pudding (Asida and Cuin), porridge (Madida), flat bread or pancake known as 'Kisra (Grenier et al., 2004). In certain cases, the flour is mixed with cassava to produce a solid texture and a palatable taste. Large quantities of sorghum are made into local beer known as ‘Mou' or ‘Marisa' and an alcoholic spirit known as ‘Warragi’. Fresh stalk is chewed as sugarcane and is sometimes crushed with mortars and pestle, the product of which is soaked in water to extract juice for cooking porridge and a dish called ‘Awal-walla’ (a popular Dinka food). Sorghum stalk is also used as livestock feed and may provide fuel for cooking in the dry season. The shelled panicles and glumes are used to smoke cattle room and keep mosquitoes away (FAO, 2016)

Sorghum genotypes grown in South Sudan are landraces of long duration with low yields ranging from 0.4 to 0.6 t ha^{1}. So far, there has been no agricultural research conducted on sorghum and other crops in South Sudan due to the long periods of war and insecurity. The first attempt to initiate sorghum research in South Sudan started with the ICRISAT-HOPE project in 2009 whose broad objective was to increase the productivity of dryland sorghum in Eastern and Central Equatoria states (CIAT, 2010) and the project has so far released two varieties (CIAT, 2010; FAO, 2016). Another research program by AGRA PASS program based at Halima/Wau, Western Bahr El Ghazal state focuses on facilitating farmers access to high quality seeds of improved varieties, creating farmers awareness, encouraging farmers to test new varieties and promoting local seeds and input industry (CIAT, 2010).

1.2 Problem statement

Sorghum production in all the six agro-ecological zones of South Sudan is constrained by frequent drought and prolonged dry spell leading to crop failure for most of the seasons. Most of the local landraces grown are susceptible to drought stress. Drought stress at seedling stage mainly occurs during long rain season in May and short season in in most States (FAO, 2016) leading to replanting and gap filling to ensure germination (FAO, 2017). Due to severity and frequent occurrence of the drought spell, a shift in the planting occurs and may extend into May and June months of the year (FAO, 2017).

Food and Agriculture Organization (FAO, 2016) indicated that farm yields do not exceed 0.6 t ha^{-1} across the country but there is a potential for 4.5-7.0 t ha^{-1} yield. The problem of low yields due to low moisture availability is compounded by the late maturation of the local landraces including Shalla, Kec, Bher ,Ngethin, Nyandok,nuerbai,Rapjung ,Rabdit, Akuorachot , Aluel and Ayella which may take up to 120-220 days.

.According to Ngugi et al., (2013) sorghum genotypes grown in semi-arid areas either escape drought and therefore mature early or have inherent drought tolerance mechanisms that allow them to produce some yield despite the stress. In South Sudan, despite the fact that the landraces are late -maturing, grain yield losses due to drought stress are estimated to be at 53% mainly because of lack of drought tolerance mechanisms (FAO, 2017). There is a need to collect, screen, identify and breed germplasm with inherent drought tolerance alleles that together with drought escaping genes exhibited in earliness could be improved and harnessed for adaptation to drought stress in drought stress prone agro-ecologies of the East African region (Ngugi and Orek, 2013).

1.3 Justification of the study

Sorghum has its centre of origin in Africa and specifically in the Ethiopia-Sudan region. In the past decades, South Sudanese subsistence farming communities have identified, selected and sustained diverse landraces of sorghum with better adaptation to their agro-ecological zones of evolution particularly in Upper Nile, Bar-El Ghazel and Equatoria regions. The 2009 sorghum germplasm collection exercise in the two States of Central and Eastern Equatoria led to the collection of forty seven accessions, each with a different landrace grain colour and local names portraying the level of diversity that exists in South Sudan. These collections have not been characterized hence their yield potential, earliness and tolerance to drought stress are not known. Evaluation of these collections together with hitherto undescribed germplasm introduced from ICRISAT-Nairobi is necessary in order to identify drought tolerant cultivars that combine earliness and high yield; traits useful in mitigating the effects of drought. The development of drought tolerant genotypes with early maturing and high yielding traits will help reduce frequent crop failures and increase the number of sowing seasons for sorghum production from one season to three seasons per year. This will ensure food and nutrition security for the people of South Sudan.

1.4 Objective

The main objective of this research was to contribute to sorghum productivity in the rural and marginal areas of South Sudan for food security and poverty alleviation through identification of drought tolerant sorghum genotypes which are high yielding.

1.4.1 Specific objectives of the study

1. To identify drought tolerant, early maturing and high yielding sorghum genotypes for drought prone agro-ecological zones
2. To determine combining ability for drought tolerance among identified donor sources and drought stress susceptible, late maturing and farmer preferred sorghum lines

1.4.2 Hypothesis

1. There is no genetic variation for drought tolerance, earliness and high grain yield among the South Sudanese landraces and exotic lines.
2. There is no combining ability for drought tolerance, earliness and yield between South Sudan sorghum germplasm and ICRISAT staygreen donor lines..

CHAPTER TWO

LITERATURE REVIEW

2.1 Sorghum (Sorghum Bicolor (L) Moench)

Sorghum (Sorghum bicolor (L) Moench) is a key C4 crop cultivated for human and livestock consumption, building materials and brewing. Sorghum is the second important crop after maize (Zea mays) in the tropics able to give high yield under harsh environmental conditions where other cereal crops fail to grow and produce. Sorghum is more tolerant to several stresses including heat, drought stress, flooding, dry spell, low soil fertility and salinity relative to other cereal crops (Grenier et al., 2004). The crop survives in warm and dry regions as well as cool weather and waterlogged habitats (Zhang et al., 2015). Therefore, sorghum has a wider adaptation, making it an important crop to billons of human population living in the arid and semi-arid drylands of the world (Ngugi and Maswili, 2010 ; Ngugi et al., 2013).

2.2 Origin and distribution of sorghum

Sorghum originated in Eastern Africa where its first place of domestication was in the Ethiopia- Sudan region (Grenier et al., 2004). Genotypic diversity of domesticated and undomesticated species are common in the Ethiopia- Sudan region some of which have better adaptation to several agro-ecological zones in Africa, Asia, Australia and America (Borrell et al., 2004 ; Gamar and Mohamed, 2013; Grenier et al., 2004). In East Africa, over 70% of cultivation is carried out mainly in dry and warm lowlands with low soil fertility that constrain production of other crops (Amelework et al., 2016). In South Sudan for example, while the crop is cultivated in all the States, it is more common in the marginal areas with low rainfall and poor soil fertility where it occupies 859,662 hectares and produces 634,700 metric tonnes annually (FAO, 2017).

Sorghum production is in the hands of small scale poor farmers who grow low yielding landraces using farmer saved seed and farmer-to-farmer exchanges (FAO, 2016).

In Kenya, where semi-arid area covers75% of land mass (Ngugi et al., 2013), sorghum provides food and nutritional security and serves as a suitable alternative for maize. The crop is predominantly grown in the former Eastern, Western and Nyanza provinces which produce 99% of total grain sorghum in Kenya (Ngugi and Maswili, 2010) ; Ngugi et al., 2013). On-farm yield ranges from 0.6-to 1.5 t ha^{1} for open pollinated varieties and 4.5 to 7.0 t ha^{1} for hybrids (Ngugi and Maswili, 2010). The high yield in Kenya is attributed to a well-established extension system, modern farming practices, improved technologies and breakthrough in yield barriers through cytoplasmic male sterility (Ngugi et al., 2013).

In Uganda, sorghum is a leading staple cereal particularly in the West, Northern and Eastern parts where it is consumed in the form of bread, ugali and local alcoholic beverages (Awori et al., 2015). The crop yields up to 1.52 t ha^{1} for well managed local varieties and 5 t ha^{1} for improved open pollinated varieties (Robert, 2011). In Ethiopia, sorghum is utilized in various forms including local bread, floor, cake, local alcohol beverages and roasted or boiled grain (Amelework et al, 2012). In Ethiopia, sorghum is utilized in various forms including making local bread, floor, cake and for preparing local alcoholic beverages and is consumed as roasted or boiled grain (Amelework and Beyene, 2012). In Eritrea, sorghum accounts for more than 50% of the total food crop produced annually and is grown more in the warm lowland areas of the country where rainfall is erratic and unpredictable (Tesfamichael et al., 2015).

2.3 Constraints to sorghum production in East Africa

The average on-farm sorghum yield in Eastern Africa is 0.6-1.5 t ha^{1} vis-a-vis worldwide average yield of more than 4.5 t ha^{1} (Ngugi and Maswili, 2010). While yield losses are attributed to many abiotic and biotic stresses, drought stress is ranked as the major yield constraint globally because it is hard to predict at various phases of crop growth of cropping season in semi-arid areas that rely on rainfall.(Beyene *et al.*, 2015; Dalawai, 2017). Sorghum grain yield losses attributed to drought stress in South Sudan is estimated to be from 53 – 70% in the semi-arid areas(FAO, 2016).

2.4 Effects of drought stress on sorghum development and productivity

The severity of drought is unpredictable because of its dependence on many factors such as occurrence, duration and soil moisture retention capacity which are hard to quantify simultaneously (Tuinstra et al., 1997). Drought stress causes reduction of plants growth, impairment of photosynthesis and wilting by damaging carbon and nitrogen metabolism (Sanchez et al., 2002). Drought stress occurs at different stages of growth and adversely affects plants growth and yield parameters which lead to reduction in net yield (Kebede et al., 2001). The extent of grain losses caused by drought stress vary with sorghum genotypes and their stages of growth (Reddy et al., 2007). When drought stress occurs at the seedling stage of crop development, plant establishment is affected (Beyene et al., 2015). When drought stress occurs at pre-flowering period in barley and wheat for instance, grain fill phase is shortened and grain yield is reduced by decreasing the number of tillers, spike, grain per plant, grain weight and time to anthesis(Nguyen, 2001).

Short duration drought stress mostly reduces grain yield while prolonged drought stress leads to complete death of plant (Farooq and Wahid, 2009). Post-anthesis drought stress is considered more detrimental to grain yield regardless of the stress severity because photosynthesis per unit leaf area is decreased leading up to 70% yield losses (Tadesse et al.,2015). As drought severity increases, photosynthesis is impaired due to a decline in RUBISCO activity which leads to reduction in grain size attributable to interruption of grain filling because of reduced level of sucrose synthase activity (Shamsul et al., 2017). Similarly, growth is constrained by the inactivation of adenosine –glucose –pyophysphorylation in wheat (Farooq anf Wahid, 2009) while in maize, drought stress causes yield reduction by delaying silking which leads to increased anthesis to silking interval (Bänziger et al., 2004). Drought stress at flowering in maize usually leads to barrenness caused by reduction in the assimilate flux to the developing ear (Neil, 2012).

Sorghum crop post flowering drought stress causes the susceptible genotypes to exhibit stalk lodging, reduced seed size, susceptibility to charcoal rot, reduced biomass, loss of chlorophyll, degradation of photosynthesis, reduced seed weight, reduced grain number, reduced 100-seedwieght and premature leaf and stalk senescence (Sanchez1 et al., 2002). Post flowering drought stress affects transpiration efficiency, carbon dioxide fixation, carbohydrate translocation which ultimately lead to decreased photosynthate and reduced yield (Morka., 2015). Pre-flowering drought stress of susceptible genotypes leads to leaf rolling, irregular leaf erectness, delayed flowering, floret abortion, reduced seed set, reduced panicle size, reduced plant height and premature plant death usually at grain fill phase in Sorghum (Nguyen, 2000).

Sorghum genotypes respond to drought stress through different genetic mechanisms involving adjustments at the level of morphology, phenology, physiology and biochemistry (Mafakheri et al., 2010). The timing and intensity of the stress plays a vital role in determining the sequence of plant responses contributing to large genotype by environment interaction (Borrell et al., 2014). Drought resistance in plants is due to both drought stress avoidance and tolerance mechanisms (Peacock, 1982). Drought avoidance and escape mechanisms (earliness) are key water tolérance traits which have been well studied and categorized (Reddy et al., 2006).

2.5 Sorghum drought tolerance mechanisms.

2.5.1 Drought escape

Drought escapes is defined as the plants ability to reach vital stage of life cycle before stress commences (Acquaah et al., 2012). Plants escape drought stress by making good use of optimal conditions available at the beginning of cropping season to develop vigor required to complete the lifecycle (Acquaah et al., 2012; Burke et al., 2010). Drought escaping genotypes do exhibit essential morphological modifications that enhance water use efficiency (WUE), rapid phenological development and development plasticity to escape stress periods (Rao and Nigam, 2003).

2.5.2 Drought avoidance

Drought avoidance is the ability of plants to prevent decrease of water potential under drought stress conditions (Amelework et al., 2012). Plants avoid drought by maximizing water uptake at the roots and making good use of water by minimizing stomatal water losses (Balko et al., 1975; Tadesse et al., 2008). Avoidance can be either water conservation mechanism if the plant uses C_4 photosynthetic pathways or water uptake mechanisms if the plant develops deep root system which enhances plant reach to underground water resources (Tesfamichael, 1999). Genotypes that use water conservation mechanisms do exhibit specialized morphological adaptations including increased stomatal, cuticular resistant and reduced leaf growth in a bid to mitigate water losses whereas genotypes that use collection mechanism do exhibit extended root growth (Staggenborg, 2010).

2.5.3 Drought recovery

The ability of sorghum plants to recover from drought depends on the severity of the wáter stress (Ogbaga et al., 2016). Severe drought stress impairs wáter absorption and transport which inhibits post-drought stress recovery (Ogbaga et al., 2016). Drought stress impairs warer intake by altering the root function and structural configuration of the root plasma membrane which leads to reduced stomatal opening and reduced transpiration rate due to reduced stomatal area (Ogbaga et al., 2016; Sadaqat et al., 2012). As the drought stress severity spins and excedes critical wáter potential, inhibition of intake of wáter and inorganic ion solutes esencial for osmoregualtion occurs leading to wilting and plant death (Abdipur et al., 2013).

The second way through which drought stress affects plant recovery ability is by impairing photosynthesis through photo-inhinbition in the reaction centres of wáter stress sensitive photosystem II (Ogbaga et al., 2016). Plants that recover from wáter stress do exhibit functional staygreen adaptations and functions including functioning phtosynthetic machinery, effeicient photosysntstem II , intact electron transport chain and high level of storage sugar which acts as osmolytes by ensurring cell membrane stability to prevent photoinhibition and cell bleaching (Motlhaodi, 2016).

2.5.4 Drought tolerance

Drought tolerance is the plants ability to survive low tissue water content in a drought stress conditions (Peacock, 1982). The fundamental basis of drought tolerance is staygreen trait which enhances plant growth and reproduction under drought stress conditions (Walulu, 1991; Staggenborg, 2010).

2.5.4.1 Staygreen trait

Staygreen is defined as an enhanced foliar greenness during graining fill phase to physiological maturity under post anthesis drought stress (Rosenow et al., 2002). Staygreen is an important trait associated with drought tolerance in several plants including sorghum crop (Borrell et al., 2014). Staygreen trait enhances disease resistance and reduces severity of lodging (Borrell et al., 2014; Dalal, 2012). Similarly, staygreen loci play key roles in source - sink reduction by reducing canopy size through reduced tillering, increased size of lower leaves, reduced size of upper leaves and reduction of number of leave per culm which minimize transpiration water loss and water demanding sink-sources (Borrell et al., 2011;Thomas and Ougham, 2014).

Staygreen trait improves sorghum yield and yield components under post anthesis drought stress conditions (Borrell, 2000). The trait improves grain yield by increasing grain number per panicle and 100-seed weight (Prasad et al., 2008). The better yield performance among staygreen genotypes is due in part to their high efficiency in converting absorbed water into biomass and grain yield as well as sustained photosynthate flow through sustained stability of chloroplast and photosynthetic machinery under stress condition (Beyene et al., 2015; Borrell, 2000; Tesfamichael et al., 2015; Harris et al., 2018).

Staygreen is expressed as functional or cosmetic (Thomas and Ougham, 2014). Functional staygreen is an important economic trait that allows for maintenance of photosynthetic activities in drought stress conditions. Functional staygreen is manifested as staygreen type A, B and E (Rosenow et al., 2002 ;Dalawai, 2017;). Cosmetic staygreen is of no economic value and is characterised by impaired photosynthetic capacity and chlorophyll pigment retention in already senesced leaves of the plant (Dalawai, 2017b; Rosenow et al., 2002; Thomas and Ougham, 2014). Cosmetic staygreen is expressed as staygreen type C and D (Krupa et al., 2017).

The clear distinctive differences between functional and cosmetic staygreen are that functional staygreen is associated with delayed transition from carbon-capture to nitrogen-remobilization phase of plant development while cosmetic staygreen does not delay this transition phase (Thomas and Ougham, 2014). Functional staygreen is associated with high green leaf area duration (GLAD) at physiological maturity unlike cosmetic staygreen (Thomas and Ougham, 2014). Functional staygreen is positively correlated with xylem pressure potential and grain yield which results in prolonged high water potential, green leaf duration at maturity (GlAM) and sustained photosynthetic activities unlike cosmetic staygreen (Thomas and Ougham, 2014).

2.5.4.1.1 Genetic basis of stay green

Staygreen trait is governed by a major gene (Walulu, 1991). Recent advances in genetic mapping have discovered four main staygreen quantitative trait loci (QTLs) namely Stg2, Stg1, Stg3 and Stg4 (Subudhi et al., 2000). These staygreen QTLs confer staygreen trait, earliness and yield (Beyene et al., 2015; Sanchez et al., 2002). The staygreen QTLs also account for 84% of phenotypic variation exhibited by staygreen genotypes (Subudhi et al., 2000). QTLs for stg1 and stg2 loci have been mapped to linkage A while stg3 and stg4 loci were mapped onto linkage group D and J (Subudhi et al., 2000).

2.5.4.1.2 Screening techniques for stay green

Direct and indirect selection approaches have been widely used as staygreen screening techniques. Direct approaches use environmental conditions in which the onset of stress factors is uniform and predictable whereas indirect ones use well managed and stress environments (Abdipur et al., 2013; Beyene et al., 2015). Selection under both optimal and drought conditions represent the ideal screening approach for yield and yield stability (Tuinstra et al., 1997). To achieve this, both visual scoring of leaf and plant senescence and genomic tools such as marker assisted selection (MAS) can be used to select for ideal staygreen genotypes (Reddy et al., 2014). Marker assisted selection (MAS) is more efficient, less time and resource consuming than conventional breeding approach (Borrell et al., 2014). Selection in either of the screening technique should always factor in yield and yield components to disprove of the concept that staygreen may be correlated with low yield attributed to low sink-source under post anthesis drought stress (Borrell et al., 2014; Beyene et al., 2015 ; Amelework et al., 2017).

Selection may also be done at plant growth phase at which they are more susceptible to drought stress (Reddy et al., 2007). In the case of sorghum, the plant is more susceptible to drought stress at germination phase, near-germination phase, vegetative phase and post-flowering phase (Sakhi et al., 2014). Thus, any screening technique should identify and select for tolerant cultivars at all phases of susceptibility to drought stress (Reddy et al., 2007).

2.5.4.1.3 Introgressing the stay-green trait

Most breeding programs employ pedigree and recurrent selection methods to develop staygreen candidate populations (Beyene et al., 2015). The choice of method of introgression depends on the breeding objective (Subudhi et al., 2000). If the breeding objective is to introgress staygreen QTLs into high yielding drought susceptible local cultivar, backcrossing selection method can be used (Rosenow et al., 2002) and if the aim is to develop staygreen populations, recurrent and pedigree selection methods can be used (Subudhi et al., 2000). Introgression of staygreen trait is easily achieved because of high heritability of staygreen loci present in donor parents B35 and E-36-1 (Subudhi et al., 2000 ; Reddy et al., 2007; Thomas and Ougham, 2014).

2.5.4.1.4 Selection criteria for staygreen

Selection criteria for staygreen genotypes are best executed under controlled and drought-stress environments because of the polygenic nature of the trait and high influence of genotype x environment interaction (Beyene et al., 2017). Drought stress conditions offer the best chances for tolerant cultivars to be developed, identified and selected based on staygreen core features such as high yield and yield and yield components stability under drought stress condition (Zhang, 2015).

2.6 Drought tolerance mechanisms of staygreen genotypes

A number of mechanisms are involved namely morphological adaptations, physiological defense mechanism, biochemical defense mechanisms and hormonal defense mechanisms.

2.6.1 Morphological adaptations.

Reduced canopy is an adaptation trait of staygreen genotypes that is linked to increased grain yield under post anthesis drought stress (Borrell et al., 2014). Staygreen genotypes reduce canopy to scale down water loss and maximize water use efficiency at flowering (Farooq et al., 2009). They do so through morphological modifications that reduce leaf area, tillering, leaf number per culm, plant height and leaf size (Dalawai, 2017). Leaf area can be reduced by reduced tillering (Borrell ' et al., 2014) while transpiration per unit leaf area can be reduced through reduced stomatal density, timing of stomatal opening and hydraulic factors (Borrell et al., 2014; Fracasso et al., 2016). By minimizing water use during the pre-anthesis phase, water is conserved for sustained grain filling during the grain development phase which leads to improved grain yield (Borrell et al., 2014 ; Beyene et al., 2015).

2.6.2 Physiological mechanism

Selection for physiological characters is limited to secondary attributes for drought tolerance (Beyene et al., 2015). Knowledge of plant physiology has improved breeders understanding of the complex networks of drought tolerance traits, the genes conferring tolerance and how they can be exploited on conventional and genomic platforms to screen and select for cultivars with better adaptation to drought stress (Schaffert et al., 2012; Harris et al., 2018).

Leaf rolling is a plant physiological defense mechanism against drought stress (Walulu, 1991). Cereal crops use leaf rolling to signal yellowing and wilting (Yoder et al., 2017). Leaf rolling occurs mostly at vegetative, pre anthesis, anthesis, grain fill onset phase and tillering in water stress environments (Shimelis et al., 2015). It contributes to drought tolerance by minimizing transpiration rate by altering leaf stomatal conductance and leaf area reduction (Staggenborg, 2010) as well as ameliorating heat intensity and incident solar radiation by lowering leaf temperature (Beyene et al., 2015). Leaf rolling is triggered by reduced leaf water potential although its severity varies among sorghum genotypes (Sanchez et al., 2002). Severe leaf rolling is associated with diminished water potential (Beyene et al., 2015) and serves as an indication of low leaf turgor attributed to poor osmotic adjustment (Anami et al., 2015). Cultivars with favorable osmotic adjustment at low leaf water potential develop less leaf rolling (Beyene et al., 2015; Shimelis et al., 2015) as exhibited by genotypes with functional staygreen trait (Staggenborg, 2010). If the plant initiates leaf rolling in the late phase of plant growth under post anthesis drought stress, it is indicative of continued plant growth and plant ability to recover after stress (Beyene et al., 2015).

Waxy bloom is a life enhancing trait exhibited by manifold terrestrial plants for survival in abiotic and biotic stress prone agro-ecologies (Yared et al., 2010). It plays an important role in maintenance of water potential (Staggenborg, 2010), leaf water retention ability (Assefa et al., 2010), drying avoidance (Farooq et al., 2009), excessive ultraviolent light reflectant (Farooq et al., 2009), insulation of plant against extreme solar radiation (Prasad et al., 2008) and enhanced water use efficiency in sorghum by regulating timely water loss (Dalal, 2012). Cuticular wax biosynthesis, translocation, deposition and compositions are influenced by environmental factors such as light, temperature, moisture and humidity in some species (Dalal, 2012; Rooney et al., 2014). There are significant correlations between the wax contents and yield, drought stress tolerance and water use efficiency in crops such as sorghum (Borrell, 2000; Borrell et al., 2004), Maize (Neil et al., 2012) Barley (Abera et al., 2009) , Rice (Dalal. et al., 2012) and wheat (Guo et al., 2016). Plants with dense wax were found to have drought stress tolerance and high yields relative to non-waxy crops (Guo et al., 2016). Dense wax load is also positively correlated with harvest index (Rooney et al., 2014). This suggests that genes that encode for biosynthesis of wax bloom can as well be utilized as valuable genetic resources for improving crop water stress tolerance and yield increment in drought prone agro-ecologies (Dalal, 2012).

Osmotic adjustment enhances crop yield through delayed leaf rolling, leaf senescence and effective leaf area retention which keeps up the photosynthetic apparatus intact for continued biosynthesis of photosynthates (Prasad et al., 2008; Zhang et al., 2015). Sustained photosynthesis and high assimilate content exhibited by genotypes with high osmotic adjustment confer improved yield compared to genotypes with low osmotic adjustment (Amelework et al., 2015). Genotypes with low osmotic adjustment do face competing demands for the remobilized assimilate to fill the grain and provide for energy required to keep up the osmotic adjustment processes running which leaves little or no assimilate for translocation up the plant for grain filling (Amelework et al., 2012; Beyene et al., 2015). The distinctive differences between genotypes with low and high osmotic adjustment is therefore expressed in the forms of grain size, grain number, grain weight, harvest index and biomass (Amelework et al., 2012; Beyene et al., 2015). All these differences vary with the genotype, stress intensity and duration (Khayatnezhad and Gholamin, 2012).

2.6.3 Biochemical mechanisms

Biochemical defense mechanisms for drought tolerance involve accumulation of compatible solutes including proline, glycine-betaine and trehalose (Hayat et al., 2017). These osmolytes maintain cells turgor and ameliorate the harmful effects of drought (Stephanie et al., 2015).

Proline accumulation in sorghum genotypes promote cultivar recovery ability (Amelework et al., 2012). It provides for respiratory energy required by stress genotypes to recover from water stress (Beyene et al., 2015). Proline determines critical water levels for which a plant can survive (Amelework et al., 2012). Its accumulation increases cell solute concentration which leads to increased water potential in the tissue through osmotic adjustments. The breeders use proline accumulation in sorghum as a good selection criterion for water stress tolerance (Amelework et al.,2012; Beyene et al., 2015).

Plants with low-molecular weight soluble compounds function as protective mechanisms through osmotic adjustment, detoxication of reactive oxygen species, stabilization of cell membranes and structural integrity of enzymes and proteins (Farooq et al., 2009). In sorghum, glycine-betaine and sugar function as osmolytes that protect cells from dehydration, bleaching and rupture (Beyene et al., 2015). Glycine-betaine and sugars accumulation in the cell assist in maintenance of cellular water content and plant water status (Amelework et al., 2012).

Plants use remobilized assimilate to enhances survival under post-anthesis drought stress conditions (Azarinasrabad et al., 2016). Both photosynthetic assimilate and stem assimilates are used for growth of vegetative organs, grain filling and grain development (Inoue et al., 2004). Assimilate remobilization and utilization is stimulated if photosynthetic assimilate pathways are impaired by drought stress, heat and diseases (Blum, 2017). When post anthesis drought stress proceeds with irreversible damage to photosynthetic machinery, plants resort to utilizing assimilate remobilized from photosynthetic assimilate and pre-anthesis assimilate banked in the stem and leaves to fill their grains and power biochemical process. This specialized adaptation is specific to staygreen genotypes unlike senescence susceptible genotypes which depend only on remobilized pre-anthesis stem assimilates to fill their grains (Inoue et al., 2004). Shortage of assimilate among drought sensitive genotypes leads to enhanced assimilate sink-source which creates a physiological burden to stem and leaves leading to wilting and drying off (Assefa et al., 2010; Thomas and Ougham, 2014).

2.6.4 Hormonal mechanisms

Cytokinin is the most potent oppressor of senescence as it regulates it by ensuring late onset of senescence thus creating staygreen phenotype (Farooq et al., 2009). Cytokinin mediated staygreen phenotype is a result of alteration in hormone metabolism and signalling in which cytokinin secretion is elevated and ethylene stimulation and secretion is inhibited (Rashotte et al., 2013).

2.7 Mating designs

Mating design is a procedure of producing progenies (Acquaah et al., 2012). Mating design is alternatively defined as the process of making possible crosses among the cluster of genotypes to produce subsequent filial generations (Griffing, 1956; Yuewen et al., 2010). There are two known types of design in plant breeding namely the mating designs and the experimental designs (Acquaah et al., 2012). Breeders main interest in mating design is to find out if there is significant variation among the genotypes and if that variation is heritable and the gene action controlling their expressions (Haussmann et al., 2002). Mating designs are used for specific objectives such as to generate improved technologies, select for genetically valuable parents and devise a powerful selection procedure (Acquaah et al, 2012). The commonly used mating designs are North Carolina design I, II and III, Line x tester design and diallel I, II, III and IV (Acquaah et al., 2012). These designs aid to generate information on the genetic influence of a particular character by partitioning such genetic influence into either additive and or non-additive components (Acquaah et al, 2012). The choice of either one of these designs is affected by the objective of the study, breeder resources, time, space, cost of germplasm, pollination type, method of crossing, method of pollen dissemination (wind or insect), absence of male sterility, goal of the breeding program, the size of the breeding populations required and the availability of project infrastructure (Acquaah et al., 2012). A number of assumptions are employed in the use of mating designs namely; diploid behavior at meiosis, independence of genes distribution, no multiple alleles at the loci controlling the character, no reciprocal differences and no genotype x environment interactions (Gorz et al., 1987; Shattuck and Christie, 1993). .

Diallel is a type of mating design used to study the genetic properties of particular inbred lines (Acquaah et al., 2012). Diallel is very informative in that it generates vital information about the combining ability of a particular line as well as estimating the genetic attributes of a population under study (Acquaah et al., 2012). The commonly used diallel mating designs are half diallel, full diallel and disconnected diallel. Diallel are distinguished on the basis of whether the parents or reciprocal effects are part in the model (Isik, 2009). All diallel types do estimate the variation due to the crosses which is divided into sources due to general combining ability and specific combining ability (Isik, 2009). A relatively large GCA and SCA variance ratio is an indicative of additive genetic effect and epistatic gene effect respectively (Harry et al., 2001). The use of diallel enables the discrimination of parental lines by partitioning genetic influence into general combining ability and specific combining ability (Acquaah et al., 2012).

2.7.1 Griffing's diallel

Full diallel is also known as complete diallel cross design. It entails the occurrence of equal numbers of each of the different crosses among P inbred lines, where P stands for large or reciprocal crosses as compared to direct crosses.(Griffing, 1956 ; Aloke et al., 1998).

$$\mathbf{P\ (P\text{-}1) = \frac{P(P-1)}{2\ \text{crossesofthetype}\ (i,j)\, i<j, ij=1,2\ldots p}} \text{...} \mathbf{(1)}$$

Where P= is the number of inbred lines under breeder's consideration, this type of diallel design s known as complete diallel cross.

2.7.2 Griffing method I, Model I

The method 1, model I comprises of parents, one set of F1's and the reciprocals (Griffing 1956). Griffing method I is therefore the mathematical models for combining ability analysis for the fixed effects which is provided for by fixed effect model in (equation 8).

Fixed effect model I

$$\mathbf{Y_{ij} = \mu + g_i + g_j + S_{ij} + r_{ij} + \frac{1}{bc}\sum_k \sum_l Eijrd} \text{...} \mathbf{(2)}$$

Where:

μ= Mean of the population

gi, g,= I^{th} and J^{th} parents general combining effect

Sij=is the specific combining ability effect for cross between the Ith and Jth parents where S_i=$S_{j.}$

r_{ij}= reciprocal effect comprising of the reciprocal crosses involving the Ith and Jth parents so as r_i=r_j an

e_{ijkl}= experimental error due to environmental effect associated with the ijklth.

2.7.3 Griffing's method II, Model II

This model incorporates the parents, set of F1's and the reciprocals. The difference it has from the fixed model is the assumption that the samples used are randomly picked from some parents population from which inference can be made on individual line in the sample representing the population (Griffing, 1956; Shattuck and Christie, 1993).

Random effect or model II.

$Yij= \mu + g_i + g_j + S_{ij} + v_{ij} + \frac{1}{bc}\sum (bv)\ \frac{1}{bc}\sum_k \sum_l E_{ijkl}$.. (3)

Where

μ= 1/px …$g_{i=}$ 1/2p(xl+ xi)+ 1/p X

S_i=i/2(X_{ij}+X_{ji})1/2p(x_l + x_j + x_i) +1/p^2X

R_j=1/2(X_{ij} + X_{ji}) (Griffing 1956). It is important to note these limitatons.$\sum_{gi}$=0 and $\sum 0_{ij}$+S_{ji}=0.

The variance of the effect can be ascertained using the following equations.

Variance (μ)= 1/p^2 α^2

Variance (g_i)=P-1/2p^2 α^2

Variance (S_j)= 1/2p (P2-2p+2) of the effect

Variance (rj)= ½ $\boldsymbol{\alpha^2}$

2.8 Combining ability

Combining ability is defined as the ability of a parental line to perform well or worse in hybrid combination (Laosuwan, 1975). Combing ability acts as a precise tool for quantifying the nature of gene action underpinning quantitative trait (Owolade, 2006). The knowledge of combining ability is essential in understanding the inheritance of the characters, generation of superior lines as well as facilitating the selection of parental lines for hybrid (Fasahat et al., 2016). The real measure of combining ability is progeny testing (Fasahat et al., 2016). Combining ability is divided into general combining ability (GCA) and specific combining ability (SCA) (Acquaah et al, 2012). General combining ability (GCA) is the mean performance of the genotypes in hybrid combination (Gilchrest, 2017) while specific combining ability (SCA) is the deviation of a cross from the mean performance of the parental genotypes (Mutava, 2014). GCA is due to additive gene action whereas the SCA is due to non-additive gene action (Acquaah et al., 2012). A low GCA estimate whether positive or negative indicates that the mean of a parent in a cross does not differ largely from the general mean of the crosses of the lines in combination. Conversely, a high GCA estimate indicates that the parental mean is superior or inferior to the general mean (Fasahat et al., 2016). Superior genotypes are identified on the basis of performance of their progenies (Acquaah et al, 2012).

Both general and specific combining ability are important concepts for studying and comparing the performance of inbred lines (Isik, 2009). They generate genetic information useful for selecting for superior parent in hybrid combinations as well as delineating the type of gene action for various traits of economic value (Mutava, 2014; Chikuta et al., 2017). The GCA and SCA concepts have also been used for genetic diversity evaluation, heterotic pattern classification and heterotic estimation (Acquaah et al., 2012; Fasahat et al., 2016).

Reciprocal crosses are involved in Griffing method I and Method III. These methods allow for partitioning of reciprocal effects into maternal effects and non-maternal effects (Harry et al., 2001). The inclusion of reciprocal crosses is vital in that it positively influences the estimates of SCA effects (Mahgoub, 2011). Reciprocal crosses have been reported to have a major positive impact on determination of yield of hybrid (Fasahat et al., 2016).

CHAPTER THREE

EVALUATION OF GRAIN YIELD, EARLINESS AND DROUGHT TOLERANCE PERFORMANCE OF SOUTH SUDAN LANDRACES UNDER WELL WATERED ABD DROUGHT STRESSED CONDITIONS.

3.1 Introduction

Sorghum is grown in all the States of South Sudan but more so in marginal areas with low rainfall and poor soil fertility occupying 859,662 hectares and producing 634,700 metric tonnes annually (FAO, 2017). The importance of sorghum lies in its roles as a cheap source of fibre, protein, carbohydrate, vitamins, fat, minerals (P, K, Fe Zn), phenolic acids, flavonoids and other bioactive compounds which act as antioxidants. Sorghum is also gluten free which makes it suitable as food for people with celiac disease (Rooney et al., 2004; Amelework et al., 2012; Ngugi et al., 2013; Tesfamichael et al., 2015).

The major constraints to sorghum on farm yield in South Sudan and Eastern Africa are prolonged drought stress, frequent dry spell, heat intensity and lack of drought tolerance technologies to farmers who need them (Ngugi et al., 2013). Both post anthesis and pre anthesis drought stresses do completely destroy sorghum on farm yield. Post-anthesis water stress on one hand leads to lodging, reduced biomass, loss of chlorophyll, degradation of photosynthetic apparatus, reduced seed size (Tuinstra et al., 1997), reduced seed weight (Jabereldar et al., 2017), reduced grain number, reduced 100-seed weight (Dalal, 2012) and enhances susceptibility to charcoal rot and premature sorghum leaf and stem senescence (Tuinstra et al., 1997). Pre anthesis drought stress on the other hand leads to late anthesis, floret abortion, reduced seed set, reduced panicle size, reduced plant height and premature death of plant (Beyene et al., 2015).

Sorghum is an important crop to South Sudan food security and farmer household income. It is cultivated by small-scale farmers for subsistence purpose and the surplus is marketed to earn income. The major sorghum grain attributes that determine grain and grain product marketing and consumption are grain quality, grain weight and grain product taste. Drought stress affects the dynamic of marketing because the desire and tendency to process grain sorghum by value addition groups depend on grain quality. The grain marketing by rural farmers is based on grain weight and grain product consumption by consumers is also determined by grain product quality taste. Drought stress affects these qualities by reducing grain weight, grain size and grain chemical components which leads to reduced protein and starch levels (Khaton et al., 2016). In order to alleviate drought stress reduction of grain quality, nutrition quality and product quality taste, there is a need to collect, screen and identify germplasm that possess staygreen trait that can be improved and harnessed for adaptation to drought stress in the drought prone agro-ecologies of Eastern Africa (Ngugi et al., 2013).

Introgressing functional Staygreen trait into South Sudan sorghum landraces will improve sorghum productivity and food security in drought stress prone agro-ecologies. Sorghum genotypes with this trait do exhibit improved yield, yield components and yield stability in water stress conditions (Tao et al., 2000). The yield superiority of staygreen genotypes relative to drought stress susceptible genotypes is associated with their higher level of cytokinin, stem sugars, leaf chlorophyll, biomass, leaf specific nitrogen, water potential and accumulated proline from flowering to physiological maturity (Subudhi et al., 2000; Tao et al., 2000; Borrel et al., 2006; Dalal, 2012; Wang et al., 2012; Zwack and Aaron 2013; Borrell et al., 2014; Stephanie et al., 2015; Harris et al., 2018).

Staygreen genotypes are also characterized by higher green leaf and stem duration (Borrell et al., 2014), higher efficacy of water conversion into biomass and grain yield (Acquaah et al., 2012) and improved balanced between water supply and water demand at flowering to grain fill phase (Tuinstra et al., 1997). The trait enhances resistance to lodging (Kamal et al., 2017), diseases (Borrell et al., 2014) and is associated with decreased canopy (Borrell et al., 2014), reduced tillering (Jordan et al., 2014), dwarf habit and insensitivity to photoperiod (Thomas and Ougham, 2014).

Plants employ host of defence mechanisms against drought stress including phenological response mechanisms through early anthesis and early physiological maturity (Dalal, 2012). Physiological mechanisms is through high cuticular wax deposition, high stem reserves and photosynthetic efficiency (Beyene et al., 2015). Hormonal mechanism is achieved through sustained secretion of cytokinin and inhibition of ethylene (Blum, 2011; Thomas and Ougham, 2014). Morphological adaptation mechanism are exhibited through dwarfism, reduced canopy and reduced tillering (Borrell et al., 2014). Biochemical mechanisms operate through well balancing of osmolytes and production of anti-oxidant defences (Thomas and Ougham, 2014).

There are emerging techniques breeders employ to generate staygreen genotypes in various plant species. Excessive production of chlorophyll through over expression of genes that encodes for chlorophyllide a oxygenase results into cosmetic type E staygreen (Dalal, 2012). Hormonal staygreen is produced by stimulating secretion of cytokinin while ethylene is inhibited (Zwack and Aaron, 2013). Staygreen also results from minimized water use during vegetative phase allowing for water to be conserved for sustained longer grain fill duration (Jordan et al., 2014). The aim of this study was to assess for drought stress tolerance, earliness and yield in South Sudan sorghum germplasm and ICRISAT lines to increase sorghum productivity for improved food security and poverty alleviation in water stress prunes agro-ecologies of South Sudan.

3.2 Materials and methods

3.2.1 Description of site of study

The study was carried out at ICRISAT-Nairobi field station at Kiboko in Makueni County in the year 2016 and 2017. Kiboko is located at 2” 20 S latitudes and 37 “45” E longitude. Kiboko lies in warm low-land of the semi-arid zone of eastern Kenya with an altitude of 900m above sea level. The area receives an annual rainfall of 604 per annum spread over a short rain season with the maximum temperature of 29.4^{0}C and minimum temperature of 16.6^{0}C.

3.2.2 Germplasm

Sorghum accessions comprising of 47 genotypes from South Sudan and 34 elite lines from ICRISAT were used (Table 3.1). The genotypes were chosen on the basis of farmer preference across Eastern Equatoria, Central Equatorial and Jonglei States of South Sudan. A number of check varieties were used in this study, namely Macia, Kiboko local 1 and Kiboko local 2. Macia is a drought tolerant variety with B35 donor staygreen QTLs. It was released by ICRISAT in 2011 for semi-arid agro-ecologies of East and Southern Africa. Kiboko local1 is a high yielding local variety with good adaptation to semi-arid coastal agro-ecological zones while Kiboko local 2 is an early maturing variety cultivated by farmers in semi-arid coastal areas of Kenya. Therefore, Macia was used as a check variety for drought tolerant trait; Kiboko local 1 and 2 were used as check varieties for yield and earliness in this study.

Table 3. 1. List of South Sudan sorghum germplasm and ICRISAT-Nairobi elite lines used in the study

Entry	Farmer	Cultivar	Village	County
1	James Lako	Landi-white	Tereka central	Tereka
2	James Lako	Lodoka	Tereka central	Tereka
3	Emmanuel Wuya	Lodoka(white)	Tereka central	Tereka
4	Emmanuel Wuya	Jeri	Tereka central	Tereka
5	Emmanuel Wuya	Majoldi	Tereka central	Tereka
6	Peter Lado	Medenge	Digala	Juba
7	Peter Lado	Lodoka	Digala	Juba
8	Cecilia Doki	Jeri	Kuli papa	Juba
9	Augustine Taban	Merese(brown/red)	Ganji payam	Juba
10	Augustine Taban	Merese(light brown)	Ganji payam	Juba
11	John Oryam	Deri(jeri)	Rajaf payam	Juba
12	Ikalik Enisha	Olerere	Kudo payam	Torit
13	Ikalik	Olodiong	Kudo payam	Torit
14	Ikalik	Omuhathi	Lohilo	Torit
15	Ikalik	Okabir	Kudo payam	Torit
16	Ayuen Kuany	Ber	Jongle	Bor
17	Ayuen Reech	Akwar achot	Jonglei	Bor
18	Joseph Oting	Deri	Bur payam	Torit
19	Joseph Oting	Deri	Bur payam	Torit
20	Idiongo Elijo	Miteen(okoro)	Bur payam	Torit
21	Guido Hayoro	Amachiha	Bur payam	Torit
22	Idiongo Elijo	Alwala	Bur payam	Torit
23	John Amaharanya	Amachiha	Hilieu	Torit
24	Atero Domnic	Athati	Himodonge payam	Torit
25	Miraya Labalang'	Natari	Central payam	Ikotos
26	Miraya Labalang'	Nachot	Central payam	Ikotos
27	Miraya Labalang'	Ibursar	Central payam	Ikotos
28	Miraya Labalang'	Lolodoka	Central payam	Ikotos

Table 3. 1. List of South Sudan sorghum germplasm and ICRISAT-Nairobi elite lines used in the study

Entry	Farmer	Cultivar	Village	County
29	Miraya Labalang'	Burjalure	Central payam	Ikotos
30	Mary Kubal	Gwada	Ikotos	Ikotos
31	Paul Lochi	Lolodoka	Ikotos	Ikotos
32	Paul Lochi	Osman assai	Ikotos	Ikotos
33	Lucia Naboyi	Nohonyek hohoro	Ikotos	Ikotos
34	Lokodo Cirilo	Nolokidok	Central payam	Ikotos
35	Lokodo Cirilo	Nolomutuk	Central payam	Ikotos
36	Emilia Murang	Lobuheti	Lomohidang n payam	Ikotos
37	Ajayo Lado	Kodu kine	Lirya payam	Juba
38	Ajayo Lado	Lodoharie	Lirya payam	Juba
39	Ajayo Lado	Lolikitha	Lirya payam	Juba
40	Ille Peliche	Lowoi kudo payam	Oderi	Torit
41	James Lako	Lodudu	Tereka central	Tereka
42	James Lako	Landi-red	Tereka central	Tereka
43	ICRISAT	Gadam hamam	Kiboko	Makueni
44	ICRISAT	Hariray	Kiboko	Makueni
45	ICRISAT	Hugurtay	Kiboko	Makueni
46	ICRISAT	ICSR 161	Kiboko	Makueni
47	ICRISAT	ICSV 111 IN	Kiboko	Makueni
48	ICRISAT	IESV 23006 DL	Kiboko	Makueni
49	ICRISAT	IESV 23010 DL	Kiboko	Makueni
50	ICRISAT	IESV 91104 DL	Kiboko	Makueni
51	ICRISAT	IESV 91111 DL	Kiboko	Makueni
52	ICRISAT	IESV 91131 DL	Kiboko	Makueni
53	ICRISAT	IESV 92028 DL	Kiboko	Makueni
54	ICRISAT	IESV 92029 DL	Kiboko	Makueni
55	ICRISAT	IESV 92043 DL	Kiboko	Makueni
56	ICRISAT	IESV 92170 DL	Kiboko	Makueni
57	ICRISAT	IESV 92172 DL	Kiboko	Makueni
58	ICRISAT	IS 3679	Kiboko	Makueni
59	ICRISAT	Kaguru	Kiboko	Makueni
60	ICRISAT	Bizany	Kiboko	Makueni
61	ICRISAT	Kiboko local 1	Kiboko	Makueni
62	ICRISAT	Kiboko local 2	Kiboko	Makueni
63	ICRISAT	Macia	Kiboko	Makueni
64	ICRISAT	Mahube	Kiboko	Makueni
65	ICRISAT	Mugeta	Kiboko	Makueni
66	ICRISAT	PP 290	Kiboko	Makueni
67	ICRISAT	Wad ahmed	Kiboko	Makueni
68	ICRISAT	ZSV 3	Kiboko	Makueni

Table 3. 1. List of South Sudan sorghum germplasm and ICRISAT-Nairobi elite lines used in the study

Entry	Farmer	Cultivar	Village	County
69	ICRISAT	CR 35:5	Kiboko	Makueni
70	ICRISAT	Mbeere 81-3	Kiboko	Makueni
71	ICRISAT	Tharaka 118	Kiboko	Makueni
72	ICRISAT	Tharaka 6	Kiboko	Makueni
73	ICRISAT	IESB 2	Kiboko	Makueni
74	ICRISAT	Wote collection 1	Kiboko	Makueni
75	ICRISAT	Khalid	Kiboko	Makueni
76	ICRISAT	Tabat	Kiboko	Makueni
77	ICRISAT	AG 8	Kiboko	Makueni
78	AWIEL	Malual	Awiel	Aweil
79	AWIEL	Makwach	Awiel	Aweil
80	JONGLE	Nuer bai	Bor	Bor
81	ICRISAT	Farmer local	Kiboko	Makueni

3.2.3 Experimental design and layout

The trials were set up in a 9 x 9 alpha lattice square design. Each trial was replicated three times with replicate spacing of 1.5m; inter row spacing of 75cm and intra-row spacing of 20 cm. The drought stress plots were separated from well irrigated plots by a buffer zone of 7m.

Overhead irrigation system was used to apply water to the trials every week from sowing to when the seedlings were at the pencil length height. At second weeding to booting stage, irrigation was applied after every two weeks. Based on the data recorded from three rain gauges in each trial, drought stress trial received 90mm while well-watered trial received 120mm of irrigated water. To induce water stress in the drought stressed trial, irrigation was withheld at 50% flowering while well-watered trial continued to receive water till grain fill phase. On sowing, seeds were drilled into furrows and later thinned to one plant per hill. The experiments were fertilized with

Diammonium Phosphate (DAP) - 18-46-0 (18% N, 46% P_2O_5, 0% K_2O) at planting and top-dressed with Calcium Nitrate (CN) 15.5% N; 19%N.) at second weeding.

3.2.4 Data collection

Data collected were grouped into earliness, drought tolerance and yield characters.

3.2.4.1 Earliness characters.

(i) Days to 50% flowering was obtained by counting days from emergence to when 50% of plants flowered.

3.2.4.2 Drought tolerance characters.

(i) Waxy bloom (0-9) was visually scored at vegetative phase on the scale of (0-9), where 0- stands for no waxy bloom 1-3 stands for slightly present. 4-5- stands for medium bloom, 7-8 stands for mostly bloomy and 9- stands for completely bloomy.

(ii) Leaf area (m^2) was measured on the tagged leaves of sampled plants by measuring leaf length and the width in centimeters at anthesis

(iii) Chlorophyll content (SPAD-) was measured for five sampled plants on the fourth middle leaf after two weeks of drought stress onset for consecutive five weeks.

(iv) Stem girth was measured in centimeters on the upper sheath of the fourth leaf at grain fill stage.

(v) Leaf rolling (1-5) was visually scored after two weeks of drought onset on the scale of 1-5; where 1- stands for evidence of leaf rolling, 2-3 stands for slightly rolled leaf, 4- stands for rolled leaf and 5- stands for cylindrical shape or completely rolled leaf.

(vi) Lodging susceptibility (1-7) was visually scored at physiological maturity on the scale of 1-7, where 1-3 stands for low lodging, 4-5 –stands for medium lodging and 6-7 stands for high lodging.

(vii) Leaf senescence (1-9): was visually scored at physiological maturity on the scale of 1-9, where 0- stands for no senescence on the leaf and stalk. 1-2 stands for very slightly senescent leaf and stalk. 3- stands for slightly senescent leaf and stalk.4-5 stands for intermediate leaf and stalk senescence, about half of leaves death and 6-7 stands for mostly senescent leaf and stalk.8-9 stands for completely senescent leaf and stalk.

(viii) Leaf drying score (LDS) was visually scored at physiological maturity, leaf and stalk drying score was calculated by divided the number of dry leaves by total plant's leaves number and multiplied by 100 as shown in (equation 5).

$$\mathbf{DLS} = \frac{\text{Number of dry leaves}}{\text{Total number of leaves}} \times 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \mathbf{(5)}$$

3.2.4.3 Yield characters.

(i) Length of flag leaf (cm) was measured in centimeters at grain fill stage. The length of flag leaves of tagged sample plants [per plot were measured in centimeters from the base of the leaf to the tip top of the leaf.

(ii) Peduncle length (cm) was measured in centimeters from the base of the first node where the sheath of flag leaf attaches to the base of the panicle at physiological maturity.

(iii) Peduncle exertion (cm) was measured in centimeters from the sheath of the flag leaf to the bottom of the panicle.

(iv) Panicle width (cm) was measured in centimeters from the widest middle position of the panicle at physiological maturity.

(v) Panicle length (cm) was measured in centimeters at physiological maturity from the base of the panicle to the upper tip top.

(vi) Plant height (cm) was measured in centimeters at vegetative phase from the ground to the tip top of the panicle for five sampled plants per plot.

(vii) Numbers of productive tillers were visually scored by counting per plant all reproductive tillers for five tagged plant samples at dough stage.

(viii) Panicle weight (Kg) was measured in gram for harvested plant samples after physiological maturity.

(ix) Threshability (%) was visually scored from values obtain after harvesting, threshing percentage is calculated mathematically by dividing grain of a plot sample by panicle weight of plot sample divided by 100%.as showed in (equation 6).

(x) **Threshability (%)** = $\frac{\text{Grain weight (g)}}{\text{Panicle weight (g)}} \times 100$...................................... **(6)**

(xi) Harvesting index (%) was obtained by dividing the grain weight by the biological yield and multiplied by 100% as shown in (equation 7).

Harvest Index= $\frac{\text{Grain wieght (g)}}{\text{Biological weight (Biomass + Panicle weight) (g)}} \times 100$................. **(7)**

(xii) 100-seedweight (Kg) was measured in gram by weighing100 seeds per plot.

(xiii) Grain yield (t ha^{-1}) was recorded after threshing, heads of five randomly tagged plants were weighed and the yield was measured by weighing threshed grains of tagged grains samples in ton per hectares.

3.2.5 Data analysis

Data collected on each genotype over a season for the two water regimes were subjected to the analysis of variance. Combined analysis of data for two water regimes was done using general treatment structure without blocking to obtain the means which were compared using the Fischer's protected least significant levels (L.S.D) at P ≤ 0.05.

3.3 Results

3.3.1 Phenology and morphological traits for the different sorghum genotypes

3.3.1.1 Analysis of variance for the plant phenology and morphological traits at Kiboko

Combined analysis of variance for plant phenology and morphological characters showed highly significant (P≤0.05) differences for all the traits under study. All the traits showed significant differences for all genotypes and across the water regimes (Table 3.2). The interaction between the water regimes and the genotypes showed significant differences for all traits except for days to 50% flowering; total leaf counts and dry leaf score (Table 3.2).

Table 3.2. Means squares of plant phenology and morphological characters under well irrigated and drought stressed environments

Sources of variation	DF	DFL	Stg	TTL	DLS	LA	WB	LR	LG
Water regimes	1	3022.52**	562.817*	109.796*	111904.2*	3899933*	642.965*	354.3724*	247.755*
Genotypes	80	2530.03**	2.104*	37.545*	276.1*	69045*	4.437*	1.1602*	5.467*
W X G	80	77.79ns	2.05*	2.623ns	239.1ns	25704*	1.903*	1.111*	2.038*
Residual	324	84.17	1.399	2.397	196.5	3011	1.412	0.2832	1.868
Total	485								

WxG= water regimes by genotypes; DF= degree of freedom; DFL=days to 50% flowering, StG= Staygreen; WB= waxy bloom; LA= leaf area; TTL= total leaf count; DLS= dry leaf score; * significance at 0.05 and ns= no significance.

3.3.1.2 Mean performance of plant phenology and morphological characters for South Sudanese sorghum germplasm and ICRISAT lines under drought stress conditions.

Based on means range, the germplasm were grouped into early lines (56 to 60 days), medium lines (70- 88 days) and late lines (90- 135 days). The superior genotypes for earliness than the check variety were Wotecollection1 (56 days), IESV 23010 DL (58 days), ZSV3 (60 days), Bizany (61 days) and Tabat (61 days). Over twenty eight lines were medium. The late lines to flower were Amachiha2 (135 days), Meresebrownred (134cm), Olerere (132cm) (Table 3.3).

The overall mean for staygreen trait was 5.148 with range from 1.963 to 8. Based on mean range, all the genotypes were grouped into highly staygreen (1.963 to 3.9), intermediate staygreen (4.0 to 5.0) and non-staygreen (6 .0 to 7.852) (Table 3.3). The superior staygreen lines that outperformed the check variety were Olerere (1.963), Meresebrowred (2. 481), Lowoikudupayam (3.204), IESV 92028 DL (3.704), Gwada (3.704) and IESV 23010 DL (3.944). Over 50 sorghum genotypes expressed intermediate staygreen trait and 20 genotypes were highly susceptible to drought stress conditions (Table 3.3).

As for leaf counts, the overall mean was 8.25 with mean range from 4.17 to 16.78. The highest total leaf counts were scored by genotypes Olerere (16.78), Amachiha1 (14.93) and Amachiha2 (14.33). The slightly leafy genotypes were Matual (4.7) Kaguru (4.34), Jeri1 (4.66), Majoldi (5.35), ZSV3 (5.4), Hugurtay (5.64), Hariray

(5.86), Wote collection1 (5.89), IESV 23006 DL (6.02), Nolomutuk (6.02) and Lolikitha (6.1) Table 3.3).

For dry leaf score, the overall genotypic mean was 44.6% with mean range from 12.82% to 76.23%). The lowest dry leaf score was recorded by top staygreen genotypes Olerere (12.02%), Lowoikudopayam (19.43%), Meresebrownred (20.09%), and Macia (25.74%).

For leaf area, large leaf area was recorded by staygreen landraces Meresebrownred ($321m^2$), Olerere ($295.4m^2$), Lowoikudupayam ($285.5m^2$), Amachiha2 ($279.7m^2$) and Amachiha1($274.3m^2$while Small leaf area was recorded by improved staygreen genotypes such as IESV 91131 DL ($70.6m^2$), Mahube($74.9m^2$), IESV 92029 DL($82.2m^2$), IESV 92172 DL($88.7m^2$), PP290 ($90.1m^2$), AG8 ($91.7m^2$), Tabat ($106.7m^2$), IESV 91111 DL ($108.9m^2$), IESB2($110,9m^2$), Wad ahmed($115.9m^2$), CR 355 ($117.1m^2$) Gadamhamam ($119.1m^2$), IESV 92028 DL($119.5m^2$) and Macia($119.8m^2$).

For waxy bloom, dense wax load was recorded by improved staygreen genotypes, Gwada, ICSR 161, Mahube, AG8, IESV 91131 DL, IESV 91111 DL, IESV 92028 DL, IESV 92172 DL and Malual (Table 3.3).

The overall mean for leaf rolling score was 4.907. Severe leaf rolling was recorded by genotype Omuhathi while rolled leaf was recorded by genotype, Nachot, Athati, Burialure, Derijeri, Jeri2, Lowoikudupayam, Olerere, Osmanassai and Medenge (Table 3.3). The genotypes that showed severe leaf rolling exhibit white leaf midrib colour (data not shown), this suggests that leaf rolling occurs on pithy genotypes.

The genotypes that showed resistance to lodging were predominantly improved staygreen lines namely IESV 23010 DL, ICSV 111 IN, IESV 23006 DL, IESV 91131 DL, IESV 92170 DL, Kaguru, Khalid, Kiboko local, Mahube, Malual, Wadehamed, IESV 92172 DL, Kiboko local2, CR355 and few landraces involving lines, Wote collection1, Miteenokoro, Lobuheti, Lodoka2 and Lodudu (Table 3.3).

Table 3.3. Performance of South Sudan and ICRISAT sorghum germplasm under drought stress condition

Genotypes	DFL	StG	TTL	DLS%	LA	WB	LR	LG
AG8	63.74	5.056	6.79	43.59	91.7	7.425	1.791	3.315
Akuorachot	61.52	5.167	6.54	48.6	135.5	4.056	2.15	4.574
Alwala	109.96	6.389	11.06	58.79	224.6	4.222	2.913	3.63
Amachiha1	120.48	4.241	14.93	34.29	274.3	4.902	3.17	2.981
Amachiha2	135.83	4.537	14.35	30.93	279.7	5.148	3.802	2.648
Athati	113.96	4.056	12.93	33.89	264.2	5.537	3.821	4.093
Ber	67.63	7.796	7.06	71.08	131.6	4.131	2.833	4.87
Bizany	61.17	4.63	6.23	37.25	135.8	6.204	1.854	3.37
Burialure	102.46	4.093	13.09	33.32	222.2	7.047	3.704	4.019
CR355	64.98	5.722	6.17	46.81	117.1	6.259	2.125	2.722
Deri1	115.93	5.019	13.54	46.67	255	5.222	3.132	4.556
Deri2	105.81	5.444	12.78	44.84	226.6	5.796	3.358	3.667
Derijeri	118.43	4.537	13.79	33.74	260.6	5.215	4.037	5.074
Farmerlocal	69.41	5.093	7.47	42.15	174.3	3.148	2.057	4.019
Gadamhamam	63.5	5.833	6.14	52.3	119.1	6.773	2.519	3.148
Gwada	122.7	3.759	13.26	33.48	242.1	6.999	3.497	5.259
Hariray	62.24	5.222	5.86	46.72	134.3	3.889	2.389	3.167
Hugurtay	80.22	7.204	5.64	64.15	151.6	5.036	2.877	2.926
Ibursar	104.19	4.778	10	41.57	249.8	5.463	3.469	3.074
ICSR161	66.52	5.574	7.28	47.9	133	6.593	1.926	2.056
ICSV111IN	58.31	5.296	6.64	41.18	146.6	5.381	2.167	1.741
IESB2	66.02	4.852	6.39	45.35	110.9	5.926	2.83	3.278
IESV23006DL	62.44	4.667	6.02	41.61	154.2	4.074	2.386	1.741
IESV23010DL	58.06	3.87	6.15	34.29	136.3	5.556	2.058	0.185
IESV91104DL	67.72	5.352	7.25	47.46	126	5.074	2.255	3.704
IESV91111DL	66.31	3.593	6.72	29.08	108.9	8.019	1.87	2.593
IESV91131DL	70.31	4.519	7.37	32.53	70.6	7.297	2.074	1.407
IESV92028DL	68.11	3.704	7.3	32.26	119.5	5.37	2.463	1.63
IESV92029DL	75.37	6.204	8.76	58.59	82.2	7.643	2.081	3.259
IESV92043DL	71.76	4.667	6.27	41.03	153.3	3.907	2.683	2.963

Table 3.3. Performance of South Sudan and ICRISAT sorghum germplasm under drought stress condition

Genotypes	DFL	StG	TTL	DLS%	LA	WB	LR	LG
IESV92170DL	73.63	4.185	7.33	35.2	124.6	4.9	1.928	1.556
IESV92172DL	70.94	5.13	7.53	39.47	88.7	8.37	1.524	1.519
Jeri1	76.39	7.444	4.66	72.26	230.9	4.994	3.111	6.352
Jeri2	119.33	4.981	12.61	45.47	241.9	5.328	3.889	4.648
Kaguru	62.67	7.852	4.34	76.23	152.3	4.513	1.613	1.981
Khalid	65.2	4.667	6.7	40.64	147.6	4.889	2.092	1.907
Kibokolocal1	70.04	4.593	7.03	36.79	140.6	6.149	2.28	1.315
Kibokolocal2	61.41	4.389	6.43	35.23	159.4	4.296	1.928	1.722
Kodukine	61.96	6.852	6.25	59.52	170.4	4.111	2.685	3.5
Landired	67.41	5.778	6.71	47.14	155.1	4.907	1.94	3.167
Landiwhite	66.28	7.296	6.97	71.03	230.7	4.809	3.37	3.667
Lobuheti	69.22	6.593	7.92	59.05	136.5	4.944	1.84	1.815
Lodoharie	61.48	5.611	6.66	48.34	156.7	4.141	2.574	2.556
Lodoka1	112.06	4	7.41	37.24	272.1	3.864	2.556	4.5
Lodoka2	86.83	4.796	7.51	41.34	242.4	4.959	3.644	2.13
Lodokawhite	97.22	5.63	7.24	54.42	244	4.957	3.33	3.778
Lodudu	71.09	5.333	7.13	48.69	175.2	4.241	2.021	2.019
Lolikitha	66	6.241	6.1	54.96	156.2	5.852	2.719	2.426
Lolodoka1	90.39	5.296	8.66	45.37	237.6	5.277	3.389	4.87
Lolodoka2	88.06	5.259	9.34	48.73	249.5	3.833	3.496	4.833
Lowoikudopayam	113.76	3.204	13.89	19.43	285.5	6.556	4.056	3.907
Macia	70.07	3.944	8.14	25.74	119.8	6.111	2.583	2.241
Mahube	69.28	4.093	8.31	34.49	74.9	7.259	2.144	1.611
Majoldi	65.87	7.333	5.35	69.27	174.3	3.569	3.074	5.5
Makuach	82.76	5.778	8.49	48.87	151.4	4.76	3.068	3.463
Malual	71.57	5.148	6.57	42.01	145.1	7.198	2.346	3.111
Matual	82.48	5.389	4.17	48.23	163.8	5.555	2.447	1.148
Mbeere813	64.43	5.63	6.78	49.83	120.2	5.279	2.477	3.852
Medenge	113.78	4.815	11.18	40.43	224.1	5.55	4	2.519
Meresebrownred	134.41	2.481	10.94	20.09	321	4.328	4.305	3.222
Mereselightbrown	84.65	5.815	7.97	51.64	223.3	5.476	3.833	3.315
Miteenokoro	65.65	3.963	6.74	30.24	146.2	5.159	1.747	1.963
Mugeta	79.2	5.796	7.83	56.86	124.6	5.141	3.128	3.722
Nachot	91.83	4.463	11.78	35.04	234.5	5.352	3.687	3.352
Natari	94.94	4.407	7.9	35.17	246	4.927	3.471	2.907
Nohonyekhohoro	77.98	5.296	7.85	49.7	270.5	4.796	4.076	4.833
Nolokidok	86.22	5.037	7.61	48.79	204.7	4.879	4.352	3.833
Nolomutuk	74.3	6.407	6.02	62.42	199.7	5.42	3.204	6.259
Nuerbai	63.85	4.5	6.21	38.58	176.6	5.593	2.976	3.074
Okabir	77.5	5.352	7.63	43.24	236.8	4.185	3.185	4.019
Olerere	131.98	1.963	16.76	12.82	295.4	5.833	4.33	3.556

Table 3.3. Performance of South Sudan and ICRISAT sorghum germplasm under drought stress condition

Genotypes	DFL	StG	TTL	DLS%	LA	WB	LR	LG
Olodiong	126.72	4.722	13.92	39.01	260	5.278	4.37	3.315
Omuhathi	108.31	4.907	13.66	40.98	255.8	5.111	4.907	4.037
OsmanAssai	117.33	5.537	8.13	43.96	261.7	6.296	3.722	7.093
PP290	66.19	4.093	7.95	29.01	90.1	6.778	2.171	2.759
Tabat	61.17	5.778	6.77	50.93	106.7	6.259	2.087	2.352
Tharaka118	64.57	5.056	7.03	46.5	147	5.352	3.033	2.5
Tharaka6	65.85	6.574	6.88	61.35	130.9	2.259	3.373	4.315
Wadahmed	61.57	5.333	6.53	42.34	115.9	6.402	2.181	1.704
Wotecollection1	56.94	4.907	5.89	44.06	153.7	5.307	2.379	1.796
ZSV3	60.09	6.481	5.4	58.76	127.8	4.278	3.033	3.13
Mean	81.46	5.148	8.25	44.6	179.4	5.344	2.864	3.214
CV (%)	12.7	26.1	23.6	33.3	11.6	19.3	22.9	47.6
L.S.D ($P \leq 0.05$)	23.916	3.0948	4.484	34.265	47.98	2.3765	1.5133	3.522

Key. DFL= days to 50% flowering, StG= staygreen, WB= waxy bloom, LA= leaf area, LR= leaf rolling, LG= lodging, TTL= total leaf counts, DLS= dry leaf score, SED= standard error of deviation, CV= coefficient of variance and LSD= least significant difference

3.3.1.3 Means ccomparison for plant phenology and morphological characters under drought stress and well irrigated conditions.

Mean comparisons (Table 3.4) showed that sorghum genotypes under well irrigated conditions reached flowering slightly early than the genotypes under drought stress conditions. The overall mean for genotypes under well irrigated conditions was 77days, way lower as compared to 82 days under drought stress conditions.

The earliest line under drought stress conditions was wote collection1 (56 days compared to IESV 23006 DL (57days) under well irrigated conditions. Conversely, the latest line under drought stress conditions were Amachiha2 (135 days) compared to Olodiong (125 days) under well irrigated conditions. Despite delayed flowering under drought stress condition, genotype, Hariray, ICSV III 1N, IESV 23010 DL, Kiboko local, Landiwhite, Nuerbai, Tabat and Wadahamed reached flowering early under drought stress conditions than under well irrigated conditions while flowering under both water regimes was attained at the same time by accessions Burialure (102 days), ICSR 161(66 days), Lodoharie (61.days), Lodoka1 (90.days), PP290 (66.02 days).

There was high variability among the genotypes for the staygreen trait under drought stress conditions than well irrigated conditions. The overall staygreen mean under drought stress conditions was 5.148 with mean range from 1.963 to7.882 compared to overall mean of 2.996 with mean range from 1.796 to 3.463 under well irrigated conditions (Table 3.4)

Total leaf counts were lower under drought stress conditions with an overall mean of 8.23 leaves and mean range from 5.448 to16.041 leaves compared to well irrigated trials where total leaf counts were high recording an overall mean 9.227 and mean range from 4.17 to 16.78. Dry leaf score (DLS) percent were higher under drought stress conditions with an overall mean 44.6% and mean range from 12.32 to 76.23% compared to low DLS% under well irrigated conditions with an overall mean 14.25$ and mean range from 6.53 to27.91%.

Leaf area was reduced under drought stress conditions recording an overall mean of 179.4cm^2 and means range from 70.6 to 321cm^2 compared to larger leaf area under well irrigated conditions with an overall mean of 358.6cm^2 and means range from 161.2 to 788.3cm^2. Wax load was dense under drought stress conditions recording an overall mean 5.344 and mean range from 2.259 to 8.37 mean compared to low load under well irrigated conditions with an overall mean of 3.433 scores and mean range from 0.778 to 4.778. Leaf rolling was high under drought stress conditions with an overall mean of 2.864 scores and mean range from 1.524 to 4.907 compared to lower leaf rolling under well irrigated conditions with an overall mean 1.161 scores and mean range from 0.741 to 2.463. Lodging was high under drought stress conditions with means range from 3.186 to 7.093 compared to reduced lodging under well irrigated conditions with mean range from 0.556 to 4.074 (Table 3.4).

Table 3.4 Plant phenology and morphological characters for drought stress tolerance of South Sudan and ICRISAT sorghum germplasm

Genotypes	DFL		StG		TTL		DLS (%)		LA (cm)		WB		LR		LG	
	IRR	WS	IRR	WS	IRR	WS	IRR	WS	IRR	WS	IRR	WS	IRR	WS	IRR	WS
AG8	61.4	63.7	2.8	5.1	8.2	6.8	14.2	43.6	246.0	91.7	4.2	7.4	1.4	1.8	1.2	3.3
Akuorachot	66.9	61.5	3.1	5.2	7.5	6.5	12.3	48.6	166.8	135.5	1.9	4.1	1.0	2.2	1.8	4.6
Alwala	101.6	110.0	3.1	6.4	13.3	11.1	18.3	58.8	655.5	224.6	2.1	4.2	1.6	2.9	4.0	3.6
Amachiha1	104.9	120.5	3.2	4.2	13.5	14.9	14.2	34.3	582.1	274.3	3.5	4.9	1.2	3.2	3.0	3.0
Amachiha2	106.7	135.8	2.8	4.5	12.9	14.4	17.2	30.9	610.2	279.7	3.2	5.1	1.1	3.8	4.1	2.6
Athati	108.6	114.0	2.6	4.1	14.0	12.9	10.9	33.9	519.8	264.2	2.8	5.5	1.3	3.8	2.0	4.1
Ber	66.0	67.6	3.1	7.8	7.5	7.1	18.3	71.1	232.0	131.6	2.6	4.1	1.1	2.8	1.4	4.9
Bizany	60.5	61.2	2.9	4.6	7.1	6.2	14.8	37.3	243.6	135.8	1.9	6.2	0.9	1.9	1.7	3.4
Burialure	102.2	102.5	3.1	4.1	11.9	13.1	14.2	33.3	548.0	222.2	3.5	7.0	1.0	3.7	2.7	4.0
CR355	60.4	65.0	2.9	5.7	7.6	6.2	11.0	46.8	206.9	117.1	4.5	6.3	0.8	2.1	1.1	2.7
Deri1	104.1	115.9	3.1	5.0	12.9	13.5	12.0	46.7	637.4	255.0	4.4	5.2	1.3	3.1	2.9	4.6
Deri2	98.4	105.8	2.8	5.4	10.3	12.8	9.3	44.8	584.6	226.6	4.0	5.8	1.0	3.4	1.2	3.7
Derijeri	116.1	118.4	3.2	4.5	13.6	13.8	14.4	33.7	726.4	260.6	4.0	5.2	1.1	4.0	3.6	5.1
Farmerlocal	65.8	69.4	1.8	5.1	7.6	7.5	9.4	42.2	320.0	174.3	1.6	3.1	0.9	2.1	2.1	4.0
Gadamhamam	59.9	63.5	3.2	5.8	8.0	6.1	11.2	52.3	192.2	119.1	3.6	6.8	1.1	2.5	1.0	3.1
Gwada	92.9	122.7	3.5	3.8	10.1	13.3	27.9	33.5	680.3	242.1	2.9	7.0	1.1	3.5	1.6	5.3
Hariray	68.8	62.2	3.1	5.2	7.0	5.9	22.4	46.7	192.5	134.3	2.5	3.9	1.0	2.4	2.1	3.2
Hugurtay	59.9	80.2	3.1	7.2	7.0	5.6	15.9	64.2	171.3	151.6	1.9	5.0	1.3	2.9	2.7	2.9
Ibursar	83.6	104.2	3.1	4.8	9.5	10.0	15.2	41.6	274.0	249.8	3.4	5.5	1.0	3.5	2.1	3.1
ICSR161	66.4	66.5	3.1	5.6	8.7	7.3	16.6	47.9	414.4	133.0	2.9	6.6	1.4	1.9	0.6	2.1
ICSV111IN	59.0	58.3	3.3	5.3	7.2	6.6	15.9	41.2	233.4	146.6	2.4	5.4	1.0	2.2	1.2	1.7
IESB2	64.7	66.0	3.2	4.9	7.7	6.4	23.9	45.4	350.2	110.9	3.6	5.9	0.9	2.8	2.2	3.3

Table 3.4 Plant phenology and morphological characters for drought stress tolerance of South Sudan and ICRISAT sorghum germplasm

Genotypes	DFL		StG		TTL		DLS (%)		LA (cm)		WB		LR		LG	
	IRR	WS	IRR	WS	IRR	WS	IRR	WS	IRR	WS	IRR	WS	IRR	WS	IRR	WS
IESV23006DL	57.9	62.4	3.0	4.7	7.7	6.0	12.9	41.6	287.3	154.2	2.1	4.1	1.0	2.4	1.4	1.7
IESV23010DL	67.2	58.1	3.1	3.9	7.0	6.2	13.1	34.3	305.3	136.3	2.4	5.6	1.4	2.1	1.2	0.2
IESV91104DL	66.9	67.7	3.0	5.4	9.0	7.3	14.7	47.5	315.0	126.0	1.8	5.1	1.3	2.3	0.9	3.7
IESV91111DL	63.1	66.3	2.9	3.6	7.8	6.7	9.5	29.1	353.9	108.9	3.3	8.0	0.9	1.9	1.0	2.6
IESV91131DL	67.7	70.3	3.2	4.5	9.5	7.4	13.4	32.5	428.1	70.6	3.7	7.3	1.1	2.1	1.0	1.4
IESV92028DL	68.0	68.1	3.0	3.7	9.1	7.3	9.6	32.3	348.8	119.5	2.7	5.4	1.0	2.5	1.4	1.6
IESV92029DL	69.4	75.4	3.1	6.2	10.8	8.8	11.0	58.6	263.7	82.2	3.7	7.6	1.4	2.1	1.0	3.3
IESV92043DL	65.6	71.8	2.9	4.7	7.8	6.3	16.0	41.0	355.7	153.3	0.8	3.9	1.1	2.7	0.8	3.0
IESV92170DL	65.2	73.6	2.1	4.2	7.2	7.3	11.4	35.2	345.5	124.6	2.1	4.9	1.2	1.9	1.0	1.6
IESV92172DL	72.1	70.9	3.1	5.1	9.6	7.5	9.1	39.5	344.3	88.7	3.6	8.4	1.2	1.5	1.1	1.5
Jeri1	66.6	76.4	3.1	7.4	8.8	4.7	13.7	72.3	225.2	230.9	2.9	5.0	1.2	3.1	3.6	6.4
Jeri2	118.8	119.3	3.0	5.0	13.5	12.6	8.9	45.5	624.8	241.9	2.9	5.3	1.0	3.9	1.6	4.6
Kaguru	61.0	62.7	3.0	7.9	7.0	4.3	16.0	76.2	249.3	152.3	2.2	4.5	1.6	1.6	1.5	2.0
Khalid	62.5	65.2	1.8	4.7	6.6	6.7	8.8	40.6	287.9	147.6	3.9	4.9	1.0	2.1	1.2	1.9
Kibokolocal1	65.4	70.0	3.4	4.6	8.3	7.0	19.3	36.8	273.9	140.6	3.1	6.1	0.9	2.3	1.4	1.3
Kibokolocal2	62.3	61.4	2.9	4.4	7.6	6.4	14.7	35.2	235.5	159.4	1.6	4.3	0.9	1.9	1.5	1.7
Kodukine	60.5	62.0	2.9	6.9	7.8	6.3	14.9	59.5	191.4	170.4	1.6	4.1	1.0	2.7	1.9	3.5
Landired	65.2	67.4	2.9	5.8	8.3	6.7	12.2	47.1	260.2	155.1	2.1	4.9	0.9	1.9	1.2	3.2
Landiwhite	67.7	66.3	3.1	7.3	9.1	7.0	17.3	71.0	234.1	230.7	3.6	4.8	1.0	3.4	1.6	3.7
Lobuheti	67.7	69.2	3.1	6.6	9.4	7.9	11.5	59.1	317.7	136.5	2.9	4.9	1.0	1.8	1.1	1.8
Lodoharie	61.1	61.5	3.2	5.6	7.2	6.7	21.6	48.3	314.3	156.7	2.4	4.1	1.0	2.6	2.3	2.6
Lodoka1	87.6	112.1	3.3	4.0	9.7	7.4	13.1	37.2	604.7	272.1	3.2	3.9	1.4	2.6	2.3	4.5

Table 3.4 Plant phenology and morphological characters for drought stress tolerance of South Sudan and ICRISAT sorghum germplasm

Genotypes	DFL		StG		TTL		DLS (%)		LA (cm)		WB		LR		LG	
	IRR	WS	IRR	WS	IRR	WS	IRR	WS	IRR	WS	IRR	WS	IRR	WS	IRR	WS
Lodoka2	84.3	86.8	3.1	4.8	9.3	7.5	17.8	41.3	285.7	242.4	3.2	5.0	1.1	3.6	3.3	2.1
Lodokawhite	75.2	97.2	3.1	5.6	9.4	7.2	15.6	54.4	261.0	244.0	3.5	5.0	1.1	3.3	2.2	3.8
Lodudu	67.0	71.1	3.1	5.3	9.0	7.1	15.7	48.7	292.1	175.2	3.4	4.2	1.0	2.0	1.1	2.0
Lolikitha	60.1	66.0	3.1	6.2	7.7	6.1	14.8	55.0	268.4	156.2	2.0	5.9	1.1	2.7	1.4	2.4
Lolodoka1	90.1	90.4	3.1	5.3	9.3	8.7	14.0	45.4	330.1	237.6	3.7	5.3	1.0	3.4	1.9	4.9
Lolodoka2	113.1	88.1	3.0	5.3	13.1	9.3	11.7	48.7	594.9	249.5	2.9	3.8	1.4	3.5	3.2	4.8
Lowoikudopayam	106.6	113.8	2.9	3.2	12.2	13.9	13.0	19.4	610.7	285.5	3.6	6.6	1.5	4.1	2.0	3.9
Macia	67.8	70.1	3.4	3.9	9.1	8.1	17.8	25.7	278.2	119.8	3.5	6.1	0.9	2.6	1.5	2.2
Mahube	65.8	69.3	3.2	4.1	8.2	8.3	16.5	34.5	253.2	74.9	4.2	7.3	1.5	2.1	0.6	1.6
Majoldi	64.3	65.9	2.9	7.3	7.7	5.4	16.6	69.3	220.2	174.3	2.9	3.6	1.4	3.1	1.9	5.5
Makuach	61.5	82.8	3.0	5.8	6.5	8.5	18.0	48.9	347.4	151.4	2.3	4.8	1.4	3.1	2.1	3.5
Malual	67.2	71.6	2.8	5.1	7.8	6.6	12.8	42.0	295.3	145.1	4.0	7.2	1.0	2.3	1.0	3.1
Matual	67.3	82.5	2.9	5.4	5.4	4.2	9.7	48.2	189.4	163.8	1.3	5.6	1.4	2.4	1.6	1.1
Mbeere813	59.6	64.4	1.9	5.6	7.3	6.8	8.1	49.8	238.6	120.2	3.3	5.3	1.2	2.5	1.1	3.9
Medenge	104.2	113.8	3.3	4.8	12.3	11.2	16.7	40.4	532.6	224.1	4.2	5.6	1.0	4.0	1.5	2.5
Meresebrownred	120.9	134.4	3.2	2.5	16.0	10.9	11.6	20.1	583.4	321.0	3.3	4.3	1.2	4.3	3.2	3.2
Mereselightbrown	77.8	84.7	3.1	5.8	10.4	8.0	17.1	51.6	445.4	223.3	3.6	5.5	1.4	3.8	1.5	3.3
Miteenokoro	60.3	65.7	3.0	4.0	8.6	6.7	18.0	30.2	222.7	146.2	2.3	5.2	1.0	1.7	0.9	2.0
Mugeta	66.7	79.2	3.1	5.8	7.0	7.8	13.9	56.9	341.7	124.6	2.1	5.1	0.7	3.1	1.0	3.7
Nachot	84.9	91.8	3.5	4.5	11.9	11.8	16.6	35.0	584.2	234.5	3.0	5.4	1.0	3.7	1.6	3.4
Natari	80.6	94.9	3.3	4.4	9.4	7.9	12.7	35.2	363.6	246.0	3.8	4.9	1.4	3.5	2.4	2.9
Nohonyekhohoro	76.7	78.0	3.0	5.3	9.7	7.9	14.6	49.7	326.9	270.5	2.9	4.8	0.9	4.1	3.4	4.8

Table 3.4 Plant phenology and morphological characters for drought stress tolerance of South Sudan and ICRISAT sorghum germplasm

Genotypes	DFL		StG		TTL		DLS (%)		LA (cm)		WB		LR		LG	
	IRR	WS	IRR	WS	IRR	WS	IRR	WS	IRR	WS	IRR	WS	IRR	WS	IRR	WS
Nolokidok	75.0	86.2	3.2	5.0	10.2	7.6	13.9	48.8	370.5	204.7	3.9	4.9	1.1	4.4	3.5	3.8
Nolomutuk	72.2	74.3	3.1	6.4	8.2	6.0	12.8	62.4	161.2	199.7	3.0	5.4	1.1	3.2	3.1	6.3
Nuerbai	64.1	63.9	2.9	4.5	7.6	6.2	6.5	38.6	210.7	176.6	0.8	5.6	1.0	3.0	1.4	3.1
Okabir	71.0	77.5	3.0	5.4	9.3	7.6	12.6	43.2	293.8	236.8	2.7	4.2	1.0	3.2	1.0	4.0
Olerere	122.4	132.0	3.1	2.0	15.1	16.8	9.9	12.8	564.2	295.4	4.2	5.8	1.1	4.3	2.4	3.6
Olodiong	125.0	126.7	2.9	4.7	12.1	13.9	13.7	39.0	788.9	260.0	4.7	5.3	1.5	4.4	3.9	3.3
Omuhathi	104.8	108.3	3.0	4.9	13.0	13.7	10.2	41.0	538.8	255.8	3.1	5.1	2.5	4.9	0.6	4.0
OsmanAssai	104.8	117.3	3.0	5.5	10.0	8.1	16.8	44.0	721.2	261.7	4.5	6.3	1.0	3.7	1.6	7.1
PP290	66.0	66.2	3.0	4.1	8.9	8.0	15.2	29.0	271.5	90.1	4.8	6.8	1.5	2.2	1.0	2.8
Tabat	70.3	61.2	2.8	5.8	8.1	6.8	12.5	50.9	292.2	106.7	4.3	6.3	1.5	2.1	1.3	2.4
Tharaka118	63.5	64.6	2.9	5.1	7.4	7.0	13.3	46.5	176.6	147.0	3.1	5.4	0.9	3.0	0.9	2.5
Tharaka6	60.7	65.9	3.4	6.6	7.4	6.9	16.1	61.4	239.1	130.9	2.7	2.3	1.4	3.4	2.1	4.3
Wadahmed	63.8	61.6	2.9	5.3	7.7	6.5	14.2	42.3	167.6	115.9	3.7	6.4	1.4	2.2	1.0	1.7
Wotecollection1	59.2	56.9	2.0	4.9	6.8	5.9	10.0	44.1	264.7	153.7	3.4	5.3	0.9	2.4	1.1	1.8
ZSV3	60.6	60.1	3.3	6.5	6.8	5.4	21.2	58.8	162.8	127.8	3.7	4.3	1.6	3.0	0.9	3.1
Mean	76.5	81.5	3.0	5.1	9.2	8.3	14.3	44.6	358.6	179.4	3.1	5.3	1.2	2.9	1.8	3.2
CV(%)	9.6	12.7	15.6	26.1	12.5	23.6	50.3	33.3	20.3	11.6	38.3	19.3	30.9	22.9	63.5	47.6
LSD ($P \leq 0.05$)	17.0	23.9	1.1	3.1	2.7	4.5	16.5	34.3	167.8	48.0	2.7	2.4	0.8	1.5	2.6	3.5

Key. DFL= days to flowering, StG= staygreen, TTL= total leaf counts, DLS= Dry leaf score, LA= leaf area, WB= waxybloom, LR= leaf rolling, LG= lodging, LMC= leaf midrib colour, IRR= irrigated, WS= water stress

3.3.2 Assessment of growth components of South Sudan Sorghum germplasm under drought stress and well-irrigated conditions.

3.3.2.1 Assessment of growth components.

The analysis of variance showed significant (P≤0.05) variations for all the growth-related traits for all the genotypes and across the water regimes (Table 3.5). The interaction between the water regimes and genotypes showed significant differences for all traits except peduncle length and peduncle exertion (Table 3.5).

Table 3.5. Means square of growth components of South Sudan and ICRISAT sorghum germplasm under well irrigated and drought stress conditions

Sources of variation	DF	PH	SG	PEL	PEX	PL	PWI	BM
Water regimes	1	77026.8*	211.5124*	2668.92*	1279.99*	547.9**	1135.6*	8.9575**
Genotypes	80	32414.2*	2.2476*	610.54*	244.82*	441.3**	17445.6*	1.7456**
W X G	80	1517.2*	0.9783*	47.92ns	19.91ns	100.3ns	382.8*	0.51**
Residual	324	556.8	0.4205	47.77	27.58	111.4	170.2	0.3076
Total	485							

Key. DF= degree of freedom, PH= plant height. SG= stem girth, PEL= peduncle length, PEX= peduncle exertion; PWI= panicle weight, AT= aerial tillers and BM= biomass

3.3.2.2 Mean performance of the sorghum genotypes for growth components

Plant height recorded an overall mean of 179cm with mean range 72.5cm to 318.8cm. The tallest genotypes were Meresebrownred (321cm) and Olerere (295.4cm) (Table 3.5). The shortest genotypes were Mahube, IESV 91131 DL, IESV 92029 DL, AG8, IESV 92172 DL, PP290, IESB2, Tabat and IESV 91111 DL (Table 3.6).

Stem girth overall mean was 3.379cm with mean range from 1.6cm to 4.6cm. The highest stem girth was noted on genotypes Lowoikudopayam (4.681cm) and Amachiha2 (4.437cm).

Peduncle length overall mean 49.3cm and range from 26.86cm to77.96cm. The largest peduncle length was recorded by genotype Lodoka2 (71.96cm), Natari (70.48cm), Osmanassai (68.25). Peduncle exertion recorded an overall mean of and 14.59cm and mean range from 2.91cm to 32.1cm. Longer peduncle exertion was noted on genotype, Lodoka1 (32.1cm), Nolokidok (29.02cm), Majoldi (27.9cm), Landiwhite (27.48cm), Natari (27.48cm) and Lodokawhite (26.16cm). The panicle width overall mean was 7.67cm and mean range from 3.77cm to 13.08cm. The widest panicle width was recorded for genotype Lodoka1 (13.08cm), Natari (12.43cm), Lolikitha (12.06cm), Lodoka2 (11.28cm), Lodokawhite (10.93cm), Kiboko local1 (10.23cm). Panicle length recorded an overall mean of 24.15cm with mean range from 7.65cm to 102.72cm. The longest panicle length was recorded by genotypes Lodoka1 (102.72cm), Jeri1 (42.26cm), Amachiha1 (38.72cm), Nohonyekhoro (37.34cm), Lodoka2 (34.17cm). Biomass recorded an overall mean of 1.115kgwith mean range from 0.0156kg to 2.374kg. Higher biomass was given by genotype, Mahube (2.374cm), IESV 91131 DL (2.333kg), Gadamhamam (2.163kg), Amachiha1 (1.976kg), Mereselightbrown (1.963kg), Lodoka2 (1.939kkg), Jeri2 (1.896cm), ICSR 161 (1.863kg), Nachot (1.824kg), Olerere (1.796kg), Burialure (1.722kg) and Lodokawhite (1.7kg).

Table 3.6. Mean values of growth characters of South Sudan and ICRISAT sorghum germplasm under drought stress conditions.

Genotypes	PH	SG	PEL	PEX	PWI	PL	BM
AG8	92.1	2.856	37.63	7.27	7.26	16.93	1.056
Akuorachot	133.6	2.919	52.23	17.83	6.74	15.23	1.437
Alwala	224.6	3.752	51.11	14.91	7.45	26.26	1.043
Amachiha1	274.3	4.167	52.21	11.97	6.72	38.77	1.976
Amachiha2	281.2	4.433	50.03	9.73	8.29	28.32	0.548
Athati	264.2	4.059	55.47	21.28	4.41	25.92	0.396
Ber	131.6	2.656	50.7	14.84	7.54	17.67	0.8
Bizany	135.8	2.859	37	6.54	6.05	36.24	0.307
Burialure	222.2	4.137	56.14	11.12	4	14.97	1.722
CR355	117.1	2.819	39.84	10	9.43	16.65	1.611
Deri1	255	3.581	53.41	16.59	6.66	32.78	0.728

Table 3.6. Mean values of growth characters of South Sudan and ICRISAT sorghum germplasm under drought stress conditions.

Genotypes	PH	SG	PEL	PEX	PWI	PL	BM
Deri2	226.6	4.015	46.3	4.39	6.43	29.67	1.548
Derijeri	260.6	4.263	55.73	5.09	6.14	18.23	1.639
Farmerlocal	174.7	3.107	49.29	13.4	9.18	19.45	0.55
Gadamhamam	119.1	3.163	48.29	18.83	7.48	23.94	2.163
Gwada	242.1	4.311	42.91	6.94	6.13	30.17	1.546
Hariray	132.4	2.9	48.95	23.47	6.81	15.12	0.772
Hugurtay	151.6	3.011	41.6	14.7	8.65	8.75	0.478
Ibursar	249.8	3.652	62.42	18.5	7.62	31.79	0.928
ICSR161	133	3.381	40.84	10.42	7.33	23.64	1.863
ICSV111IN	148.1	3.041	42.21	6.68	6.97	12.77	0.743
IESB2	111.2	3.8	41.49	3.75	7.82	22.24	0.704
IESV23006DL	154.2	2.985	42.39	12.38	8.81	21.58	1.407
IESV23010DL	136.3	3.511	37.31	6.56	6.28	20.22	0.607
IESV91104DL	126	3.696	36.54	9.85	7.53	21.17	0.811
IESV91111DL	108.9	3.041	32.11	4.55	6.86	16.86	1.183
IESV91131DL	70.6	3.733	26.86	2.91	7.18	20.04	2.333
IESV92028DL	117.7	3.333	41.86	9.99	8.94	21.27	1.293
IESV92029DL	82.2	4.096	31.86	4.11	8.86	29.53	1.343
IESV92043DL	153.3	3.463	47.3	11.55	7.38	21.61	1.306
IESV92170DL	124.6	2.981	58	13.09	7.59	14.86	1.33
IESV92172DL	88.7	3.867	40.81	7.43	7.37	23.61	0.931
Jeri1	232.3	2.389	64.88	19.13	6.36	40.26	1.104
Jeri2	240	3.996	55.44	10.43	6.28	32.74	1.896
Kaguru	152.3	2.752	57.79	22.36	7.26	23.95	1.05
Khalid	147.9	3.159	50.53	16.86	7.05	19.03	1.104
Kibokolocal1	142.1	3.385	42.74	10.16	10.23	18.19	0.561
Kibokolocal2	157.6	3.041	52.11	14.04	6.76	23.87	1.061
Kodukine	170.4	3.063	56.77	23.37	8.22	20.05	1.476
Landired	155.1	3.433	46.37	16.68	8.55	17.51	0.565
Landiwhite	230.7	3.404	62.72	27.48	10.93	32.31	0.156
Lobuheti	136.5	3.741	43.02	13.31	8.27	17.43	0.865
Lodoharie	156.7	3.226	50.08	12.69	9.24	13.73	0.935
Lodoka1	272.1	3.8	38.01	32.1	13.08	102.72	0.726
Lodoka2	242.4	3.622	71.96	22.07	11.28	37.17	1.939
Lodokawhite	244	3.626	60.29	26.16	10.93	31.23	1.7
Lodudu	175.2	3.578	49.85	15.59	9.66	20.25	0.539
Lolikitha	157.7	3.563	48.65	19.85	12.06	18.38	0.846
Lolodoka1	239.1	3.937	62.69	19.99	8.2	32.88	0.822
Lolodoka2	249.5	4.437	63.8	23.2	8.75	29.82	0.965
Lowoikudopayam	285.5	4.681	63.54	22.06	5.39	26.08	1.609
Macia	119.8	3.837	42.79	12.39	8.85	24.41	1.433
Mahube	74.9	3.33	42.22	12.63	6.68	20.49	2.374
Majoldi	174.3	2.878	60.47	27.9	7.63	30.15	1.03
Makuach	151.7	3.226	54.91	15.56	8.61	18.85	0.457

Table 3.6. Mean values of growth characters of South Sudan and ICRISAT sorghum germplasm under drought stress conditions.

Genotypes	PH	SG	PEL	PEX	PWI	PL	BM
Malual	145.4	3.344	40.46	10.84	8.06	26.58	0.741
Matual	163.8	2.333	33.94	17.1	6.37	12.34	0.454
Mbeere813	120.2	3.467	41.34	10.22	7.71	14.51	1.339
Medenge	224.1	3.867	44.45	10.84	5.83	30.47	0.304
Meresebrownred	321	2.837	53.16	14.24	6.43	28.82	1.38
Mereselightbrown	223.3	3.181	59.26	20.93	9.41	27.91	1.963
Miteenokoro	146.2	3.159	48.19	14.45	7.66	12.91	0.907
Mugeta	124.6	3.604	45.96	7.52	6.01	7.65	0.844
Nachot	232.7	3.633	56.67	20.26	5.26	23.76	1.824
Natari	246	3.748	70.48	27.38	12.43	36.27	1.413
Nohonyekhohoro	270.5	3.944	58	11.3	8.29	37.94	1.5
Nolokidok	204.7	3.374	66.22	29.02	10.04	24.86	0.206
Nolomutuk	197.9	3.026	63.57	23.19	8.45	35.92	1.276
Nuerbai	144.3	2.741	44.47	17.27	5.44	15.84	0.47
Okabir	238.2	3.307	58.59	19.99	9.73	26.93	1.354
Olerere	295.4	1.419	51.21	7.52	6.75	29.6	1.796
Olodiong	260	1.57	49.83	9.82	7.61	25.14	0.874
Omuhathi	255.8	3.222	50.22	12.25	3.77	21.69	1.593
OsmanAssai	261.7	4.111	68.25	21.18	5.23	29	0.681
PP290	90.1	3.578	41.1	10.69	7.9	20.13	1.554
Tabat	107.1	3.622	43.73	13.91	7.82	28.06	1.537
Tharaka118	145.2	3.285	29.7	5.63	6.33	8.12	0.631
Tharaka6	132.4	3.111	33.04	5.58	7.44	15.24	0.557
Wadahmed	115.9	2.878	39.86	15.32	7.27	22.11	1.269
Wotecollection1	154.1	2.563	61.97	21.15	5.53	11.86	0.515
ZSV3	127.8	3.048	47.22	17.66	6.29	14.37	1.004
Mean	179	3.379	49.3	14.59	7.67	24.15	1.115
CV%	11.8	19.2	14.6	35.8	25.4	60.1	68.9
L.S.D ($P \leq 0.05$)	48.87	1.4969	16.604	12.051	4.487	33.425	1.7697

PH= plant height, SG= stem girth, PEL= peduncle length, PEX= peduncle exertion, PWI= panicle width, PL= panicle length, BM= biomass

3.3.2.3 Comparison of mean values for growth components under well irrigated and drought stress conditions.

Mean comparison (Table 3.7) showed significant differences among genotypes for all growth characters studied across both water regimes. Sorghum genotypes under drought stress conditions recorded reduced overall means for growth characters compared to genotypes under well irrigated conditions. Stem girth recorded mean reduction from 4.7 to 3.4. Genotype Mugeta gave the highest stem girth under drought stress conditions than under well irrigated conditions. For plant height, mean reduction was from 204.2cm to 179cm. Accessions that were taller under drought stress conditions than under well irrigated conditions were CR 355, ICSR 161, IESV 23006 DL, IESV 923010 DL, IESV 92043 DL, Jeri1, Kodukine, Malual, Okabir, Tharaka11 and Wote collection1.

Peduncle length recorded reduction from 53.99cm to 49.3cm. Longer peduncle length under water stress than well irrigated conditions was given by accessions Ber, IESV 92043 DL, IESV 92172 DL, Kaguru, Kiboko local1, Kiboko local2, Kodukine, Lodoka2, Lolodoka2, Macia, Makuach, Matual, Meresebrownred and Mereselightbrown. Peduncle exertion recorded mean reduction from 17.94cm to 49.3cm but drought reduction effect was not observed on genotypes Alawala, Gadamhamam, Hariray, IESV 91131 DL, IESV 92172 DL, Lodoka1, Lolodoka1, Makuach, Matual, Meresebrownred and Tharaka6. Panicle length recorded mean reduction from 26.27cm to 24.15cm. Longest panicle length under water stress than control was given by accessions, Gadamahamam, IESB2, IESV 92029 DL, Kaguru, Kiboko local1, Kiboko local2, Kodukine, Lodoka1, Lodoka2, Lolikitha, Macia, Majoldi, Malual, Nolomutuk, Tabat, Tharaka6, and Wadahamed.

Panicle width recorded mean reduction from 9.27cm to 7.67cm. The genotypes that showed increased panicle width under drought stress than under well irrigated conditions were CR355, Farmer local1, Gadamahamam, Kaguru, Kiboko local1, Landiwhite, Lodoka1, Lodoka2, Lodokawhite, Lolikitha, Matua, Mbeere 813 and Tharaka11. Biomass was reduced from 0.8464kg to1.7697kg. The genotypes that recorded higher biomass under drought stress compared to under well irrigated conditions were Alwala, Amachiha1, Amachiha2, Athati, Bizany, Deri1, Farmer local, Jeri2, Khalid, Kiboko local1, Landiwhite, Lobuheti, Lodoharie, Lodudu, Nolokidok, Olerere, and Olodiong (Table 3.7).

Table 3.7. Comparison of growth response of South Sudan and ICRISAT sorghum germplasm under well irrigated and water stress conditions.

Genotypes	PH (cm)		SG (cm)		PEL (cm)		PEX (cm)		PWI (cm)		PL (cm)		AT		FBM (cm)	
	WS	IRR	WS	IRR	WS	IRR	WS	IRR	WS	IRR	WS	IRR	IRR	WS	IRR	WS
AG8	92.1	95.0	2.9	4.4	37.6	37.8	7.3	11.4	7.3	8.8	16.9	16.8	1.5	0.6	1.1	0.4
Akuorachot	133.6	173.9	2.9	3.8	52.2	53.7	17.8	23.6	6.7	12.8	15.2	18.4	0.1	0.1	1.4	0.4
Alwala	224.6	318.9	3.8	5.5	51.1	61.0	14.9	14.4	7.5	9.8	26.3	37.6	0.1	0.0	1.0	1.7
Amachiha1	274.3	329.9	4.2	5.6	52.2	65.3	12.0	19.6	6.7	12.2	38.8	41.3	0.0	0.0	2.0	1.9
Amachiha2	281.2	341.3	4.4	6.4	50.0	56.6	9.7	11.3	8.3	9.5	28.3	29.8	0.1	0.1	0.5	2.7
Athati	264.2	356.1	4.1	5.2	55.5	71.3	21.3	26.0	4.4	6.0	25.9	31.7	0.1	0.0	0.4	1.9
Ber	131.6	157.3	2.7	3.6	50.7	50.5	14.8	21.8	7.5	8.7	17.7	19.2	0.2	0.0	0.8	0.5
Bizany	135.8	169.5	2.9	4.4	37.0	48.5	6.5	18.2	6.1	7.8	36.2	14.2	0.2	0.0	0.3	0.7
Burialure	222.2	288.8	4.1	4.8	56.1	65.3	11.1	21.1	4.0	7.5	15.0	31.0	0.1	0.0	1.7	1.6
CR355	117.1	106.4	2.8	4.0	39.8	44.6	10.0	15.1	9.4	7.2	16.7	18.5	0.3	0.1	1.6	0.2
Deri1	255.0	310.2	3.6	5.2	53.4	61.9	16.6	22.7	6.7	7.9	32.8	37.8	0.2	0.0	0.7	1.9
Deri2	226.6	292.1	4.0	5.3	46.3	65.2	4.4	18.6	6.4	9.3	29.7	39.4	-0.1	0.0	1.5	1.9
Derijeri	260.6	348.6	4.3	6.6	55.7	68.1	5.1	18.1	6.1	8.3	18.2	40.5	0.0	0.0	1.6	2.8
Farmerlocal	174.7	184.6	3.1	4.0	49.3	55.9	13.4	18.6	9.2	9.0	19.5	22.0	-0.1	0.0	0.6	0.6
Gadamhamam	119.1	129.3	3.2	4.0	48.3	49.4	18.8	15.5	7.5	6.2	23.9	18.4	0.5	0.2	2.2	1.0
Gwada	242.1	326.4	4.3	6.0	42.9	58.7	6.9	14.6	6.1	6.9	30.2	34.7	0.1	0.0	1.5	2.6
Hariray	132.4	162.1	2.9	3.7	49.0	49.7	23.5	21.7	6.8	7.4	15.1	16.9	0.3	0.7	0.8	0.9
Hugurtay	151.6	154.0	3.0	2.8	41.6	46.3	14.7	22.5	8.7	8.7	8.8	14.1	0.7	0.6	0.5	0.3
Ibursar	249.8	253.4	3.7	4.7	62.4	69.3	18.5	20.3	7.6	10.3	31.8	41.2	0.0	0.0	0.9	1.5
ICSR161	133.0	111.2	3.4	4.8	40.8	40.4	10.4	13.5	7.3	7.8	23.6	25.1	0.2	0.2	1.9	0.6
ICSV111IN	148.1	137.5	3.0	4.3	42.2	51.1	6.7	16.2	7.0	9.4	12.8	20.6	-0.1	0.0	0.7	0.5
IESB2	111.2	99.3	3.8	4.9	41.5	38.4	3.8	5.7	7.8	10.7	22.2	22.1	-0.1	0.0	0.7	0.1

Table 3.7. Comparison of growth response of South Sudan and ICRISAT sorghum germplasm under well irrigated and water stress conditions.

Genotypes	PH (cm)		SG (cm)		PEL (cm)		PEX (cm)		PWI (cm)		PL (cm)		AT		FBM (cm)	
	WS	**IRR**	**WS**	**IRR**	**WS**	**IRR**	**WS**	**IRR**	**WS**	**IRR**	**WS**	**IRR**	**IRR**	**WS**	**IRR**	**WS**
IESV23006DL	154.2	136.8	3.0	4.2	42.4	51.7	12.4	14.1	8.8	9.0	21.6	23.1	0.2	0.0	1.4	0.6
IESV23010DL	136.3	110.7	3.5	4.5	37.3	47.6	6.6	8.4	6.3	10.6	20.2	22.8	0.3	0.0	0.6	0.5
IESV91104DL	126.0	150.4	3.7	5.2	36.5	40.9	9.9	13.0	7.5	8.3	21.2	22.0	0.0	0.0	0.8	0.8
IESV91111DL	108.9	124.4	3.0	4.4	32.1	42.0	4.6	9.1	6.9	8.9	16.9	22.4	0.2	0.0	1.2	0.5
IESV91131DL	70.6	106.8	3.7	5.1	26.9	35.9	2.9	1.4	7.2	9.6	20.0	24.5	0.5	0.0	2.3	1.0
IESV92028DL	117.7	143.0	3.3	5.2	41.9	44.3	10.0	13.1	8.9	9.1	21.3	22.9	0.3	0.0	1.3	0.9
IESV92029DL	82.2	137.0	4.1	5.3	31.9	34.7	4.1	5.4	8.9	9.3	29.5	23.2	-0.1	-0.1	1.3	0.5
IESV92043DL	153.3	131.8	3.5	4.9	47.3	42.3	11.6	9.6	7.4	7.4	21.6	22.5	0.0	-0.1	1.3	0.5
IESV92170DL	124.6	152.2	3.0	4.0	58.0	46.8	13.1	15.7	7.6	8.8	14.9	25.1	0.0	0.0	1.3	0.5
IESV92172DL	88.7	108.0	3.9	4.7	40.8	38.1	7.4	5.8	7.4	9.6	23.6	25.9	0.0	-0.1	0.9	0.7
Jeri1	232.3	215.8	2.4	4.1	64.9	72.6	19.1	22.8	6.4	10.0	40.3	36.2	0.4	0.3	1.1	1.0
Jeri2	240.0	357.9	4.0	5.6	55.4	65.2	10.4	11.3	6.3	7.4	32.7	37.7	0.0	0.1	1.9	2.3
Kaguru	152.3	169.8	2.8	4.0	57.8	55.2	22.4	21.5	7.3	5.5	24.0	19.0	1.2	0.7	1.1	0.4
Khalid	147.9	161.1	3.2	4.0	50.5	54.9	16.9	23.2	7.1	7.9	19.0	21.3	0.1	0.0	1.1	1.2
Kibokolocal1	142.1	146.4	3.4	5.0	42.7	40.3	10.2	10.8	10.2	10.1	18.2	17.6	0.0	0.0	0.6	0.7
Kibokolocal2	157.6	192.2	3.0	3.9	52.1	50.1	14.0	14.4	6.8	9.3	23.9	22.8	0.8	0.2	1.1	1.0
Kodukine	170.4	146.6	3.1	3.8	56.8	55.3	23.4	26.8	8.2	9.3	20.1	17.7	1.0	0.2	1.5	0.5
Landired	155.1	161.0	3.4	3.8	46.4	51.6	16.7	22.5	8.6	9.0	17.5	17.6	0.2	0.0	0.6	0.6
Landiwhite	230.7	237.1	3.4	4.5	62.7	70.5	27.5	33.3	10.9	10.3	32.3	27.8	0.3	0.0	0.2	1.0
Lobuheti	136.5	153.3	3.7	4.9	43.0	46.1	13.3	16.1	8.3	8.9	17.4	20.3	-0.1	0.0	0.9	1.0
Lodoharie	156.7	157.6	3.2	4.2	50.1	49.5	12.7	20.8	9.2	11.8	13.7	21.9	0.7	0.2	0.9	0.7
Lodoka1	272.1	295.5	3.8	5.4	38.0	62.7	32.1	24.1	13.1	10.7	102.7	44.8	0.3	0.0	0.7	1.9

Table 3.7. Comparison of growth response of South Sudan and ICRISAT sorghum germplasm under well irrigated and water stress conditions.

Genotypes	PH (cm)		SG (cm)		PEL (cm)		PEX (cm)		PWI (cm)		PL (cm)		AT		FBM (cm)	
	WS	IRR	WS	IRR	WS	IRR	WS	IRR	WS	IRR	WS	IRR	IRR	WS	IRR	WS
Lodoka2	242.4	274.2	3.6	4.7	72.0	60.5	22.1	22.1	11.3	10.0	37.2	36.0	0.2	0.0	1.9	1.3
Lodokawhite	244.0	261.1	3.6	4.8	60.3	71.3	26.2	32.7	10.9	10.8	31.2	33.3	0.2	0.0	1.7	1.4
Lodudu	175.2	183.9	3.6	4.4	49.9	57.6	15.6	19.3	9.7	10.6	20.3	22.7	0.9	0.2	0.5	0.8
Lolikitha	157.7	166.0	3.6	4.4	48.7	54.9	19.9	25.9	12.1	10.2	18.4	16.1	0.2	0.2	0.8	0.7
Lolodoka1	239.1	280.7	3.9	5.2	62.7	71.0	20.0	22.4	8.2	10.4	32.9	39.0	0.0	0.0	0.8	1.8
Lolodoka2	249.5	323.4	4.4	5.8	63.8	60.5	23.2	20.0	8.8	9.1	29.8	34.3	0.1	0.0	1.0	2.2
Lowoikudopayam	285.5	312.8	4.7	5.5	63.5	66.6	22.1	25.7	5.4	7.9	26.1	30.5	0.0	0.1	1.6	2.3
Macia	119.8	127.0	3.8	5.5	42.8	42.2	12.4	15.5	8.9	8.9	24.4	23.8	0.0	-0.1	1.4	0.6
Mahube	74.9	92.0	3.3	4.2	42.2	42.5	12.6	15.0	6.7	8.0	20.5	21.6	0.2	0.0	2.4	0.4
Majoldi	174.3	211.0	2.9	4.2	60.5	61.6	27.9	28.5	7.6	8.8	30.2	26.9	0.5	0.1	1.0	0.9
Makuach	151.7	186.8	3.2	3.8	54.9	51.9	15.6	15.1	8.6	7.1	18.9	23.2	0.4	0.1	0.5	0.5
Malual	145.4	133.4	3.3	4.5	40.5	39.7	10.8	10.2	8.1	8.6	26.6	22.9	0.0	0.1	0.7	0.5
Matual	163.8	136.6	2.3	3.2	33.9	52.1	17.1	10.5	6.4	4.4	12.3	20.4	0.4	0.4	0.5	0.4
Mbeere813	120.2	111.3	3.5	4.1	41.3	43.5	10.2	12.5	7.7	6.8	14.5	16.8	0.2	0.1	1.3	0.6
Medenge	224.1	320.0	3.9	5.6	44.5	60.5	10.8	18.8	5.8	9.8	30.5	33.5	0.1	0.0	0.3	1.8
Meresebrownred	321.0	368.9	2.8	6.0	53.2	52.9	14.2	13.5	6.4	10.0	28.8	34.7	0.0	0.2	1.4	3.1
Mereselightbrown	223.3	228.9	3.2	5.7	59.3	58.5	20.9	21.0	9.4	11.6	27.9	29.4	0.0	0.0	2.0	1.4
Miteenokoro	146.2	139.5	3.2	4.4	48.2	48.3	14.5	15.7	7.7	9.9	12.9	23.1	0.1	0.4	0.9	0.4
Mugeta	124.6	190.7	3.6	3.5	46.0	42.2	7.5	13.7	6.0	10.1	7.7	21.9	0.3	0.0	0.8	0.3
Nachot	232.7	287.6	3.6	5.2	56.7	64.1	20.3	24.8	5.3	8.0	23.8	35.2	0.0	0.0	1.8	1.3
Natari	246.0	263.8	3.7	4.6	70.5	72.9	27.4	28.0	12.4	31.2	36.3	37.2	0.3	0.0	1.4	1.3
Nohonyekhohoro	270.5	290.1	3.9	4.8	58.0	61.2	11.3	13.1	8.3	12.9	37.9	42.8	0.0	-0.1	1.5	1.4

Table 3.7. Comparison of growth response of South Sudan and ICRISAT sorghum germplasm under well irrigated and water stress conditions.

Genotypes	PH (cm)		SG (cm)		PEL (cm)		PEX (cm)		PWI (cm)		PL (cm)		AT		FBM (cm)	
	WS	IRR	WS	IRR	WS	IRR	WS	IRR	WS	IRR	WS	IRR	IRR	WS	IRR	WS
Nolokidok	204.7	252.4	3.4	5.3	66.2	68.4	29.0	30.2	10.0	10.2	24.9	26.9	0.1	0.0	0.2	1.9
Nolomutuk	197.9	209.7	3.0	4.2	63.6	63.6	23.2	26.1	8.5	8.2	35.9	33.0	0.3	0.4	1.3	0.6
Nuerbai	144.3	162.7	2.7	4.3	44.5	50.4	17.3	24.7	5.4	12.8	15.8	17.1	0.2	0.2	0.5	0.6
Okabir	238.2	230.4	3.3	4.6	58.6	62.8	20.0	24.6	9.7	10.7	26.9	28.8	0.0	0.0	1.4	0.9
Olerere	295.4	356.9	1.4	7.0	51.2	62.0	7.5	12.7	6.8	8.9	29.6	35.4	0.0	0.1	1.8	2.5
Olodiong	260.0	327.0	1.6	6.7	49.8	65.3	9.8	18.9	7.6	8.6	25.1	36.6	0.3	0.0	0.9	3.2
Omuhathi	255.8	303.8	3.2	4.9	50.2	64.7	12.3	26.0	3.8	4.9	21.7	25.6	0.1	0.1	1.6	1.3
OsmanAssai	261.7	296.0	4.1	6.0	68.3	72.0	21.2	24.7	5.2	12.3	29.0	39.7	0.1	0.1	0.7	2.7
PP290	90.1	130.8	3.6	4.1	41.1	44.1	10.7	15.2	7.9	7.9	20.1	24.2	0.1	0.0	1.6	0.3
Tabat	107.1	120.2	3.6	4.4	43.7	46.1	13.9	11.8	7.8	13.3	28.1	25.2	-0.1	0.1	1.5	0.5
Tharaka118	145.2	141.2	3.3	4.1	29.7	31.9	5.6	7.6	6.3	5.9	8.1	10.9	1.1	0.9	0.6	0.5
Tharaka6	132.4	138.6	3.1	4.0	33.0	35.9	5.6	5.4	7.4	7.7	15.2	15.0	0.4	0.2	0.6	0.4
Wadahmed	115.9	133.0	2.9	4.0	39.9	48.4	15.3	16.1	7.3	7.5	22.1	18.6	0.2	0.0	1.3	0.5
Wotecollection1	154.1	159.1	2.6	3.3	62.0	58.2	21.2	22.4	5.5	7.4	11.9	20.4	4.2	1.8	0.5	0.3
ZSV3	127.8	146.3	3.0	4.1	47.2	55.9	17.7	21.1	6.3	6.7	14.4	15.1	0.2	0.0	1.0	0.4
Mean	179.0	204.2	3.4	4.7	49.3	54.0	14.6	17.8	7.7	9.3	24.2	26.3	0.3	0.1	1.1	1.1
CV (%)	11.8	11.0	19.2	11.7	14.6	11.5	35.8	28.4	25.4	26.1	60.1	11.3	110.0	151.0	68.9	33.9
L.S.D(P≤0.05)	48.9	51.7	1.5	1.3	16.6	14.3	12.1	11.7	4.5	5.6	33.4	6.8	0.7	0.3	1.8	0.8

PH= plant height, STGTH= stem girth, PEL= peduncle length= PEX= peduncle exertion, PWI= panicle width, PL= panicle length, FBM= fresh biomass

3.3.3.4 Yield components of South Sudan and ICRISAT sorghum germplasm under well irrigated and drought stress conditions.

Analysis of variance showed significant differences (P≤0.05) for all the traits across the water regimes and genotypes. The interaction between water regimes by genotypes showed significant differences (P≤0.05) for all the traits except basal tillers, 100 seed weight and threshability (Table 3.8).

Table 3.8 Means squares for yield components of South Sudan and ICRISAT sorghum germplasm,

Sources of variation	DF	LFL	BT	PAWT	GWT	HSM	TH%	HI%
Water regimes	1	3295.77*	0.0053ns	17445.6*	8438.9**	19.7412*	317.9ns	89.449*
Genotypes	80	194.98*	1.839*	1135.6*	492.8**	1.7411*	344.8*	20.328*
W X G	80	90.26*	0.3306ns	382.8*	218.1**	0.3867ns	284ns	16.399*
Residual	324	58.6	0.2279	170.2	123.3	0.3055	202.1	7.971
Total	485							

DF= degree of freedom, LFL= length of flag leaf, BT= basal tillers, PAWT= panicle weight, GWT= grain weight, HSM= 100- seed weight, TH= threshability and HI= harvest index.

3.3.3.5 Mean performance of sorghum genotypes for yield components under drought stress conditions.

Largest length of flag leaf was recorded by genotype Lodoka1 (46.07cm), Lodoharie (46.01cm), Lolikitha (44.67cm), Natari (44.01cm), Ibursar (42.73cm), IESV 92043 DL (42.37cm), Nachot (41.93cm), IESV 23010 DL (41.51cm), Lodudu (41.32cm), IESV 92172 DL (40.93cm), Burialure (40.66cm), Gwada (40.61cm) and Miteenokoro (40.3cm). The highest panicle weight was recorded by genotypes Lobuheti (75.92g), Kiboko local1 (73.84g), IESV 92170 DL (71.58g), Lodoka2 (71.11g), IESV 92043 DL (69.77g), Lodoka1 (69.38g), Mereselightbrown (68.95g), IESV 91131 DL (68.98g), Nohonyekhoro (68.92g), IESV 92028 DL (66.47g), Meresebrownred (66.08g), IESV 92029 DL (66.89G), IESV 92172 DL (66.5g). The genotypes Lobuheti (50.65g), IESV 91131 DL (46.52g), Lodoka1 (47.08g) and IESV 92172 DL (46.69g) were superior for yield than the check variety.

The highest 100-seed weight was recorded by genotypes Hugurtay (3.767g), ZSV3 (3.724g), Malual (3.602g), Akuorachot (3.365g), CR 355 (2.93g), IESV 92170 DL (2. 909g), Omuhathi (2.88g), AG8 (2.85), IESV 23010 DL (2.754g), IESV 23006 DL (2.754g), (Mbeere813(2.685g), Nohonyekhohoro (2.646g), ICSR 161 (2.619g) , Kodukine (2.593g), Majoldi (2.587g), Wote collection1 (2.544g).

Threshability was relatively high for genotypes IESV 23006 DL (87.62), Majoldi (82.08g), IESV 23010 DL (81.02g), Mahube (80.74g), Farmer local (80.42), Ber (79.68g), IESB2, (78.31g), Akuorachot,(78.1), CR 355 (75.85), , Makuach (75.79g) and IESV 91131 DL (73.94). Low threshability was given by genotypes Amachiha2 (37.89), Okabir (38.99), Lolodoka1 (43.75g), Nachot (47.97), Natari (50.46), Lodoka2 (52.66) and AG8 (53.54).

The genotypes that showed increased harvest index under drought stress were Landiwhite (10.81%), Lodudu (10.01%), Lodoka1 (9.9%), Jeri (7.83%), IESV 111 IN (7.33%), Medenge (7.27%), Kiboko local1 (7.14%), IESV 92172 DL (6.86%), Landired (6.67%), Amachiha2 (6.48%), Tharaka11 (6.47%), Farmer local (6.44%) and Nolokidok (6.37%) (Table 3.9)

Table 3.9 Mean values of yield characters of South Sudan and ICRISAT sorghum germplasm under drought stress conditions.

Genotypes	LFL(cm)	BT	BM(kg)	PAWT(cm)	GWT(g)	HSM	TH (%)	HI (%)
AG8	31.55	0.385	1.056	41.67	22.33	2.85	53.54	3.05
Akuorachot	30.86	1.122	1.437	52.41	41.91	3.365	78.2	2.99
Alwala	33.71	2.167	1.043	41.23	25.96	2.15	59.37	5.08
Amachiha1	36.32	0.993	1.976	63.19	37.23	1.5	61.95	2.91
Amachiha2	40.04	0.33	0.548	63.07	27.94	1.85	37.89	6.48
Athati	31.64	1.507	0.396	41.81	24.25	2.387	62.51	5.86
Ber	22.46	0.4	0.8	43.11	34.33	2.47	79.68	4.68
Bizany	34.2	0.067	0.307	36.57	21.32	2.202	60.33	4.76
Burialure	40.66	1.311	1.722	37.65	20.59	1.593	53.97	1.3
CR355	28.07	0.156	1.611	35.33	25.19	2.93	75.85	3.69
Deri1	32.56	1.833	0.728	64.27	39.28	2.024	60.39	7.03
Deri2	32.03	1.256	1.548	61.21	35.44	1.424	64.15	2.14
Derijeri	27.95	1.341	1.639	46.2	31.1	1.946	61.99	2.54
Farmerlocal	31.1	0.8	0.55	55.4	43.98	1.928	80.42	6.44
Gadamhamam	32.46	0.607	2.163	37.6	25.43	2.263	65.8	2.11
Gwada	40.61	1.156	1.546	64.51	37.43	1.676	53.96	5.14
Hariray	28.96	0.148	0.772	41.3	23.16	2.337	56.59	3.87
Hugurtay	25.48	0.652	0.478	29.01	18.84	3.767	61.33	4.6
Ibursar	42.73	1.619	0.928	33.49	21.39	2.15	62.49	2.49
ICSR161	39.85	-0.015	1.863	58.85	39.53	2.619	67.73	2.77
ICSV111IN	35.73	0.052	0.743	57.93	41.5	2.511	71.34	7.33
IESB2	37.75	-0.096	0.704	41.41	32.39	1.396	78.31	3.25
IESV23006DL	35.43	0.178	1.407	43.55	36.59	2.754	87.62	5.09

Table 3.9 Mean values of yield characters of South Sudan and ICRISAT sorghum germplasm under drought stress conditions.

Genotypes	LFL(cm)	BT	BM(kg)	PAWT(cm)	GWT(g)	HSM	TH (%)	HI (%)
IESV23010DL	41.51	0.326	0.607	48.98	39.22	2.754	81.02	5.04
IESV91104DL	31.83	0.244	0.811	54.2	38.48	2.509	73.53	6.12
IESV91111DL	34.46	0.03	1.183	45.83	33.67	2.278	73.94	2.98
IESV91131DL	34.28	0.056	2.333	68.95	48.52	1.848	69.94	3.13
IESV92028DL	39.28	-0.026	1.293	68.47	44.22	2.091	65.09	3.84
IESV92029DL	36.36	-0.011	1.343	66.89	44.1	1.733	65.72	3.2
IESV92043DL	42.37	-0.004	1.306	69.77	35.92	2.228	51.98	4.72
IESV92170DL	38.67	0.067	1.33	71.58	42.58	2.909	61.23	3.71
IESV92172DL	40.93	0.015	0.931	66.5	46.69	2.206	67.34	6.86
Jeri1	34.25	1.926	1.104	50.94	33.92	1.896	68.32	7.83
Jeri2	26.95	0.889	1.896	49.39	31.67	2.093	65.38	3.2
Kaguru	24.21	1.781	1.05	34.06	25.02	1.998	67.99	2.62
Khalid	34.76	-0.074	1.104	50.78	34.11	2.319	66.11	6.05
Kibokolocal1	38.38	0.148	0.561	73.84	46.58	1.993	60.5	7.14
Kibokolocal2	36.69	0.381	1.061	44.1	28.87	2.033	65.2	2.67
Kodukine	36.97	-0.007	1.476	45.7	32.11	2.593	71.88	2.97
Landired	37.39	0.681	0.565	58.97	40.36	1.994	68.56	6.67
Landiwhite	31.56	1.096	0.156	57.76	37.87	1.696	66.38	10.81
Lobuheti	33.75	0.222	0.865	75.92	50.65	2.215	64.29	5.52
Lodoharie	46.01	0.707	0.935	60.79	37.98	2.35	60	5.57
Lodoka1	46.07	0.956	0.726	69.38	47.08	2.061	68.67	9.9
Lodoka2	39.47	0.848	1.939	71.11	36.88	1.687	52.66	3.39
Lodokawhite	37.17	0.522	1.7	54.11	30.38	2.004	53.72	2.04

Table 3.9 Mean values of yield characters of South Sudan and ICRISAT sorghum germplasm under drought stress conditions.

Genotypes	LFL(cm)	BT	BM(kg)	PAWT(cm)	GWT(g)	HSM	TH (%)	HI (%)
Lodudu	41.32	1.278	0.539	57.68	40.55	1.826	70.32	10.01
Lolikitha	44.67	0.637	0.846	59.17	39.54	2.269	63.3	6.04
Lolodoka1	35.07	1.248	0.822	45.67	25.73	2.009	43.75	3.57
Lolodoka2	36.65	2.144	0.965	52.51	38.63	2.1	76.73	5.99
Lowoikudopayam	38.46	1.43	1.609	28.63	15.97	2.148	63.92	2.42
Macia	32.43	-0.015	1.433	66.26	44.2	1.735	66.7	3.25
Mahube	38.79	0.074	2.374	36.63	29.41	1.785	80.74	1.76
Majoldi	26.63	1.619	1.03	50.89	39.68	2.587	82.08	5.49
Makuach	28.48	0.611	0.457	42.86	32.19	2.417	75.79	4.29
Malual	32.19	0.293	0.741	43.98	35.36	3.602	80.13	6.25
Matual	25.13	1.693	0.454	31.87	32.45	2.193	62.67	5.17
Mbeere813	37.29	0.219	1.339	42.62	26.76	2.685	66.41	2.08
Medenge	36.13	1.181	0.304	61	38.66	1.731	63.06	7.27
Meresebrownred	18.2	0.196	1.38	68.08	44.35	1.741	64.93	4.63
Mereselightbrown	32.7	0.437	1.963	68.98	39.93	1.663	56.58	2.63
Miteenokoro	40.3	0.67	0.907	52.79	35.37	1.743	66.68	5.83
Mugeta	31.4	1.293	0.844	35.92	23.04	1.856	64.48	3.31
Nachot	41.93	1.259	1.824	31.61	19.58	1.991	47.97	1.71
Natari	44.01	1.533	1.413	51.95	26.56	1.652	50.45	2.18
Nohonyekhohoro	38.81	0.911	1.5	68.92	42.19	2.646	59.18	4.67
Nolokidok	35.97	1.267	0.206	59.33	36.59	1.998	60.44	6.37
Nolomutuk	29	0.83	1.276	37.83	22.3	1.62	54.57	2.72
Nuerbai	26.14	0.981	0.47	31.68	18.57	2.1	63.55	4.72

Table 3.9 Mean values of yield characters of South Sudan and ICRISAT sorghum germplasm under drought stress conditions.

Genotypes	LFL(cm)	BT	BM(kg)	PAWT(cm)	GWT(g)	HSM	TH (%)	HI (%)
Okabir	30.9	1.063	1.354	44.08	17.32	1.793	38.99	2.54
Olerere	20.14	0.085	1.796	45.22	27.48	1.624	57.8	1.32
Olodiong	14.87	0.47	0.874	39.93	22.94	1.981	65.09	2.98
Omuhathi	26.29	2.281	1.593	26.44	19.09	2.88	66.87	0.98
OsmanAssai	36.2	1.244	0.681	27.21	18.38	2.489	58.67	2.74
PP290	35.58	0.178	1.554	58.16	36.91	2.063	58.6	4.72
Tabat	31.82	0.741	1.537	43.93	30.96	2.091	67.01	6.12
Tharaka118	19.98	0.704	0.631	45.71	33.71	2.333	75.5	6.47
Tharaka6	30.9	1.593	0.557	56.86	40.42	2.37	68.03	6.35
Wadahmed	32.49	0.893	1.269	40.95	25.79	1.9	66.27	3.61
Wotecollection1	28.01	0.993	0.515	26.34	16.62	2.544	63.83	3.95
ZSV3	23.72	0.426	1.004	38.87	25.76	3.724	70.11	2.91
Mean	33.8	0.756	1.115	50.24	32.8	2.191	64.77	4.43
CV%	23.1	59	68.9	27.2	27.6	23.6	20.1	65.5
L.S.D ($P < 0.05$)	18.029	0.778	1.7697	31.535	20.867	1.1893	29.927	6.688

Key, LFL= length of flag leaf, BT= Basal tillers, BM= biomass, PWT= panicle weight, GWT= grain weight, HSM= 100- seed weight, TH= threshability, HI=harvesting index.

3.3.3.6 Mean comparisons of yield components under well irrigated and drought stress conditions,

For all yield components, there was a significant means reduction under drought stress conditions compared to well irrigated conditions. Length of flag leaf recorded mean reduction from 39.01cm to 33.8cm. Panicle weight was reduced from 62.28g to 50.28g but genotypes ICSR161, ICSV III 1N, IESV 931131 DL, IESV 92029 DL, IESV 92170 DL, Nolokidok, Tharaka11, and Wote collection1 recorded higher panicle length under drought stress conditions than under well irrigated conditions.

Grain yield was reduced from 41.14g to 32.8g. High grain weight under drought stress conditions than under well irrigated conditions was exhibited by genotypes, Omuhathi, Nuerbai, Wadahamed, Alwala, Hariray, IESB2, AG8, Makuach, IESV 23006 DL, Malual, Kudokine, Lodoka2, Lodudu, ICSV III 1N, Deri2, Gwada, IESV 92172 DL, Mereselightbrown and IESV 92003 DL.

100-seed weight was reduced from 2.594g to 2.191g. Highest accessions under drought stress conditions than control was given by genotypes, Atahti, CR 355, Hariray, Hugurtay, IESV 92043 DL, IESV 92172 DL, Jeri2, Kiboko local, Kodukine, Lodokawhite, Lolikitha, Nolomutuk and Omuhathi. Threshability index recorded means reduction from 66.42g to 64.8g. Genotypes that recorded high threshability under drought stress conditions compared to well irrigated conditions were Akuorachot, Ber, CR 355, ICSR 161, IESB2, IESV 931111 DL, IESV 23006 DL, IESV 92029 DL, IESV 92170 DL, IESV 92172 DL, Jeri1, Lodoka1, Lodudu, Lolodoka2, Mahube, Majoldi, Makuach, Malual, Medenge, Mersebrownred, Mugeta, Nuerbai, Oludiong, Omuhathi, PP 290, and Wadehamed. Harvest index recorded means reduction from 5.28 % to 4.43%. The genotypes that showed increased harvest index under drought stress condition compared to well irrigated condition were, Alwala, Derijeri, Ibursar, ICSV 111 IN, IESV 911104 DL, IESV 92172 DL, Jeri1, Jeri2, Khalid, Lanidwhite, Lodoka1, Lodudu, Lolodoka1, Lowoikudopayam, Majoldi, Nohonyekhohoro, Nuerbai, Olodiong, Osmanassai and Tharaka6.

Table 3.10 Phenological and yield response of South Sudan and ICRISAT sorghum germplasm under well irrigated and drought stress conditions

Genotypes	LGFL (cm)		BT		PWT (g)		GWT (g)		HSM (g)		TH (g)		HI (g)	
	IRR	WS	IRR	WS	IRR	WS	IRR	WS	IRR	WS	IRR	WS	IRR	WS
AG8	35.9	31.6	0.9	0.4	44.1	41.7	34.6	22.3	3.2	2.9	79.1	53.5	7.7	3.1
Akuorachot	37.1	30.9	0.3	1.1	59.8	52.4	32.1	41.9	4.3	3.4	61.3	78.2	5.2	3.0
Alwala	23.7	33.7	0.8	2.2	80.7	41.2	57.9	26.0	2.2	2.2	71.8	59.4	3.3	5.1
Amachiha1	36.5	36.3	1.7	1.0	79.3	63.2	59.0	37.2	1.9	1.5	68.4	62.0	3.0	2.9
Amachiha2	45.7	40.0	1.4	0.3	97.9	63.1	63.4	27.9	2.2	1.9	61.2	37.9	2.9	6.5
Athati	39.7	31.6	1.1	1.5	55.6	41.8	36.5	24.3	2.0	2.4	65.9	62.5	2.4	5.9
Ber	32.9	22.5	0.6	0.4	51.4	43.1	29.9	34.3	3.5	2.5	52.3	79.7	5.1	4.7
Bizany	35.8	34.2	0.3	0.1	44.1	36.6	37.8	21.3	3.1	2.2	78.8	60.3	6.1	4.8
Burialure	42.3	40.7	1.4	1.3	63.0	37.7	33.2	20.6	2.1	1.6	59.7	54.0	2.5	1.3
CR355	34.1	28.1	0.1	0.2	44.3	35.3	29.6	25.2	2.7	2.9	70.3	75.9	9.4	3.7
Deri1	44.9	32.6	1.9	1.8	86.1	64.3	56.5	39.3	2.3	2.0	64.8	60.4	2.5	7.0
Deri2	39.5	32.0	1.8	1.3	62.6	61.2	44.0	35.4	2.5	1.4	68.2	64.2	2.2	2.1
Derijeri	38.9	28.0	1.1	1.3	94.5	46.2	69.1	31.1	2.1	1.9	70.9	62.0	2.4	2.5
Farmerlocal	39.2	31.1	0.2	0.8	63.2	55.4	53.9	44.0	2.4	1.9	86.1	80.4	9.0	6.4

Gadamhamam	34.0	32.5	0.4	0.6	40.5	37.6	34.6	25.4	3.3	2.3	73.7	65.8	4.9	2.1
Gwada	40.6	40.6	1.1	1.2	88.5	64.5	53.7	37.4	2.0	1.7	67.3	54.0	2.1	5.1
Hariray	44.1	29.0	0.6	0.1	51.1	41.3	37.4	23.2	2.1	2.3	58.0	56.6	4.9	3.9
Hugurtay	26.7	25.5	0.8	0.7	44.3	29.0	33.5	18.8	3.4	3.8	78.2	61.3	9.6	4.6
Ibursar	47.2	42.7	1.2	1.6	39.7	33.5	28.8	21.4	2.3	2.2	58.6	62.5	1.1	2.5
ICSR161	49.5	39.9	-0.1	0.0	56.7	58.9	29.4	39.5	3.0	2.6	63.3	67.7	4.4	2.8
ICSV111IN	32.5	35.7	0.0	0.1	54.6	57.9	38.8	41.5	3.3	2.5	79.2	71.3	6.7	7.3
IESB2	42.2	37.8	0.1	-0.1	56.1	41.4	29.9	32.4	2.0	1.4	56.5	78.3	11.8	3.3
IESV23006DL	39.6	35.4	0.0	0.2	52.3	43.6	33.6	36.6	4.0	2.8	71.7	87.6	5.9	5.1
IESV23010DL	35.8	41.5	-0.1	0.3	56.8	49.0	28.4	39.2	3.6	2.8	55.2	81.0	6.1	5.0
IESV91104DL	37.4	31.8	0.4	0.2	55.7	54.2	41.7	38.5	2.5	2.5	79.5	73.5	4.1	6.1
IESV91111DL	33.7	34.5	0.0	0.0	46.1	45.8	33.9	33.7	2.8	2.3	66.6	73.9	6.8	3.0
IESV91131DL	48.1	34.3	0.0	0.1	67.6	69.0	45.6	48.5	2.2	1.8	65.0	69.9	8.5	3.1
IESV92028DL	45.7	39.3	0.5	0.0	80.1	68.5	51.4	44.2	2.8	2.1	71.6	65.1	4.0	3.8
IESV92029DL	40.7	36.4	0.0	0.0	61.5	66.9	38.4	44.1	2.2	1.7	59.2	65.7	9.5	3.2
IESV92043DL	42.6	42.4	0.3	0.0	70.3	69.8	42.9	35.9	2.0	2.2	63.3	52.0	7.2	4.7
IESV92170DL	40.0	38.7	0.2	0.1	69.8	71.6	35.8	42.6	3.3	2.9	51.7	61.2	6.2	3.7
IESV92172DL	42.5	40.9	0.1	0.0	80.7	66.5	48.7	46.7	2.1	2.2	64.1	67.3	6.5	6.9
Jeri1	37.9	34.3	1.3	1.9	50.5	50.9	35.2	33.9	1.8	1.9	63.2	68.3	3.8	7.8
Jeri2	31.7	27.0	0.9	0.9	96.5	49.4	59.7	31.7	2.0	2.1	59.7	65.4	2.4	3.2
Kaguru	29.9	24.2	1.4	1.8	28.3	34.1	28.9	25.0	3.0	2.0	80.9	68.0	8.0	2.6
Khalid	37.4	34.8	0.3	-0.1	40.5	50.8	28.8	34.1	3.0	2.3	69.7	66.1	4.4	6.1
Kibokolocal1	37.3	38.4	0.8	0.1	93.9	73.8	71.4	46.6	2.0	2.0	75.7	60.5	11.2	7.1
Kibokolocal2	37.9	36.7	0.0	0.4	48.2	44.1	30.3	28.9	3.0	2.0	68.2	65.2	3.1	2.7
Kodukine	32.6	37.0	0.3	0.0	50.5	45.7	37.2	32.1	2.4	2.6	77.0	71.9	6.3	3.0
Landired	36.8	37.4	0.7	0.7	66.7	59.0	49.3	40.4	2.5	2.0	75.8	68.6	9.0	6.7

Landiwhite	34.7	31.6	1.2	1.1	57.5	57.8	43.9	37.9	2.1	1.7	73.9	66.4	4.2	10.8
Lobuheti	39.7	33.8	0.3	0.2	75.1	75.9	65.4	50.7	3.4	2.2	85.1	64.3	6.3	5.5
Lodoharie	37.4	46.0	0.4	0.7	65.9	60.8	50.0	38.0	2.4	2.4	83.7	60.0	6.9	5.6
Lodoka1	63.8	46.1	1.7	1.0	97.5	69.4	54.5	47.1	2.2	2.1	46.3	68.7	2.8	9.9
Lodoka2	49.4	39.5	0.9	0.8	74.1	71.1	55.0	36.9	2.2	1.7	69.0	52.7	6.4	3.4
Lodokawhite	45.9	37.2	0.4	0.5	58.1	54.1	47.1	30.4	1.8	2.0	59.1	53.7	3.3	2.0
Lodudu	41.7	41.3	0.6	1.3	62.7	57.7	32.4	40.6	2.2	1.8	52.2	70.3	3.6	10.0
Lolikitha	41.2	44.7	0.3	0.6	65.9	59.2	50.3	39.5	2.2	2.3	79.2	63.3	7.0	6.0
Lolodoka1	45.3	35.1	1.7	1.2	66.7	45.7	33.2	25.7	2.4	2.0	56.4	43.8	2.3	3.6
Lolodoka2	55.6	36.7	1.4	2.1	68.2	52.5	47.4	38.6	2.5	2.1	72.4	76.7	2.7	6.0
Lowoikudopayam	37.3	38.5	1.2	1.4	49.1	28.6	39.2	16.0	2.8	2.1	76.2	63.9	1.2	2.4
Macia	31.7	32.4	-0.1	0.0	71.4	66.3	52.9	44.2	2.6	1.7	77.7	66.7	9.8	3.3
Mahube	40.6	38.8	0.8	0.1	61.5	36.6	27.4	29.4	2.7	1.8	44.5	80.7	6.2	1.8
Majoldi	32.7	26.6	1.6	1.6	61.1	50.9	44.0	39.7	2.8	2.6	67.1	82.1	5.4	5.5
Makuach	30.9	28.5	1.0	0.6	50.4	42.9	26.0	32.2	2.8	2.4	51.9	75.8	5.4	4.3
Malual	44.8	32.2	0.4	0.3	53.5	44.0	37.6	35.4	4.3	3.6	63.7	80.1	8.6	6.3
Matual	21.8	25.1	0.9	1.7	48.6	31.9	36.2	32.5	2.7	2.2	74.5	62.7	7.6	5.2
Mbeere813	34.6	37.3	0.2	0.2	45.5	42.6	32.8	26.8	2.8	2.7	70.5	66.4	6.7	2.1
Medenge	44.3	36.1	1.1	1.2	87.5	61.0	53.0	38.7	2.2	1.7	71.3	63.1	3.3	7.3
Meresebrownred	44.6	18.2	0.9	0.2	131.9	68.1	75.3	44.4	2.4	1.7	54.9	64.9	2.0	4.6
Mereselightbrown	52.4	32.7	1.3	0.4	81.5	69.0	50.4	39.9	2.2	1.7	58.3	56.6	3.1	2.6
Miteenokoro	43.3	40.3	0.8	0.7	58.2	52.8	42.2	35.4	2.1	1.7	73.0	66.7	7.4	5.8
Mugeta	32.9	31.4	0.7	1.3	47.8	35.9	16.9	23.0	3.6	1.9	38.4	64.5	4.7	3.3
Nachot	38.8	41.9	1.3	1.3	75.3	31.6	52.8	19.6	2.3	2.0	72.9	48.0	4.0	1.7
Natari	49.1	44.0	1.1	1.5	54.9	52.0	31.4	26.6	1.5	1.7	51.5	50.5	3.3	2.2
Nohonyekhohoro	41.0	38.8	0.7	0.9	78.1	68.9	50.8	42.2	3.0	2.6	70.2	59.2	3.9	4.7

Nolokidok	41.0	36.0	2.0	1.3	54.3	59.3	33.8	36.6	2.1	2.0	67.4	60.4	2.4	6.4
Nolomutuk	35.7	29.0	1.2	0.8	41.6	37.8	26.6	22.3	1.5	1.6	64.7	54.6	4.4	2.7
Nuerbai	35.6	26.1	0.1	1.0	57.5	31.7	8.5	18.6	1.7	2.1	18.7	63.6	2.6	4.7
Okabir	34.6	30.9	1.6	1.1	57.6	44.1	37.1	17.3	2.8	1.8	67.2	39.0	4.2	2.5
Olerere	43.4	20.1	1.1	0.1	101.7	45.2	66.2	27.5	1.9	1.6	67.1	57.8	3.5	1.3
Olodiong	60.0	14.9	0.8	0.5	81.7	39.9	47.7	22.9	2.5	2.0	59.8	65.1	1.9	3.0
Omuhathi	32.3	26.3	1.5	2.3	51.6	26.4	28.6	19.1	2.2	2.9	59.6	66.9	2.2	1.0
Osmanassai	50.9	36.2	1.0	1.2	77.1	27.2	53.7	18.4	2.8	2.5	65.9	58.7	2.1	2.7
PP290	40.0	35.6	0.1	0.2	58.8	58.2	28.1	36.9	3.1	2.1	48.4	58.6	8.4	4.7
Tabat	32.2	31.8	1.3	0.7	47.1	43.9	37.7	31.0	2.5	2.1	69.8	67.0	8.7	6.1
Tharaka118	32.2	20.0	0.5	0.7	45.6	45.7	32.3	33.7	2.8	2.3	80.8	75.5	6.1	6.5
Tharaka6	31.2	30.9	0.3	1.6	40.7	56.9	35.2	40.4	3.8	2.4	86.1	68.0	8.8	6.4
Wadahmed	29.1	32.5	0.2	0.9	41.0	41.0	30.9	25.8	2.3	1.9	62.4	66.3	6.8	3.6
Wote collection1	29.0	28.0	2.1	1.0	23.9	26.3	18.5	16.6	2.6	2.5	82.7	63.8	5.3	4.0
ZSV3	27.1	23.7	0.4	0.4	40.8	38.9	34.5	25.8	4.6	3.7	73.8	70.1	10.5	2.9
Mean	39.0	33.8	0.8	0.8	62.3	50.2	41.1	32.8	2.6	2.2	66.4	64.8	5.3	4.4
CV (%)	17.6	23.1	59.9	59.0	19.9	27.2	25.8	27.6	20.8	23.6	21.1	20.1	43.3	65.5
LSD ($P \leq 0.05$)	15.9	18.0	1.1	0.8	26.4	31.5	24.4	20.9	1.2	1.2	29.8	29.9	5.3	6.7

DOF= days to flowering, LFL= length of flag leaf, PWT= panicle weight, GWT= grain weight, HSM= 100-seed weight, TH= threshability, HI= Harvest in

3.3.3.4 Correlation analysis

Under drought stress conditions (Table 3.11), waxy bloom was positively and significantly correlated ($P \leq 0.01$) with threshability (r=0.5658), panicle weight (r= 0.0565), length of flag leaf (r= 0.0893), biomass (r=0.0579) and negatively significantly ($P \leq 0.01$) correlated with 100-seedweight (r = -0.0697). Staygreen gave a positive and highly significant ($P \leq 0.01$) correlation with harvest index (r= 0.0831), panicle widths (r= 0.0493) and was negatively correlated with peduncle length (r= -0.0973). Panicle length was positively and highly significantly ($P \leq 0.01$) correlated with grain weight (r= 0.741). Panicle widths gave a positive and highly significant ($P \leq 0.01$) correlation with biomass (r= 0.0623). Panicle length was positively and highly significantly ($P \leq 0.01$) correlated with peduncle exertion (r= 0.549). Plant height showed a positive and highly significant ($P \leq 0.01$) correlation with peduncle length (r = 0.0656). Peduncle length gave a positive and highly significant ($P \leq 0.01$) correlation with 100-seed weight (r= 0.0814). Harvest index gave a negatively and highly significant ($P \leq 0.01$) correlation with biomass (r= - 0.6762) and grain weight (r= -0.0728). 100-seedweight gave a positive and highly significant ($P \leq 0.01$) correlation with grain weight (r= 0.075). Days to 50% flowering was positively correlated with biomass (r= 0.0576).

Results of correlations for phenotypic traits under well irrigated condition are illustrated in Table 3.10. Threshability gave a positive and highly significant ($P \leq 0.01$) correlation with 100-seedweight (r= 0.0789), plant height (r= 0.076) and negatively correlated with biomass (r= =0.0575) and staygreen (r= -0.0783). Panicle weight gave a positive and highly significant ($P \leq 0.01$) correlation with biomass (r= 0.5219), days to 50% flowering (r= 0.05501),-grain weight (r= 0.07642), panicle widths (r= 0.7759) and panicle length (r= 0.5013). Panicle showed a positive and significant ($P \leq 0.01$) correlation with biomass (r= 0.6412), days to 50% flowering (r= 0.7011), peduncle length (r= 0.6624), plant height (0.7759) and was negatively correlated with harvest index (r= -0.5463). Plant height gave a positive and significant ($P \leq 0.01$) correlation with biomass (r= 0.7792), days to 50% flowering (r= 0.8528) and a negative correlation with harvest index (r= -0.5462). Peduncle exertion gave a positive and highly significant ($P \leq 0.01$) correlation with days to flowering (r= 0.0982), peduncle length (r= 0.6836). Peduncle length gave a positive and significant ($P \leq 0.01$) correlation with biomass (r= 0.5118), days to 50% flowering (r= 0.5144) and grain weight (r= 0.0922) and negative correlation with harvest index (r= -0.5012). Harvest index gave a positive and highly significant correlation with grain weight (r= 0.0641) and negative and significant ($P \leq 0.01$) correlation with biomass) r= -0.5342) and days to 50% flowering (r= -0.5091). Days to 50% flowering was positively correlated with biomass (r= 0.752) (Table 3.12).

Table 3.11 Correlation analysis of different traits drought stress conditions

	TH	StG	PWT	PWI	PL	PHT	PEX	PEL	LGFL	Hi	HSM	GY	DOF	BM
TH	-													
StG	0.2187ns	-												
PWT	-0.0492*	-0.0347ns	-											
PWI	-0.0309ns	0.0493**	0.3572ns	-										
PL	-0.2179ns	-0.2068ns	0.1772ns	0.1021ns	-									
PHT	-0.2898ns	-0.2503ns	0.033ns	-0.0192ns	0.6096**									
PEX	-0.0973**	0.039ns	-0.1105ns	0.2583ns	0.1896ns	0.348ns	-							
PEL	-0.1816ns	-0.0932**	-0.0418ns	0.1903ns	0.5491**	0.656**	0.7125**	-						
LFL	-0.0493*	-0.129ns	0.2611ns	0.2458ns	0.2159ns	0.0211ns	0.0875**	0.084**	-					
Hi	0.2711ns	0.0831**	0.3283ns	0.1791ns	0.0229ns	0.0062ns	0.0428ns	-0.0198ns	0.1652ns					
HSM	0.2625ns	0.1105ns	-0.1122ns	-0.0437ns	-0.3003ns	-0.2534ns	0.0545**	-0.0814**	-0.1249ns	0.0728**	-			
GWT	0.516*	0.134ns	0.741**	0.2754ns	-0.005ns	-0.1614ns	-0.1274ns	-0.1243ns	0.1732ns	0.4484ns	0.075**	-		
DF	-0.2733ns	-0.3265ns	-0.0319ns	-0.2199ns	0.4484ns	0.7457**	-0.0209ns	0.3259ns	-0.1108ns	-0.0728**	-0.3003ns	-0.1676ns	-	
FBM	-0.0215ns	-0.0114ns	0.0178ns	-0.0623*	0.0678**	-0.0166ns	-0.0903**	-0.0212ns	-0.0301ns	-0.6762**	-0.1268ns	-0.0093ns	0.0576**	-

TH= threshability, StG= staygreen, PWT= panicle weight, PWI= panicle width, PL= panicle length, PHT= plant height, PEX= peduncle exertion, PEL= peduncle length, LFL= length of flag leaf,, HI= harvesting index, HSM= 100-seed weight GWT= grain weight, DF= days to flowering and BM= fresh biomass

Table 3.12 Correlation analysis of different traits under well irrigated conditions

	TH	StG	PWT	PWI	PL	PHT	PEX	PEL	LFL	HSM	HI	GWT	DF
TH	-												
StG	-0.0783**	-											
PWT	-0.1167ns	0.096**	-										
PWI	-0.1551ns	0.0679**	0.0954**	-									
PL	-0.1743ns	0.1164ns	0.5013**	0.2226ns	-								
PHT	-0.0826**	0.1224ns	0.494ns	0.0438ns	0.7759**								
PEX	-0.0405ns	-0.0283ns	-0.1085ns	0.1591ns	0.2226ns	0.3279ns	-						
PEL	-0.0615**	0.0392ns	0.161ns	0.1392ns	0.6624**	0.7128**	0.6836**	-					
LFL	-0.1111ns	0.0174ns	0.3919ns	0.2593ns	0.4131ns	0.2489ns	0.0333ns	0.129ns	-				
HSM	0.0789**	-0.0213ns	-0.2694ns	-0.1607ns	-0.3621ns	-0.391ns	-0.2464ns	-0.3388ns	-0.1967ns				
HI	0.3709ns	-0.0359ns	-0.2116ns	-0.0384ns	-0.5463**	-0.6331**	-0.326ns	-0.5612**	-0.2132ns	0.2406ns	-		
GWT	0.4882ns	0.0676**	0.7642**	0.006ns	0.3243ns	0.3622ns	-0.1222ns	0.0922**	0.2537ns	-0.2039ns	0.0641**	-	
DF	-0.0849**	0.1547ns	0.5501**	-0.0184ns	0.7011**	0.8528**	0.0982**	0.5144**	0.3297ns	-0.3738ns	-0.5091**	0.4049ns	-
BM	-0.0575**	0.0137ns	0.5218**	-0.0004ns	0.6412**	0.7792**	0.1998ns	0.5118**	0.3463ns	-0.3317ns	-0.6342**	0.4072ns	0.752

TH= threshability, StG= staygreen, PWT= panicle weight, PWI= panicle width, PL= panicle length, PHT= plant height, PEX= peduncle exertion, PEL= peduncle length, LFL= leaf, HI= harvesting index, HSM= 100-seed weight GWT= grain weight, DF= days to flowering and BM= fresh biomass.

3.4 Discussion

3.4.1 Assessment of earliness in South Sudan sorghum germplasm

Significant genotypic variability for days to flowering was recorded among the sorghum accessions evaluated. Previous studies by (Donatelli et al., 1991; Rosenow et al., 1983) reported the variability among sorghum genotypes for days to flowering. According to (Rosenow et al., 1983), sorghum genotypes exhibiting significant differences for staygreen trait do exhibit different phenological response under severe drought stress conditions. The variation in phenological response is attributed to drought avoidance and drought tolerance mechanisms of the genotypes (Donatelli et al., 1992). Menezes et al., (2015) reported 2% retardation in days to flowering which represents the variability in assimilate contents among drought evading and drought tolerance genotypes. Genotypes that escape drought do exhibit earliness under severe near-anthesis drought stress conditions because of their drought evading mechanism relative to staygreen genotypes which continue to fill their grains under severe drought stress conditions (Donatelli et al., 1992).

The superior lines that outperformed the check variety Kiboko local2 for earliness were Wote collection1 (56.94days), IESV 23010 DL (58 days, ZSV3 (60 days), Bizany (61 days) and Tabat (61 days). However, there were yield penalties recorded among the accessions wote collection1, Bizany, ZSV3 and Tabat. Thus, the accessions IESV 23010 DL would best serve as an ideal drought evading candidate with better performance for grain yield.

Early flowering under drought stress than well irrigated conditions was observed among the accessions, Hariray, ICSV III 1N, IESV 23010 DL, Kiboko local, Landiwhite, Nuerbai, Tabat and Wadahamed which is an indicative of drought avoidance. Early flowering under drought stress has been reported by Dalal, (2012) ; Dalal et al., (2015) who attributed it to rapid phenological development and development plasticity among drought evading accessions.

3.4.1 Morphological characters for drought tolerance

Genotypes and water regimes had effects on staygreen score, dry leaf scores, waxy bloom, leaf area, leaf rolling, total leaf count and lodging. This confirmed the wider variability among the genotypes under this study. The interaction between water regimes and genotypes differed significantly for staygreen, leaf rolling, leaf area and lodging, implying that drought stress affects the different traits. In this study, the absence of effect of interaction on total leaf counts and dry leaf scores suggested the stability of these traits under post-flowering drought stress conditions. The current study identified the genotypes Olerere (1.963) exhibiting staygreen trait and genotype Omuhathi (7.882) showing susceptibility to senescence. These results are in line with Tesfamichael et al., (2015) ; Rebetzke, (2016) who reported the existence of substantial variability among sorghum landraces for staygreen attributable to genetic and environmental influence.

The correlation analysis revealed that staygreen was positively correlated with panicle weight, grain yield, 100-seed weight and harvest index. Previous findings by Christopher et al., (2018) reported a positive correlation between grain yield and staygreen trait. The existence of positive correlation between these traits implied that selection for the stay green trait is possible during screening experiments. This is because staygreen genotypes can easily be distinguished from drought stress sensitive genotypes on the basis of senescence (Sakhi et al., 2014).

The dry leaf scores (DLS%) were estimated for all genotypes under drought stress to screen for accessions with a stable staygreen trait whereby the genotype Olerere (12.82%) exhibited the lowest DLS% while Omuhathi (76.23%) showed the highest senescence. Variability among sorghum genotypes for dry leaf score (DLS%) has been reported previously by Sakhi et al. (2014). The large variation for DLS% recorded may be attributed to broader genetic diversity of the accessions involved in this study. The landraces Lowoikudopayam (13.34%) and Meresebrownred (20.09% assembled from South Sudan outperformed the check variety Macia with DLS% of 25.74%. The importance of the staygreen trait is in reducing the canopy size at flowering by modifying leaf numbers and leaf size to scale down pre-flowering water use in order to conserve water for grain filling under post-anthesis drought stress (Borrell et al.,2014).

With regard to the total leaf counts, no variation was observed across the water regimes implying that the post-anthesis drought stress had no effect. Research finding by Borrell, (2000) stated that large leaf area among landraces serves as an important photosynthetic machinery for harvest of high photosynthate which is vital for running essential processes of the plant.

Reduced total leaf counts and net leaf area were observed among improved staygreen lines namely IESV 92028 DL IESV 91111 DL, Mahube, IESV 92172 DL, Gwada and IESV 23010 DL. Previous research observed reduced leaf numbers per culm and leaf area which were linked to increased grain yield under post anthesis drought stress (Tuberosa, 2012; Borrell et al., 2014). This be explained by the fact that the Staygreen genotypes minimized water use during the pre-anthesis phase so as to conserve water for grain filling during the grain development phase leading to high yields (Beyene et al., 2015; Borrell et al., 2014).

The accession Burialure is a drought susceptible, tall and moderately yielding genotypes which easily lodged. The high vulnerability to lodging could be associated with high senescence observed, coupled with its plant height and stem girth. Similar observations have been made in previous studies (McLaren, 2002; Thomas and Ougham, 2014).

3.4.2.1 Physiological characters for drought tolerance

The wax load was denser under drought stress conditions than under controlled conditions. Dense wax load under drought stress conditions has been associated with cuticular wax biosynthesis; translocation, composition and density and are influenced solely by environmental factors including solar radiation, temperature, moisture, and humidity in sorghum (Xue et al., 2017). The accessions that scored dense wax load under drought stress condition were Gwada, ICSR 161, Mahube, AG8, IESV 91131 DL, IESV 91111 DL, IESV 92028 DL and IESV 92172 DL and comprised of lines drawn from ICRISAT- Nairobi gene bank. In this study, genotypes with dense wax were superior for water stress tolerance and grain yields relative to non-waxy accessions. Borrell et al., (2014) reported the existence of significant correlations between wax contents and drought stress tolerance among staygreen genotypes. The accessions that gave leaf rolling were late maturing landraces assembled from South Sudan. The leaf rolling trait is associated with diminished water potential and low leaf turgor attributed to poor osmotic adjustment (Chaanappaoudeer et al., 2007). The leaf rolling was severe among the late accessions which may be attributed to the fact that irrigation water was withheld at 50 per cent flowering when these accessions were still at vegetative phase of growth.

3.4.3 Assessment of yield in South Sudan sorghum germplasm

The growth components, plant height, stem girth, peduncle length, peduncle exertion, panicle width, panicle length and biomass showed significant effects across the genotypes and water regimes. No reduction of growth components was recorded under controlled treatment because of presence of optimal conditions for growth and development as opposed to the drought stressed environment. Reduction of growth components due to drought stress has been reported in previous studies (Niakan et al., 2013).The reduction in plant height and stem girth is linked to low water intake and decline in net water potential created by poor osmotic adjustment (Bibi, 2012). Reduction in peduncle length and peduncle exertion is attributed to low leaf water potential which does not allow plants to maintain the extension of peduncle from the sheath under severe drought stress conditions. Longer peduncle length and peduncle exertion was scored by accession Lodoka2 and Natari; again, it is an indicative of tolerance.

Biomass is an important trait associated with grain yield and staygreen trait. The reduction in biological yield is due to reduced growth and net assimilation rates in drought sensitive genotypes (Christopher et al., 2018; Bibi, 2012). Staygreen accessions gave high biological yield with improved staygreen elite lines such as Mahube, IESV 91131 DL, and Gadamhamam topping the list followed by staygreen landraces, Mereselightbrown, Lodoka2 and Olerere. These findings corroborate those by previous researchers who reported that drought stress reduction of biomass depends on the characteristics of the genotypes and the phenological stage at which it occurred (Mendoza and Huerta, 2012).

3.4.3.1 Yield components

The yield and related components namely length of flag leaf, panicle weight, grain weight, 100-seed weight and harvest index, threshability and basal tillers showed significant variations. There were drought stress related percentage reductions which have also been reported by Sandoval, (1989). Drought stress causes yield reduction by decreasing grain weight 100-seeed weight through reduction in seed per spikelet, biomass and floret abortion (Hameed and Nouri, 2000). The flag leaf plays an important role of filling grain under drought stress condition thus the reduction in length of flag leaf may be due to drought stress effect on cell division which ultimately inhibits leaf elongation under declined leaf water potential (Hsalaoand Henderson, 1979). Only the accession Alwala recorded longer flag leaf length) 33.71cm) under drought stress condition compared to reduced length (23.73cm) under non-drought stress conditions implying tolerance to drought stress. Panicle weight reduction was significantly high under drought stress conditions with accession Lobuheti expressing better performance for panicle weight (75.92g). Reduction in panicle weight is attributed to low growth arising from reduced photosynthetic activity (Sandoval et al., 1989).

The genotypes Lobuheti (50.65g), IESV 91131 DL (46.52g), Lodoka1 (47.08g) and IESV 92172 DL (46.69g) showed superior yield weights as opposed to the check variety. These accessions had high stay green rating. Similar results have been reported associating the stay green trait with high yield (Rosenow et al., 1983; Borrell et al., 2000; Stephanie et al.,2015; Tao et al., 2000).

Means results showed that cessions, IESV 91131 DL, IESV 92172 DL, and Lobuheti were also superior for 100-seed weight. 100-seed weight is an important economic trait in South Sudan where grain marketing depends on grain weight. These accessions are ideal varieties for both subsistence and commercial farming in drought prone agro-ecologies of South Sudan. Although accession Lodoka performed well with regard to grain yield and staygreen rating, it is a late line that takes up to 112.03 days to reach physiological maturity. Therefore, it needs further improvement for earliness.

Among yield contributing components, harvest index and threshability are considered key determinants of the final grain yield. Accession IESV 91131 DL and IESV 92172 DL recorded high harvest index (3.13% and 6.86%) and threshing percentage of 73.94 and 67.34%. This shows their yield stability under drought stress condition. Results of correlation coefficients revealed that panicle weight showed a positive correlation with grain yield, harvest index, and panicle width. The existence of significant correlation coefficients between these traits means that selection for grain yield can be based on integral selection for these traits. Similarly, threshability was positively correlated with grain yield, harvest index and staygreen implying that these traits can be selected together when screening for varieties with relatively high threshing percentage.

CHAPTER FOUR

COMBINING ABILITY FOR EARLINESS,ANDYIELD AMONG F_1SORGHUM GENOTYPES

Abstract

The development of staygreen genotypes through hybridization is an important food security strategy in the semi-arid tropics. This study used 36 sorghum synthetics obtained from a 6 x 6 full diallel mating design. The parents, F1 progenies and their reciprocals showed significant difference for days to flowering suggesting their diversity with regard to this triat. There were significant differences among the maternal and non-maternal effects implying that maternal genes play a greater role in regulating maturity. There were higher genetic predictability ratios for days to flowering, panicle weight and grain weight, suggesting that additive gene action played a bigger role than non-additive genes in the control of these traits. The study identified parental lines, ICSV III IN, B5 and Macia as exhibiting earliness that can be exploited in the breeding program for drought evading hybrids. Similarly, the F1 crosses B35 x Okabir, Lodoka x B35, Okabir x Macia, ICSV II IN x Macia, ICSV III IN x Akuorachot, Lodoka x Akuorachot and Lodoka x Okabir were identified as drought evading synthetics while F1 crosses, B35 x Akuorachot, B35 x Macia, Lodoka x B35, ICSV III IN x Macia, and Lodoka x Macia were identified as high yielding synthetics.

Keywords: Sorghum, drought stress, earliness, yield, screening, South Sudan.

4.1 Introduction.

The development of staygreen genotypes is an important food security strategy for drought prone agro ecologies of Semi-arid tropics (Ngugi et al., 2013). Staygreen trait enhances plant growth and reproduction under drought stress conditions (Walulu, 1991; Staggenborg, 2010). The trait is correlated with earliness, higher yield and drought stress tolerance which are beneficial traits for subsistence farmers who rely on rainfed farming (Acquaah et al, 2012).

Staygreen trait enhances grain yield by reducing source – sink through canopy size reduction (Borrell et al., 2011; Thomas and Ougham, 2014). The better yield performance among staygreen genotypes is due to their high efficiency in converting absorbed water into biomass and grain yield as well as sustained photosynthate flow through sustained stability of photosynthetic machinery sunder severe drought stress condition (Beyene et al., 2015; Borrell, 2000; Tesfamichael et al., 2015 ; Harris et al., 2018).

Staygreen trait is governed by a major gene (Walulu, 1991). Recent advances in genetic mapping have discovered four main staygreen QTLs namely Stg2, Stg1, Stg3 and Stg4 (Subudhi et al.,2000). These staygreen QTLs confer staygreen trait, earliness and yield (Beyene et al., 2015; Sanchez et al., 2002; Subudhi et al., 2000).

Direct and indirect selection approaches are widely used staygreen screening techniques. Direct approach uses environmental conditions in which the onset of stress factors is uniform and predictable whereas indirect uses well managed and stress environments (Abdipur et al., 2013; Beyene et al., 2015). Selection under both optimal and drought conditions represents the ideal screening approach for yield and yield stability (Tuinstra et al., 1997). To achieve this, both visual scoring of leaf and plant senescence and genomic tools such as marker assisted selection (MAS) can be used to select for ideal staygreen genotypes (Reddy et al., 2014)

Most breeding programs employ pedigree and recurrent selection methods to develop staygreen candidate populations (Beyene et al., 2015). Introgression of staygreen trait is easily achieved because of high heritability of staygreen loci presence in donor parents B35 and E-36-1(Subudhi et al., 2000 ; Reddy et al., 2007; Thomas and Ougham, 2014). Selection criteria for staygreen genotypes are best executed under controlled and drought-stress environments because of the polygenic nature of trait and high influence of genotype x environment interaction (Beyene et al., 2017).

Genetic information on combining ability of parental lines and crosses on one hand is important in making choice of breeding procedure, method of selection and superior parental lines (Acquaahet al, 2012). Full diallel design on the other hand provides efficient assessment of potent parents, estimate of additive and dominance genetic effects, genetic gain from both additive and non-additive genetic variances, effects of reciprocal, subsequent partitioning of reciprocal into maternal and nonmaternal effects and the gene action controlling them.(Fasahat et al., 2016)

Partitioning of genetic effects into general and specific combining ability will generate powerful information about the roles of each parent when it is used as male and female (Girma et al., 2011). The study will also generate valuable genetic information on the inclusion of reciprocal crosses with regards to induction of earliness and yield increment. (Mahgoub, 2011)

Success in generating good combiners relies much on broader and diverse genetic background the breeder hybridizes and the choice of powerful mating design that enables estimate and wider inference of various gene effects underpinning the triat of interest (Kumar, 1985).

The aims of this study were to select for genotypes combining earliness and yield under drought stress condition for improved food and nutritional security in drought prone areas of South Sudan.

4.2 Materials and methods

4.2.1 Site description

The site descriptions remain as described in section 3.2.1.

4.2.2 Germplasm

The genetic materials used in this study involved three farmer preferred landraces (Akuorachot, Okabir and Lodoka) from South Sudan collection and three staygreen donor parents (B35, ICSV 111 IN and Macia) obtained from ICRISAT- Nairobi (Table 4.1). The six parental lines were part of a 12 x 12 full diallel mating design that was conducted in a long rain growing season of 2016 in Kiboko field station. Six parental lines failed to produce their reciprocals and were discarded for this study.

4.2.3 Experimental design

The 36 crosses and parents obtained from a 6 x 6 full diallel mating design (Table 4.1) were laid down in a randomized complete block design with two replications. Replicates were spaced at 1.5 m; inter row and intra-row spacing were 70cm and 20 cm respectively. The experiment was well irrigated from sowing to anthesis stage where irrigation was withheld for drought stress to commence.

Table 4.1 Parental lines, F1s and reciprocal crosses in a 6 x 6 complete diallel mating design

	Lodoka	ICSV III IN	B35	Okabir	Akuorachot	Macia
Lodoka		X	X	X	X	X
ICSV III IN	X		X	X	X	X
B35	X	X		X	X	X
Okabir	X	X	X		X	X
Akuorachot	X	X	X	X		X
Macia	X	X	X	X	X	

4.2.4 Data collection

The data collected included:

(i) Days to 50% flowering; was collected when 50 percent of the plants had flowered

(ii) Panicle weight (g); was recorded by weighing the panicles per plot

(iii) Grain weight (g): Was recorded by weighing total grain weights per plot

(iv) 100-seed weight: Was recorded by weighing 100-seeds per plot

4.2.5 Data analysis

Data collected over one season were subjected to SAS statistical software using GLM procedures based on Griffing method I for full diallel. The fixed model was used to separate GCA and SCA and reciprocal effects. Replication and block effects were random, and the rest were considered as fixed variables.

4.2.5.1 Griffing Method I, Model I (Fixed Model).

Griffing method I, model I was used because of its ability to utilized parents, F1s and reciprocals to generate important genetic information required to evaluate the genetic component of these parental lines that were drawn from South Sudan collection and

ICRISAT-Nairobi germplasm repository. Block and genotype effects were fixed as provided for in equation (8).

$X = \mu + G + B + GB + E_{(r1)}$ ……………………………………………….. (7)

Where X= observation, U= means of genotypes, G= effects due to genotypes B= block effects, GB= interaction between genotypes and blocks, and E= error due to environment.

When genotypes are assigned to the block, the genotypic effects G would be equated to ;

$G = g_i + g_j + s_{ij} + r_{ij}$………………………………………………………... (8)

By substituting G in equation (7) by equation (8) , the whole equation would be

$X = \mu + g_i + g_j + s_j + r_{j\,+} B + GB + E_{®}$ ………………………………….. (9)

Where:

μ= the population mean

gi, gj = General combining effect for the I^{th} and J^{th} parents

Sij= is the specific combining ability effect of the cross between the I^{th} and J^{th} parents such that $S_i = S_{j.}$

r_{ij}= is the reciprocal effect involving the reciprocal crosses between the I^{th} and J^{th} parents such that $r_i = r_j$ and

e_{ijkl}= is the experimental error due to environmental effect associated with the $ijkl^{th}$ which is assumed to be uncorrelated and normally distributed with zero mean and variance VE.

b= Number of replicates

c=Number of plants

The restrictions imposed on combining ability estimates were $Sg_i = 0$ and $Ss_{ij} = 0$ for all GCA and SCA effects,(Griffing 1956).

Baker ratios or genetic predictability ratios to determine the effects of additive and non-additive gene actions were calculated according to Baker, (1978.)

Baker ratios= $\frac{GCA}{SCA} = \frac{(2MS_{GCA})}{(2MS_{GCA}+MS_{SCA})}$ **………………………………………(9)**

Where MS_{GCA}= Mena square of general combining ability and MS_{SCA} = mean square value of specific combining ability

4.3 Results

4.3.1 Analysis of variance for the different traits among the sorghum genotypes

The mean square for the traits under study showed no significant (P≤0.05) differences for the genotypes, reciprocal, maternal and non-maternal effects except for days to flowering (Table 4.1) Predictability ratios showed high contribution of additive genetic effects relative to non-additive genetic effect for days to flowering, panicle weight and grain weight.

Table 4.1 Means square for all the traits studied under drought stress conditions

Source of variation	DF	DFL	PWT	GWT	HSW
REP	1	30.680556ns	377.66681ns	722ns	2.13555556ns
Genotypes	35	171.680556**	417.42757ns	287.66241ns	0.53136508ns
GCA	5	724.061ns	394.745ns	108.623ns	0.38261
SCA	15	78.868ns	374.911ns	198.186ns	0.87631ns
REC	15	80.367**	467.505ns	436.819ns	0.236ns
MAT	5	115.333**	607.622ns	425.809ns	0.24417ns
NMAT	10	62.883**	397.447ns	442.323ns	0.23192ns
Error	35	15.309127	436.10686	414.86971	0.4195556
Total	71				
Baker's ratios		0.9	0.6	0.5	0.4

. DF= days to flowering, PWT= panicle weight, GWT= grain weight and HSW= 100-seed weight, GCA= general combining ability, MAT= maternal effect. NMAT= nonmaterial effect ns= not significance,* significant at P<0.05 and ** = significant at P<0.01.

4.3.2 Mean performance of F1 and reciprocal crosses between South Sudan farmer preferred lines and ICRISAT elite lines.

Mean values of F1s and reciprocals are presented in table (4.2). The earliness trait was exhibited by the F1 cross, Macia x ICSV 111 IN (55 days), reciprocal combinations cross, ICSV 111IN x Macia (56 days), and parental cross ICSV 111 IN x ICSV 111 IN (55 days). However, extreme lateness was recorded by the combinations cross, Okabir x Akuorachot (93 days) and parental Lodoka x Lodoka (85 days).

The highest panicle weight was recorded for F_1 generation cross between, Okabir x Macia (93.05g) and ICSV 111 IN x Lodoka (81.45g). While the highest grain weights were given by F1 generation cross between, Okabir x Macia (76.9g) and ICSV 111 IN x Lodoka (66.55g). The highest 100-seed weight was recorded among the cross, B35 x ICSV 111 IN (4.15g) and the reciprocal cross, ICSV 111 IN x B35 (4.1g), (Table 4.2).

Table 4.2 Means performance per plot of F_1 progenies and reciprocal crosses between South Sudan farmers preferred lines and ICRISAT elites lines

Genotypes	DF	PWT (g)	GWT (g)	HSM (g)
Lodoka x Lodoka	86	42.8	34.2	3.2
Lodoka x ICSV111IN	68	66.8	43.7	3.6
Lodoka x B35	75	33.7	25.6	3.2
Lodoka x Okabir	82	59.4	51	3.1
Lodoka Akuorachot	72	38.7	30.3	3.5
Lodoka x Macia	64	55	40.1	2.5
ICSV111IN x Lodoka	64	81.5	66.6	3.1
ICSV111IN x ICSV111IN	55	45.2	35.9	2.3
ICSV111IN x B35	56	52.4	41.7	4.1
ICSV111IN x Okabir	67	65	51.5	2.7
ICSV111IN x Akuorachot	58	51.2	39.6	3.0
ICSV111IN x Macia	56	53.6	40.7	2.7
B35 x Lodoka	63	79.2	49.9	2.4
B35 x ICSV111IN	56	61.3	47.9	4.2
B35 x B35	62	44.4	30.5	1.9
B35 x Okabir	65	52.2	39.9	2.9
B35 x Akuorachot	65	66.5	53.3	2.5
B35 x Macia	57	62.2	45.9	3.0

Genotypes	DF	PWT (g)	GWT (g)	HSM (g)
Okabir x Lodoka	72	56	47.4	3.3
Okabir x ICSV111IN	70	25.1	18.1	3.4
Okabir x B35	73	44.9	33.7	2.6
Okabir x Okabir	78	71.2	46.6	2.4
Okabir x Akuorachot	93	44.2	33.6	2.5
Okabir x Macia	76	93.1	76.9	3.2
Okabir x Lodoka	71	65.3	56.2	3.2
Akuorachot x ICSV111IN	58	38.3	33.6	3.7
Akuorachot xB35	72	59.7	47.9	2.9
Akuorachot x Okabir	79	51.7	42.5	2.5
Akuorachot x Akuorachot	62	40.9	30.6	3.0
Akuorachot x Macia	65	41.8	27.8	3.0
Macia x Lodoka	73	53.8	43.3	3.4
Macia x ICSV 111 IN	55	59.9	44.4	2.4
Macia xB35	74	45.3	32.9	3.4
Macia x Okabir	60	56	23.3	2.9
Macia x Akuorachot	*67*	59.4	46.3	3.3
Macia x Macia	71	81.1	58.8	3.8
Mean	67.5972	55.5	41.9778	2.99444
CV%	5.78824	45.5934	48.5218	21.6311

Key; DFl= days to 50%flowering. PWT= panicle weight, GWT= grain weigh and HSW= 100-seed weight, 1=Lodoka, 2= ICSV111IN, 3= B35, 4= Okabir, 5= Akuorachot and 6= Macia

4.3.3 General combining ability estimates among the sorghum genotypes

Results for estimates of general combining ability effects are presented in table (4.3). Negative and significant general combining ability (GCA) effects for days to flowering was recorded by three parental lines, ICSV 111 IN (-7.97), B35 (-2.9) and Macia (-2.1g), indicating that they are good parental sources of genes for earliness. The superior general combiners with positive GCA effects for panicle weight were Macia (6.4g) and Okabir (1.9g). Highest and positive GCA for grain weight was recorded by parental lines, Lodoka (4.31) and ICSV III IN (2.3g). For 100 seed weight, three parental lines, Macia (0.28), Lodoka (0.12) and ICSV 111 IN (0.11) recorded positive GCA effects (Table 4.3).

Table 4.3 Estimate of GCA effects on six sorghum parental lines

Genotypes	DFL	PWT	GWT	HSW
Lodoka	5.3	0.53	4.31	0.12
ICSV111IN	-7.97***	-1.73	2.39	0.10
B35	-2.84**	-1.66	-3.42	-0.10
Okabir	6.8	1.98	-0.80	-0.18
Akuorachot	0.90	-5.64	-4.03	-0.01
Macia	-2.14**	6.3	1.57	0.08
V (g)	0.532	22.23	14.41	0.015
V ($g_i - g_j$)	1.276	53.36	34.6	0.035

Key: DFL= days to flowering, PWT= panicle weight, GWT= grain weight, HSW= hundred seed weight, 1=Lodoka, 2= ICSV111IN, 3= B35, 4= Okabir, 5= Akuorachot and 6= Macia *= 0.05, **= 0.01, ***= 0.001

4.3.4 Specific combining ability effects among the sorghum hybrids

Results for estimates of specific combining ability effects on F1 hybrids are presented in table (4.4). For days to flowering, negative specific combining ability effects was recorded by F1 generation crosses, B35 x Okabir (-2.5), Lodoka x B35 (-1.28), Okabir x Macia (-1.08) ICSV III IN x Macia (-3.8), ICSV III IN x Akuorachot (-2.8) and ICSV II IN x B35 (-10.3). The F1 hybrids cross, B35 x Akuorachot (14.98) recorded the highest and positive SCA for panicle weight while Lodoka x Macia (30g) and B35 x Akuorachot (14.6g) gave the highest and positive SCA for grain weight. Highest and positive SCA for 100-seed weight was recorded by F1 generation crosses, B35 x Macia (1.1g) and ICSV III IN x B35 (1.1g)

Table 4.4 Estimate of Specific combining ability effects on sorghum F1 progenies

Genotypes	DFL	PWT	GWT	HSW
Lodoka x ICSV111IN	1.1	19.5	11.9	0.13
Lodoka x B35	-1.3	1.9	-6.5	-0.23
Lodoka x Okabir	-2.9	-0.51	2.3	0.21
Lodoka x Akuorachot	-2.3	1.3	-0.4	0.20
Lodoka x Macia	-10.3	6.0	10.2	-0.24
ICSV111IN x B35	-1.3	4.7	2.4	1.1
ICSV111IN x Okabir	2.1	-10.6	-10.2	0.1

ICSV111IN x Akuorachot	-2.8	-3.4	-5.2	0.24
ICSV111IN x Macia	-5.8	3.5	7.5	0.29
B35 x Okabir	-2.5	-7.3	-2.4	0.04
B35 x Akuorachot	2.8	14.8	14.6	-0.19
B35 x Macia	3.0	1.3	3.97	1.1
Okabir x Akuorachot	10.7**	-3.9	-0.47	-0.3
Okabir x Macia	-1.0	-0.98	1.2	0.3
Akuorachot x Macia	7.2	-2.2	0.83	0.04
V ($S_{II)}$	1.0631	44.464	38.885	0.2914
V(S_{II} – S_{ij})	10.2061	426.85	373.299	0.27970
V (S_{ii} – S_{jj})	10.2061	426.85	373.299	0.27920
V (S_{ii} – S_{ijk})	7.6546	320.18	279.975	0.20978

Key; DFL= days to flowering, PWT= panicle weight, GWT= grain weight and HSW= hundred seed weight 1=Lodoka, 2= ICSV111IN, 3= B35, 4= Okabir, 5= Akuorachot and 6= Macia, *= significant 0.05, **= significant at 0.01, ***= 0.001

Results for estimates of reciprocal combining ability (RCA) effects are presented in table (4.5). The RCA effects for days to flowering were negative and significant for reciprocal crosses, Macia x Lodoka (-4.3), Okabir x B35 (-4) and Macia x B35 (-8, 3). While highest and positive reciprocal effects for days to flowering were given by Macia x Okabir (8). Akuorachot x Okabir (7) and Okabir x Lodoka (5.3). For panicle weight, highest and positive panicle weight was recorded by reciprocals crosses Okabir x ICSV III IN (19.9) and Macia x Okabir (18.5). As regards grain weight, highest and positive reciprocal effects were recorded by reciprocal crosses Maxia x Okabir (26.8) while highest and positive reciprocal effects for 100-seed weight was recorded by reciprocal cross, B35 x Lodoka (0.4).

Table 4.5 Estimates of combining ability effects on reciprocal crosses between South Sudan farmer preferred sorghum lines and ICRISAT elite lines

Genotypes	DFL	PWT	GWT	HSW
ICSV III IN x Lodoka	2	-7.4	13.6	0.3
B35 x Lodoka	6.3*	-22.8	-12.2	0.4
Okabir x Lodoka	5.3*	1.7	1.8	-0.1
Akuorachot x Lodoka	0.5	-13.3	-12.9	0.2
Macia x Lodoka	-4.3*	0.6	-1.6	-0.4
B35 x ICSV III IN	0.1	-4.5	-3.1	-0.02
Okabir x ICSV III IN	-1.5	19.9	16.7	-0.4

Akuorachot x ICSV III IN	-0.2	6.5	3	-0.4
Macia x ICSV III IN	0.5	-3.1	-1.9	0.12
Okabir x B35	-4*	3.6	3.1	0.2
Akuorachot x B35	-3.5	3.4	2.7	-0.2
Macia x B35	-8.3***	8.5	6.5	-0.2
Akuorachot x Okabir	7***	-3.8	-4.5	0.1
Macia x Okabir	8***	18.5	26.8	0.12
Macia x Akuorachot	-0.8	-8.9	-9.3	-0.15
V(r)	3.8273	160.069	103.717	0.10489
V (r_{ij} – $r_{kj)}$	7.6546	329.139	207.485	0.20978

Key, DLF= days to flowering, PWT= panicle weight, GWT= grain weight and HSM= hundred seed mass

4.4 Discussion

4.4.1 General combining ability estimates among the sorghum genotypes

The parents, F1 progenies and their reciprocals showed significant differences for days to flowering suggesting their diversity with regard to physiological maturity. There were significant differences among the maternal and non-maternal effects implying that maternal genes play a greater role in regulating maturity There were higher genetic predictability ratios for days to flowering, panicle weight and grain weight, suggesting that additive gene action played a bigger role than non-additive genes in the control of these traits. Similar findings were reported by (Padhar et al.,, 2013; Chandra et al., 2014) The absence of significance among the general and specific combining ability effects for panicle weight, grain weight and 100-seed weight could be attributed to the effect of epistatic gene action..

Negative significant general combining ability effects (GCA) were noted for days to flowering for parents ICSV 111 IN, B35 and Macia, suggesting that these parents had the earliness trait that can be exploited for the development of drought-stress evading hybrids. Previous research have reported negative GCA effects for days to maturity

(Girma et al., 2011; Sally et al., 2017). Similarly (Meng et al., 1988; Siddiqual and Baig, 2001) have advocated for the significant roles of negative GCA relative to positive GCA in conferring earliness trait in sorghum. The parents Lodoka, Okabir and Akuorachot exhibiting positive GCA for days to flowering implied lateness, thus conferring the late physiological maturity.

With regard to the panicle weight, the parental lines with positive and high GCA values are chosen the superior combiners. Genotypes Macia and Okabir recorded positive GCA and high mean values for panicle weight, implying the important roles of GCA than SCA in contributing to desirable panicle weight. Similar findings were reported by (Meng et al., 1999’ Girma et al., 2011) who identified superior parents with positive GCA for the interest traits.

With regard to the combining ability for grain yield, the parents Macia and ICSV 111 IN showed positive GCA effects implying that they are good combiners for grain yield compared to parental lines B35, Okabir and Akuorachot which showed inferiority for grain weight. The significant of GCA in discriminating superior parents from inferior parents for grain yield was reported by (Tourchi and Rezal, 1996). High GCA for grain yields is a result of additive gene action, implying the importance of additive gene action in the inheritance of yield trait. (Meng et al., 1998).

For the 100-Seed weight, the parent Macia and ICSV 111 IN showed positive GCA suggesting that they are good combiners for this trait. The high GCA effects are governed by genes with additive effects (Sally and Odongi, 2017).

4.4.2 Estimates of specific combining ability effects among the sorghum hybrids

The measure of deviation of a cross from the average performance of the parental genotypes is defined as specific combining ability (Sally and Odongi, 2017). Crosses that gave positive significant SCA for days to maturity induce lateness (Girma et al., 2011).

Significant and negative specific combining ability for days to flowering was exhibited by nine F_1 progenies including, B35 x Okabir, Lodoka x B35, Okabir x Macia, ICSV II IN x Macia, ICSV III IN x Akuorachot, Lodoka x Akuorachot and Lodoka x Okabir. However, crosses that showed significant and negative SCA effect expressed earliness (Girma et al., 2011). Thus, the negative significant SCA exhibited by F1 combination crosses ,Lodoka x B35, Okabir x Macia , Lodoka x Akuorachot might be due to additive gene effect in parent B35, Macia and Akuorachot overriding non-additive gene action in the genetic backgrounds of late parental Okabir and Lodoka.

For panicle weight, the highest and positive SCA effects were recorded by F1 progeny crosses, B35 x Akuorachot, Lodoka x ICSV III IN, Lodoka x B35, ICSV III IN x B35 and ICSV III IN x Macia. Positive and highest SCA effects are chosen when selecting for yield determinants of hybrids (Rao, 1970).

As regards, grain weight, positive and highest SCA was recorded by F1 progenies, B35 x Akuorachot, B35 x Macia, Lodoka x B35, ICSV III IN x Macia, and Lodoka x Macia. High and positive SCA are preferred when selecting for high yield hybrids (Rao, 1970). The F1 progenies that exhibited the highest SCA effects for grain yields resulted from crosses involving high x high, high x low and low x low types of combiners, implying the presence of additive x additive, additive x dominance and dominance x dominance in their genetic backgrounds. Similar results were reported by (Padhar et al., 2013; Chandra et al., 2014; Mutava, 2014;). Highest and positive SCA effects emanating from involvement of superior x superior combiners as in F1 crosses between, B35 x Macia, ICSV III IN x Macia and B35 x Akuorachot might be due to complementary actions of additive genes in their genetic backgrounds. Similarly, the highest and positive SCA emanating from crosses involving superior x inferior type of combiners as in F1 crosses between, Lodoka x Macia and Lodoka x B35 is due to additive gene action in the superior parents and epistatis gene action in inferior parents acting in a complementary fashion that maximizes grain yield in the inferior parents (Chandra et al., 2014). .

For 100-seed weight, only three out of 15 F1 generation crosses recorded positive and highest specific combining ability (SCA) effects. The F1 progenies, B35 x Macia, B35 x ICSV III IN and Lodoka x Macia were superior for 100-seed weight implying that these crosses could be used as superior genotypes for development of commercial synthetics in drought prone agro ecologies of South Sudan. These findings are in full agreement with (Lyanar et al., 2001; Umakanth et al., 2002; Patill 2004) who had previously reported higher variance of SCA for 100-seed weight. 100-seed weight is an important economic trait that determines grain sorghum prices in the semi-arid tropics where sorghum crop serves as staple food security crop.

4.4.3 Reciprocal specific combining ability effects among the sorghum hybrids

The analysis of reciprocal effects showed no significant differences for days to flowering. Negative reciprocal effects were recorded by reciprocal crosses Okabir x B35, Macia x B35 and Macia x Akuorachot, Macia x Lodoka, implying the roles of maternal genes in contributing to earliness. In reciprocal crosses, Okabir x B35 and Macia x B35, the maternal alleles in maternal parents B35 had contributed to earliness. Similarly, in a reciprocal cross, Macia x Akuorachot, the role of maternal parent, Akuorachot (medium maturing parent) had contributed to medium anthesis. Similar results were reported by (Wu and Matheson, 2001)

For panicle weight, positive and highest reciprocal effects was recorded by reciprocal crosses, Okabir x ICSV III IN, Akuorachot x ICSV III IN and Akuorachot x B35. The high panicle weight in these reciprocal crosses can be traced back to the high performance of maternal parents B35 and ICSV III IN whose maternal genes helped elevate panicle weight in these reciprocal crosses, implying the positive roles of maternal genes in increasing panicle weight.

For grain weight, positive and highest grain weights were recorded by reciprocal cross, Okabir x ICSV III IN, implying the roles of maternal alleles in increasing grain yields. Previous studies by (Wu and Matheson, 2001) had advocated the inclusion of reciprocal crosses in breeding program because of their positive contribution to positive SCA effects useful in selecting for higher grain yield. There were no positive and high reciprocal effects for 100-seed weight, implying that inclusion of reciprocal crosses is not so important when breeding for this trait.

CHAPTER FIVE
GENERAL DISCUSSION, CONCLUSION AND RECOMMENDATION

5.1 GENERAL DISCUSSION

The aim of this study was to identify drought tolerant, early maturing and high yielding sorghum genotypes for drought prone agro-ecological zones and also to establish the combining ability for earliness, drought tolerance and yield related components among an assortment of sorghum genotypes assembled from diverse origins. Genotypes and water regimes had effects on days to flowering, staygreen score, dry leaf scores, waxy bloom, leaf area, leaf rolling, total leaf count and lodging implying genetic diversity for the sorghum genotypes evaluated in this study. The superior lines that outperformed the check variety for earliness were Wote collection1 (56 days), IESV 23010 DL (58.days, ZSV3 (60 days), Bizany (61 days) and Tabat (61 days). However, there were yield penalties observed among the accessions wote-collection1, Bizany, ZSV3 and Tabat. Thus, the accessions IESV 23010 DL would best serve as an ideal drought evading candidate with better performance. The correlation coefficient revealed that staygreen was positively correlated with panicle weight, grain yield, 100-seed weight and harvest index suggesting that these traits could be used to select for drought tolerant sorghum genotypes. The sorghum genotypes Olerere (12.82%) exhibited the lowest DLS% while Omuhathi (76.23%) showed the highest senescence. Reduced total leaf counts and net leaf area were recorded among improved staygreen lines namely IESV 92028 DL IESV 91111 DL, Mahube, IESV 92172 DL, Gwada and IESV 23010 DL. The sorghum genotypes with staygreen traits minimize water use during the pre-anthesis phase so as to conserve water for grain filling during the grain development phase leading to high yields. The accessions that scored dense wax load under drought stress condition were Gwada, ICSR 161, Mahube, AG8, IESV 91131 DL, IESV 91111 DL, IESV 92028 DL and

IESV 92172 DL and comprised of lines drawn from ICRISAT- Nairobi gene bank. Dense wax load under drought stress condition has been associated with cuticular wax biosynthesis; translocation, composition and density and are influenced solely by environmental factors including solar radiation, temperature, moisture, and humidity in sorghum. for grain yield, the genotypes Lobuheti (50.65g), IESV 91131 DL (46.52g), Lodoka1 (47.08g) and IESV 92172 DL (46.69g) showed superior yield weights as opposed to the check variety. Among yield contributing components, harvest index and threshability are considered key determinants of the final grain yield. Accession IESV 91131 DL and IESV 92172 DL recorded high harvest index (3.13% and 6.86%) and threshing percentage of 73.94 and 67.34%. Results of correlation coefficient revealed that panicle weight showed positive correlation with grain yield, harvest index, and panicle width suggesting that these traits could be used as the basis for selection for high grain yield in sorghum breeding programs.

There were significant differences among the maternal and non-maternal effects implying that maternal genes play a greater role in regulating maturity. Genetic predictability ratios were high for days to flowering, panicle weight and grain weight indicating that additive genes play a bigger role than non-additive genes in control of such traits. Negative significant general combining ability effects (GCA) were noted for days to flowering for parents ICSV 111 IN, B35 and Macia, suggesting that these parents had the earliness trait that can be exploited for development of drought evading hybrids. The parents Lodoka, Okabir and Akuorachot with positive days to flowering implied lateness thus conferring the late physiological maturity. With regard to the panicle weight, the parental lines Macia and Okabir recorded positive GCA and high mean values for panicle weight. These parental lines are superior combiners for panicle weight. With regard to the combining ability for grain yield, the parents Macia and ICSV 111 IN showed positive and high GCA effects implying they are good combiners for grain yield compared to parental lines B35, Okabir and Akuorachot which were inferior for grain weight. For the 100-Seed weight, the parent Macia and ICSV 111 IN showed positive GCA suggesting that they are good combiners for this trait and are therefore good parental lines for developing commercial hybrids. Significant negative specific combining ability for days to flowering was exhibited by F_1 crosses, B35 x Okabir, Lodoka x B35, Okabir x Macia, ICSV II IN x Macia, ICSV III IN x Akuorachot, Lodoka x Akuorachot and Lodoka x Okabir, implying that these synthetics can be advanced for development of early maturing hybrids and inbredlines. For 100-seed weight, only three out of 15 F1 generation crosses recorded positive and highest specific combining ability (SCA) effects. The F1 progenies, B35 x Macia, B35 x ICSV III IN and Lodoka x Macia were superior for 100-seed weight implying that these crosses could be used as superior genotypes for development of commercial synthetics in drought prone agro ecologies of South Sudan. The analysis of reciprocal effects showed no significant differences for days to flowering but negative reciprocal effects were recorded by reciprocal crosses Okabir x B35, Macia x B35 and Macia x Akuorachot, Macia x Lodoka, implying the roles of maternal genes in contributing to earliness.

5.2 RECOMMENDATIONS

1. Superior sorghum genotypes were identified in this study. These genotypes should be screened across more diverse environments to validate the results
2. The superior parents could also be used to develop superior synthetics for release to the drought prone areas of South Sudan

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