HETEROSIS AND COMBINING ABILITY FOR SUGAR CONTENT AND GRAIN YIELD IN SWEET AND GRAIN SORGHUM (*SORGHUM BICOLOR* L. MOENCH) HYBRIDS

BY

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DECLARATION

I declare that the work in this dissertation entitled “HETEROSIS AND COMBINING ABILITY FOR SUGAR CONTENT AND GRAIN YIELD IN SWEET AND GRAIN SORGHUM (*SORGHUM BICOLOR* L. MOENCH) HYBRIDS” has been carried out by me in the Department of Plant Science. The information derived from the literature has been duly acknowledged in the text and a list of references provided. No part of this dissertation was previously presented for another degree or diploma at this or any other institution.

Regina Ori AGBESE	________________	________________
	Signature	Date

CERTIFICATION

This dissertation entitled “HETEROSIS AND COMBINING ABILITY FOR SUGAR CONTENT AND GRAIN YIELD IN SWEET AND GRAIN SORGHUM (*SORGHUM BICOLOR* L. MOENCH) HYBRIDS” by Regina Ori AGBESE meets the regulations governing the award of the degree of Master of Science of the Ahmadu Bello University, and is approved for its contribution to knowledge and literary presentation.

Professor Mary Y. Yeye ____________________ ____________________
Chairman, Supervisory Committee Signature Date

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Dean, School of Postgraduate Studies Signature Date

DEDICATION

I dedicate this dissertation to the wonderful memory of my late parents, Mr. Michael Owobi Ede and Mrs. Cecilia Ede who have been and will always be my source of inspiration. May your gentle souls continue to rest in peace, Amen.

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ABSTRACT

This research was conducted to study heterosis and inheritance of sugar, grain yield and other agronomic traits in sweet sorghum. The parental materials used in this study comprised ten parents (seven males and three females) selected based on their high sugar level. Seven sweet sorghum genotypes were used as male parent which were crossed with three IAR improved grain sorghum as female parents.

The parents were mated in a North Carolina mating design II Model I in IAR Samaru field, generating 21 F_1s. The 10 parents and their 21 F_1 progenies were evaluated at Institute for Agricultural Research (IAR) Samaru, Ahmadu Bello University Zaria irrigation field during the 2015/2016 dry season. The experiment was laid out in a randomized, 4 x 8 alpha lattice design with two replications. Data were collected on some agronomic traits along with brix content and sugar yield. . Data were analyzed using SAS (2002) following alpha lattice and NCII design model I. Significant genetic variations were observed for most of the characters studied indicating the presence of variability among the genotypes which is a pre-requisite for any crop improvement programme. High heritability was observed in days to 50% flowering, plant height and brix content while panicle exertion recorded the lowest heritability, indicating that the expression of most of the trait is not easily affected by environment. Baker's ratio value revealed the preponderance of additive gene action for the inheritance of sugar concentration, brix content, plant height and 1000-grain weight. Hybrids Samsorg 40 x F5.3ssm10-31/2-3 (3938.64 kg/ha, 11.38 g/l), Samsorg 14 x F5.3ssm10-31/5-1 (3086.4 kg/ha, 13.18 g/l), Samsorg 40 x F5.3ssm10-1/1-8 (3000.16 kg/ha, 12.53 g/l) had resulted in higher grain yields and sugar content when compared to the original grain-type parents. They also had negative heterosis for days to flowering making them early materials. IESV92028DL and F5.3ssm10-31/2-3 were good general combiners for earliness. Samsorg 14, Samsorg 40 and Samsorg 44 were good general combiners for brix content and sugar concentration. Parents that exhibited combining abilities in the desired direction could be useful in hybridization programmes. The crosses Samsorg 44 x F5.3ssm10-14/2-1 (1.66) and Samsorg 14 x F5.3ssm10-1/1-8 recorded highest positive SCA effect values for brix content while for sugar concentration, the crosses Samsorg 14 x F5.3ssm10-14/2-1 and Samsorg 44 x IESV92028DL contributed non-significant and positive SCA values and hence were good specific combiners for brix and sugar concentration. The hybrids, Samsorg 14 x F5.3ssm10-31/2-3, Samsorg 40 x F5.3ssm10-8/2-2 and Samsorg 44 x F5.3ssm10-8/2-2 had significant and positive heterotic values for 1000-grain weight, brix content and sugar concentration.

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CHAPTER ONE

INTRODUCTION

Sorghum (*Sorghum bicolor* L. Moench) belongs to the family Poaceae. Sorghum is the 5th most important cereal after rice, wheat, maize and barley in the world according to world sorghum production (WSP), 2017. It is grown on 40 million ha in 105 countries of Africa, Asia, Oceania and the Americas. Sorghum Production in 2017 was 63.7 million tons with the United States leading with 8.5 million metric tonnes and Nigeria is in the 2nd position with 6.5 million metric tonnes (WSP, 2017). Sorghum grows in a wide range of temperature, high altitudes, toxic soils and tolerate drought to some extent (Richard, 1968).

Sorghum, like many grains has different uses, including human consumption and animal feed. Globally, over half of all sorghum produced in the world is used for human consumption (Ogbaga *et al.*, 2014). It is a major crop for many poor farmers, especially in Africa, Central America, and South Asia. Grain sorghum is used for flours, porridges and side dishes, malted and distilled beverages, and specialty foods such as popped grain. Sorghum is also considered to be a significant crop for animal feeds. A more recent use of sorghum is for ethanol production. New sweet sorghum varieties are being developed for bioenergy, the ethanol being attained from the lignocellulose-rich stalks after fermentation of the sweet sorghum juice (IEA, 2013).

Sweet sorghum is a water sipping, highly sustainable cropping option for producers in semi-arid regions with limited irrigation capacity or dry land producers with unpredictable rainfall. Compared to many other crops, sweet sorghum has high water and nutrient use efficiencies (Water requirement 8000 m^3 as against 25,000 m^3 for sugarcane) with a growing period of about 4 months as against 9-16 month for sugarcane and is considered environmentally sustainable (Sakellariou-Makrantonaki *et al.*, 2007). Although research on alternative uses of sweet sorghum has been done (Taylor, 2006), it is still grown mainly for syrup, forage, and grain (Gnansounou *et al.*, 2005). Sweet sorghum has the potential to produce up to 8000 Lha^{-1} ethanol: about twice the ethanol yield potential of maize, and 30% greater than the 6000 Lha^{-1} average obtained from Brazilian sugarcane (Luhnow *et al.*, 2006). Determination of starch composition in sweet sorghum seed is also important because some sweet sorghum varieties may have potential as dual-purpose crops yielding both sugar-rich extractable juice and grain.

Sweet sorghum has traditionally been grown as a pure-line cultivar, but these cultivars produce very little seed and are too tall to harvest efficiently. The development of sweet sorghum hybrids, produced on grain-type females with high sugar concentrations is a practical way to overcome this limitation. (Audilakshmi *et al.*, 2010).

Despite all the agronomic advantages of sweet sorghum as a bioenergy crop, little scientific effort has been directed in the past toward the elucidation of sweet sorghum traits relevant to biofuel production. There are many cultivars of sweet sorghum distributed throughout the world, providing a diverse genetic base from which to develop regionally specific, highly productive cultivars (Audilakshmi *et al.*, 2010). Traits like plant height, stem diameter, green biomass, stem sugar content, and stem juice extractability are the major contributors for sweet sorghum’s economic importance. However, these traits are quantitative and polygenic inheritance in nature and are complex to be manipulated directly in breeding procedure (Zou *et al.*, 2012). Therefore, to successfully improve these complex traits, they need to be dissected into smaller morphological, physiological and yield components, which could be easily analyzed and evaluated (Makanda *et al*., 2009). However, information on the extent of variation in growth (plant height and stem diameter), physiology (chlorophyll content) and components of stem sugar (brix, juice yield and stem fresh weight) among sweet sorghum germplasm are limited. Furthermore, correlations between the traits are of great importance in selection process for successful breeding programs.

The objectives of this research are:

1 To determine heterosis for sugar content and grain yield in the cross of sweet and grain sorghum

2 To determine the magnitude of heritability and mode of gene action controlling sugar content in sweet sorghum.

3 To determine correlation between brix content and other agronomic traits in sweet sorghum parents and hybrids

CHAPTER TWO

LITERATURE REVIEW

Sorghum

2.1 Botany of sorghum

2.1.1 Taxonomy

Sorghum (*Sorghum bicolor* L. Moench) belongs to the Tribe *Andropogonae* of the family *Poaceae*. The genus *Sorghum* has been classified into five subgenera: *Eusorghum*, *Chaetosorghum*, *Heterosorghum*, *Para-sorghum* and *Stipo-sorghum* (Garber 1950). Although this classification is convenient, however it does not stand for evolutionary relationships (Dillon *et al.* 2004). The *Eu-sorghum* comprises the cultivated species *S. bicolor* (L.) Moench and its subspecies are *drummondii, arundinaceum*, and wild species includes *S. alum* Parodi, *S. halepense* (L.) Pers. and *S. propinquum* (Kunth) Hitchc (deWet 1978). The *Eu-sorghum* section originated from Africa or Asia (DuVall and Doebley 1990). Sections *Chaetosorghum* and *Heterosorghum* consist of *S. macrospermum* and *S. laxiflorum* and both of these species are annuals and polyploids (Lazarides *et al.* 1991). Section *Stipo sorghum* includes ten species indigenous to northern Australia (Lazarides *et al.* 1991). *Para-sorghum* Section comprised seven African, Asian, Australian and Central American species. The basic number of chromosome of species in each section is five. The species belonging to *Para-sorghum* and *Stipo-sorghum* are mostly diploid ($2n = 10$).

Sorghum includes three species, *S. halepense, S. propinquum* and *S. bicolor. Sorghum halepense* is also known as Johnson grass, derived from a natural cross between *S. arundinaceum* and *S. propinquum* (Doggett, 1976). *Sorghum propinquum* is a perennial species related to *S. bicolor* (Chittenden *et al.* 1994). According to Harlan and deWet‘s system which is based on spikelet morphology, *Sorghum bicolor* has been classified into five races. This races consist of *Bicolor, Guinea, Caudatum, Kafir, and Durra*. Owing to the variability found in each race an additional classification scheme was developed. The new classification amalgamates the Harlan and deWet‘s classification with working groups (sub-races) based on ―head opening, which resulted in the classification of seventy working groups (Dahlberg *et al.* 2004). Early *bicolor* sorghum is believed to have arisen from the subspecies *verticilliforum* in central Africa (Dahlberg, 1995). This races; Caudatum, Kafir, Guinea, and Durra were created by the crossing of early *bicolor* with the wild forms of sorghum. It is believed that the Guinea race has evolved when the Bicolors came into contact with the wild *S. arudinaceum*. Caudatum race is also believed to develop from a cross between an early domesticated Bicolor and wild sorghum (Dahlberg, 1995). Kafir race is thought to be developed from crosses between Bicolor in northern Africa with wild verticilliflorum that was carried from east toward south by the Bantu speakers of Africa (Dahlberg, 1995). Durra race is thought to be originated in Ethiopia as a result of crossing between early bicolor and with wild *S. aethiopicum* which allowed it to cope with drier conditions (Dahlberg, 1995).

2.2 Physiological characteristics of sorghum

2.2.1 Drought tolerance

The C4 cereals, like sorghum originated from the tropics and can tolerate heat and drought condition more effectively as compared with C3 plants (like wheat), which originated from temperate regions (Blum *et al.* 1990). Under arid environmental conditions, osmotic adjustment is imperative in the drought resistance of many C4 plants and may enable sorghum to grow when leaf water potential is low (Craufurd *et* *al.* 1993). Due to several morphological and physiological properties, sorghum is better drought resistant (Purseglove 1972) in the following ways:

1. The plant grows slowly until the root system is established.
2. It can produce two time higher secondary roots.
3. During drought stress, Silica deposits in the endodermis of the root avoid tissue collapse.
4. Leaf area is about half.
5. Evapotranspiration from sorghum is about half. Leaves contain a thicker cuticle and they roll in completely under drought conditions.

Sorghum leaves subjected to wilting for 1 week recover quickly after watering, with normal diurnal stomatal rhythm being restored in 5 days. Contrary to that, normal stomatal function is permanently impaired, with no restoration of normal diurnal pattern in maize (Doggett 1988). Where the crop is dependent on stored soil water, deeper root systems result in superior yield. Sorghum has an advantage, by penetrating the soil faster and to greater depths. Sorghum roots penetrated more than 2 m, thus allowing extraction of significantly more water (Squire 1990).

2.2.2 Nutrient use efficiency

Sorghum is a C4 crop in the grass family and is characterized by its high photosynthetic efficiency. Sorghum is an annual crop with considerable variability in growth characteristics. Grain, sweet, and forage type sorghums are all compatible with current agricultural production systems. Crops with a four-carbon (C4) photosynthetic pathways produce 30% more dry matter (DM) per unit of water than three-carbon (C3) crops and are more adapted to semiarid production regions.

Sorghum plants have the ability to counterbalance production situations. Habyarimana *et al.* (2004) reported that lower plant density results in higher leaf weight per plant, higher grain weight per panicle and higher tillering ability. Sorghums have an extensive root system that can penetrate 1.5 to 2.5 meters into the soil and extend one meter away from the stem depending on the soil. The large amount of root material contributes to the build-up of soil organic carbon after removal of the aerial parts of the plant, and can alleviate concerns about depletion of soil organic matter resulting from the removal of stover (Wilhelm *et al.,* 2004). Sorghum requires less fertilizer than Maize to achieve high yield (Lipinsky and Kresovich, 1980), can tolerate a wide range of soil conditions, from heavy clay soils to light sand, with pH ranging from 5.0 to 8.5 (Smith and Frederiksen, 2000). Sorghums become dormant in the absence of adequate water but do not wilt readily and are more efficient than Maize in utilizing phosphorus and potassium.

These characteristics make sorghum suitable for cultivation as a crop in optimal conditions as well as on marginal lands.

2.3 Uses of sorghum

Worldwide, sorghum has been used for human food, animal feed, building materials and fencing (Doggett 1988). Traditionally, sorghum is used in unfermented and fermented bread, porridges, couscous, rice-like products, snacks, and malted alcoholic and non-alcoholic beverages in many African and Asian countries. Sorghum can be used to produce foods that are gluten free and in this respect the potential for new food uses exists for both the US and Europe.

The use of sorghum as forage crop is gaining importance in many region of the world. Sweet sorghum stalks consist of sugars, mainly sucrose that amounts up to 55% of dry matter and in glucose (3.2% of dry matter). They also contain fiber contents like cellulose (12.4%) and hemicelluloses (10.2%). Sugar in biomass of Sweet sorghum is readily fermentable and thus it can be considered as a tremendous raw material for fermentative hydrogen production (Billa *et al.* 1997).

2.4 Sweet Sorghum

Sweet sorghum cultivars are typically tall, high biomass types with juicy stalks and high sugar concentration in the stalk juice (Sakellariou-Makrantonaki *et al.*, 2007). These sorghums can be harvested, milled, and fermented to ethanol using the same technology used to process sugarcane.

Sweet sorghum has some relative advantages over sugarcane in that it is planted from seed with traditional planters and it is an annual plant that produces a crop in about four months compared to 12-16 months required for sugarcane (Reddy *et.al*, 2005). Sorghum fits easily into crop rotations and can extend harvest windows with staggered planting dates or correct cultivar selection. At the same time, it is also more water-use efficient than other sugar-producing crops, and this water-use efficiency is estimated to reduce water requirements by 33-50% of that required by sugarcane (Hunter and Anderson, 1997). Compared to grain sorghum, sweet sorghum is less drought tolerant, but it is more tolerant than Maize. Water use efficiency and drought tolerance are important traits in bioenergy crops that will be produced in marginal environments where rainfall is limited and irrigation is too expensive (Rooney *et.al*, 2007).

Sweet sorghum sugar grain yield vary considerably depending on the varieties, location grown (soil, water, climate, pests and diseases), inputs, and agronomic practices. Sweet sorghum cultivars are characterized by the accumulation of high levels of fermentable carbohydrates (FC) (15-23%) within the culm (Sarath, *et al.*, 2008). Total FC is comprised of three main sugars; sucrose (70%), glucose (20%), and fructose (10%) variation in percentages depends on variety and environmental conditions (Prasad *et al.*, 2007). Sweet sorghum requires less water and contains higher FC levels than corn, making it a favourable biofuel crop for semiarid temperate climate regions (Reddy *et al.*, 2007). Sugar content in the juice increases with maturity, and is low prior to seed development. Sweet sorghum is typically seeded in widely spaced rows (30-40 cm). The ideal seeding rate for most sweet sorghum varieties is 3-4 seeds per linear foot of row with a final stand of 2-3 plants per linear foot of row. If plant populations are too high, the stalks will be spindly and contain less juice.

Sweet sorghum varieties can grow 14 feet tall and produce 20 to 50 tons of biomass (fresh weight) per acre. Furthermore, Putnam *et al.* (1991) studied the performance of 13 sweet sorghum cultivars and reported total dry matter (DM) yield (16.1 to 35.8 Mg ha-1), brix values of extracted juice (5.8 to 13.7), harvest stalk moisture (67 to 76%), and extracted FC yields (2.3 to 7.0 Mg ha-1) to vary significantly among cultivars. Sweet sorghum requires less than 50% total nitrogen to produce similar ethanol yields as corn and is capable of removing 62% of total nitrogen with no difference in DM yield (Bean *et al.*, 2008). Reports have shown that sweet sorghum yielding 11-16 Mg tons will remove nitrogen, phosphorus and potassium at the rate of 112, 45, and 202 kg ha-1, respectively (Undersander *et al.*, 1990).

Ethanol production from sweet sorghum (5,600 liters ha^{-1} year-1from 140 t ha^{-1} per two crop annum^{-1} at 40 L t^{-1}) is comparable to ethanol production from sugarcane (6,500 litres ha^{-1} from 85-90 t ha^{-1} per crop at 75 L t^{-1}). Grain yield and quality characteristics of sweet sorghum and sugarcane vary with weather conditions and planting dates. Poornima *et al.* (2008) recorded higher grain (2483 kg ha-*1*) and millable cane yield (37.17 t ha^{-1}) for sweet sorghum cultivars due to favourable environmental conditions during the early growing season. Under favourable conditions, sweet sorghum is capable of producing up to 13.2 metric tons per hectare of total sugars, which is equivalent to 7682 liters of ethanol per hectare.

The production of biofuels (largely ethanol) in the world grew by 13.8% in 2010, and accounted for 0.5% of global primary energy consumption. Biofuels represent 3% of the global road transport fuel supply and are expected to account for as much as 9% by 2050. Currently, Brazil and the United States are the world leaders in ethanol production (Mussatto *et al.*, 2010). In Brazil, ethanol is fermented from sucrose that accumulates in the stems of sugarcane (*Saccharum officinarum* L.), whereas in the US it is produced from Maize (*Zea mays* L.), which accumulates about 85% starch in its seeds. Although the price of oil could play a significant role in influencing the expansion of biofuels, their production costs will also depend on input costs. Thus, reductions in costs are closely tied to the prices of feedstock commodities. Indeed, for conventional biofuels today (first-generation biofuels), feedstock account for 45–70% of total production costs. This is especially important for sugarcane-based and corn-based ethanol, where both crops are cultivated under high input conditions requiring significant amounts of water and fertilizers.

The economic value of sweet sorghum is in the stem and not in the grain as in the grain sorghum. Hence, if photosynthates used in grain formation and development could be diverted into the stems, stem yield and juice quality may be improved. Sweet sorghum stores starch as the principal of nonstructural carbohydrate in grain, but primarily stores sucrose in the stems (Miller and Creelman, 1980). It is speculated that the lower grain yield in sweet sorghum may be due to competition between elongating stems and pre-anthesis head development. In sweet sorghum, the sugar mainly sucrose, is accumulated in large amounts in the stem during the development of the inflorescence, when the panicle has formed and is emerging from the boot. During this period there is no competition between grain development and sugar accumulation (Lingle, 1987). Sucrose in the stem may increase or remain constant between the soft dough and the ripe stage of the grain, depending on variety. However, distribution of sugars, starch and acid is not uniform throughout the sweet sorghum stalks (Broadhead, 1972). The four top internodes representing about 18% of the stalk weight are higher in starch, titrable acidity and sucrose than the remainder of the stalk. Internodes near the ground level are higher in simple sugars. Broadhead (1972) observed that de-heading sweet sorghum close to the panicle increased brix, sucrose and starch, but stems contained less juice than normal plants. In addition, Ferraris (1988) also observed that leaves of de-headed plants remained green for longer and the stems were less prone to lodging.

2.5 Genetic diversity in sweet sorghum

Sorghum bicolor contains both cultivated and wild races and possesses a significant amount of genetic diversity for traits of agronomic importance (Hart *et al.*, 2001). It is used as a source of grain food, syrup, and feed for livestock. Sweet sorghum gene pool creation had not received much attention mainly because it was not considered to be among important crops in the US, and the pedigree information is scarce and incomplete. Most sweet sorghums released in the US were developed by public breeding programs in the 1900s and are mainly open pollinated cultivars (Swanson and Laude, 1934). The improvement was done mainly on syrup, sugar concentration and biomass, with lines primarily selected for improved disease resistance (Murray *et al.*, 2009). Sweet sorghums were introduced to the US as landraces from Africa and China in the 1850s (Murray *et al.*, 2009), and other cultivars were developed later, some with unknown origin. Genetic diversity or knowledge on patterns of diversity of genetic resources, is of great importance (Warburton *et al.*, 2008), and is a key component in crop improvement and plant breeding. The Meridian, Mississippi Station tried curating what may be the world sweet sorghum collection, and when it closed, materials were transferred to the USDA sorghum collection in Griffin, (A city in Atlanta Georgia (Freeman, 1979). Thus many diversity studies have concentrated on cultivars/lines that are common and known, leaving the vast majority of the collection (genetic sources) unexploited. Evaluation and characterization of germplasm are the pre-requisite for the utilization of the available diversity in the crop improvement programme. It was previously reported that significant difference in brix was observed in the U.S sweet sorghum germplasm (Ali *et al.*, 2008). Genotypic differences for brix and plant height have also been reported in a panel of 125 sweet sorghum collections in the US. Studies also show much variability exists in sugar content and juice yield among the U.S sweet sorghum collections (Makanda *et al.*, 2009). However variation in growth (plant height and stem diameter), physiology (chlorophyll content) and components of stem sugar (brix, juice yield and stem fresh weight) among sweet sorghum germplasm is less investigated than other aspects. Furthermore, correlations between the traits are of great importance in selection process for successful breeding programs.

With upwards of 4000 sweet sorghum cultivars distributed throughout the world, there is a wide and diverse genetic base from which to develop regionally specific, highly productive cultivars. Several varieties have been tested in diverse environments to assess juice yield (Grassi, *et al.*, 2002). While fermentable sugar content is reported to differ with sweet sorghum variety, sucrose is the dominant sugar in all varieties. The differences in sugar content and its proportional composition may be responsible for reported variations in ethanol yield among sweet sorghum cultivars

(Pfeiffer *et al.*, 2010). Despite challenges including fast degradation of extracted juice, and a need for nitrogen supplementation for yeast growth, sweet sorghum varieties with high biomass and juice yield hold great promise in tropical climates where water can be a limiting factor in sugarcane crop production. Sweet and grain sorghums are similar and may only differ by a few genes controlling plant height, juicy stalks, and presence of sugar in the juice (Schaffert, 1992). Sweet sorghums produce more biomass than grain sorghums, and have more rapid growth and wider adaptation (Reddy *et.al*, 2007).

2.6 Alternative Sources of Sorghum

2.6.1 Maize

Currently, maize in the USA provides more than half of all fuel ethanol produced in the world (IEA 2013). In the last few decades maize in the USA has seen a larger increase in yield per hectare than any other major crop (FAOSTAT 2013). Ethanol production as a petroleum oxygenate was incentivized with a blenders' credit in the USA. This also served as a means to give price support to maize by removing some of the surplus production relative to demand (Ferris 2013). Over the past two decades ethanol production has consumed a significant portion, but not all, of the continued increase in yield achieved by US farmers. Excluding sugarcane ethanol, maize accounts for more than 95% of fuel ethanol production today, most within the USA (EIA 2014). Wheat is being used increasingly for fuel ethanol in the EU, with significant new capacity in the UK (Jessen 2013). This appears to have less long-term economic viability than maize, however. While large increases in maize yield per unit land area are being achieved globally, wheat yield improvement has stagnated with no increase in yield per hectare over the past decade (Ray *et al.*, 2012). Various root crops have also been explored as sources of starch for ethanol production, in particular cassava. Substantial cassava to ethanol programs have been established, for example in China and Thailand (Nguyen *et al.* 2007). Given that cassava is also among the most important sources of calories for some of the world's poorest communities great care would need to be taken with this crop to avoid affecting food supply to some of the most vulnerable, while recognizing that this would be a highly location specific issue (Naylor *et al.*, 2007).

2.6.2 Sugarcane

Sugarcane is a major crop grown in the tropical and subtropical regions of the world, producing 550Mt dry biomass in 2012, assuming 70% moisture in reported yields (FAOSTAT 2013). Sugarcane is produced for its sucrose, which may be used as a sweetener, a feedstock for various chemical syntheses or for fermentation in the production of alcoholic beverages or fuel bioethanol (Amorim *et al.,* 2011). Bagasse, the lignocellulosic residue produced after sucrose extraction, is combusted to provide electricity that is used to power sugarcane mills and bioethanol production, with the excess being sold on the electricity grid. Brazil accounted for 39% of the world's harvest of sugarcane in 2012. Brazil's sugarcane production has increased more than 10-fold in 50 years and doubled in the last 10 years (FAOSTAT 2013). Sugarcane has a well-established agricultural production system and processing infrastructure to make it among the most advanced feedstocks for bioenergy. More importantly, it has a positive net energy balance across a range of production systems and environments and releases considerably less CO_2 than petroleum when used to produce transportation fuel (Wang *et al.*, 2012).

2.7 Correlation Studies

In sweet sorghum, stalk yield has significant positive correlations with plant height, stem diameter and juice yield (Audilakshmi *et al*., 2010) and also a strong association of sugar yield with brix was noticed (Pfeiffer *et al*., 2010). Therefore, selection for stalk yield should be focused on plant height, stem diameter, brix and juice yield. Studies have shown that there was significant negative correlation between grain yields and stem biomass which might eventually lead to reduced sugar yield (Makanda *et al*., 2009). However, there are no studies that showed direct correlation between physiological traits and sugar yield. The relationships between morpho-physiological and stem sugar yield traits are important. Sugar yield is a quantitative trait, which is the resultant of various traits contributing together during the crop growth, which are interdependent in their development. It is, desirable to study the association between yield and yield attributing traits since this would facilitate effective selection for simultaneous improvement of one or more yield influencing components.

Sweet sorghum genotypes were studied for their sugar yields in irrigated (2007 and 2008) and rain-fed (2008) conditions. There were large variations for plant height, stem diameter, chlorophyll content, stem fresh weight, stem dry weight, brix, juice yield and sugar yield among the sweet sorghum genotypes. Significant genotypic variability for plant height and juice brix among sweet sorghum germplasm was also reported by Murray *et al.* (2009).

Plants with greater plant height, stem diameter, Fv/Fm, stem fresh weight and juice yield also produced greater sugar yields. Similarly, Audilakshmi *et al.* (2010) reported stem fresh weight to be correlated to plant height, stem diameter and juice yield. Murray *et al.* (2009) found that plant height was highly correlated with juice yield and stem fresh weight. Pfeiffer *et al.* (2010) reported that male-sterile sweet sorghum hybrids produced greater stem yield due to taller plants with greater stem diameter. There was significant positive association between stem biomass and plant height and stem diameter of sweet sorghum (Makanda *et al.*, 2009). Genotypes with higher stem fresh weight produced higher amount of juice that can be immediately fermented to bioethanol. Among the sweet sorghum genotypes studied, Wray had the highest sugar yield which was attributed to increased juice and moderate brix. This genotype also showed minimum reduction in sugar yield when grown under rain-fed condition. This indicates that Wray, besides its desirable biofuel potential, also has greater drought resilience compared with other genotypes. Even though genotype MN 4566 had highest juice yield, its sugar yield was low because of lower brix. Genotypes with moderate brix and high juice yield produced high sugar yields (Makanda *et al.*, 2009). The sugar quality and yield traits in sweet sorghum are the outcome of interaction between genotypes and environmental factors. The rain-fed condition did not have substantial impact on growth (plant height and stem diameter) but physiological traits (chlorophyll content and Fv/Fm) tended to decrease slightly under rain-fed condition. Vasilakoglou *et al.* (2011) observed no variation in sugar concentration among six sweet sorghum genotypes under reduced irrigation. Similar situations were also observed by Miller and Creelman (1980). Reduction in sugar levels (brix) under rain-fed condition might be due to reduced nutrient uptake efficiency at one growth stage or the other (Silva *et al.* 2007). Makanda *et al.* (2009) suggested genotypes with higher juice yield and lower brix were considered better stem sugar yielder than those genotypes with lower juice yield and higher brix. Murray *et al.* (2008) reported a significant correlation between brix values and stem juiciness. The juice yield could also be directly related to stem fresh weight.

2.8 Heterosis

Female seed parents can be selected for greater seed yields, increased sugar concentration in the stalks, and combining ability to develop hybrids that produce large amounts of fermentable sugar. In addition to making seed production more reliable, sorghum hybrids typically express a moderate level of heterosis. While quantitative genetics typically defines heterosis based on mid-parent calculations, it is high parent heterosis that is important in a practical situation. If the hybrid does not out-yield the best parent, the producer will simply grow the cultivar or parental variety. However, if hybrid production solves a seed production limitation in the cultivar itself, then the process of hybridization in itself is of significant value and equal yields will be enough to justify production and adoption. In addition to heterosis per se, hybrids have additional benefits which include, but are not limited to uniformity and reproducibility. Hybrids can also be used as a means to protect investment in new cultivars and transgenes (Lamkey and Edwards, 1999).

In sweet sorghum, very low high parent heterosis for maturity, and brix, and moderate values for plant height have been observed (Table 2.1). Greater levels of heterosis were observed for grain yield, stalk yield, and juice yield which was highly variable. The wide range of variability of brix, percent sucrose, stalk yield, and biomass yield indicate the high potential for genetic improvement to produce high sweet-stalked yield coupled with high sucrose percent sweet sorghum lines (Reddy *et.al*, 2005). The predominant role of non-additive gene action for plant height, stalk diameter, brix, stalk yield, and extractable juice yield indicates the importance of breeding for heterosis for improving these traits (Reddy *et.al*, 2005). Another study found sugar concentration to be primarily additive in nature while dominance heterosis up to 150 percent was observed for biomass, juice volume, and grain yields (Murray *et.al*, 2009). Transgresive segregation was observed for glucose and fructose content, total dry matter, and grain yield in two sweet by grain sorghum recombinant inbred line populations (Ritter *et al.*, 2007).

Table 2.1 Range of percent high parent heterosis expressed by sweet sorghum for yield and agronomic traits (Meshram *et. al,* 2005)

Trait	Minimum	Maximum
Maturity	87.62 cm	103.29 cm
Plant height	102.09 cm	131.47 cm
Brix	91.13 %	106.14 %
Stalk yield	87.3 kg/ha	169.52 kg/ha
Juice yield	67.29 ml/ha	242.06 ml/ha
Grain yield	37.33kg/ha	153.45 kg/ha

The development of sweet sorghum hybrids, produced on grain-type females with high sugar concentrations is a practical way to overcome the seed supply limitation of traditional cultivars. Sweet grain-type female lines have been developed by the Texas Agrilife Research sorghum breeding program at College Station by crossing a grain-type female to a sweet sorghum cultivar, then backcrossing to the grain-type female to regain the short stature and large panicle characteristics of the grain-type parent with increased sugar concentration in the stalk. Increased sugar concentration in the seed parent is important because the preponderance of reports indicate that stem sugar concentration is an additively inherited trait; both parents must have high sugar concentration to obtain it in a desirable hybrid. Development of reliable seed parents will allow the production of hybrids in sweet sorghum utilizing the male sterile cytoplasm that is used in grain sorghum for hybrid production. First generation sweet sorghum hybrids need to be evaluated for biomass and sugar production as well as hybrid performance relative to the traditional cultivars.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Experimental Site

The experiment was conducted at the Institute for Agricultural Research (IAR) farm, Ahmadu Bello University, (A.B.U) Zaria (Latitude 11^{0}11'N and Longitude 7^{0}38'E), Northern Guinea Savannah Zone in Nigeria. The research was carried out during 2015/2016 under rain-fed. The materials was screened to select the the best performing sweet sorgum genotypes with high brix content.

3.2 Genetic materials

Genetic materials comprised 57 elite sweet sorghum and 5 grain sorghum genotypes obtained from the sorghum improvement unit of the Institute for Agricultural Research Samaru (Table 3.1). These genotypes were screened in the field for their sugar level after which the best seven performing genotypes with respect to brix content were selected and used as male parents for crossing with three IAR released varieties of grain sorghum which were used as the female parents.

Table 3.1: List of sweet sorghum varieties sourced from Kenya and Mali used in this study

S/No.	Genotypes	Source
1	F5.3 SSM10-19/1-1	Mali
2	F5.3 SSM10-14/2-1	Mali
3	F5.3 SSM10-16/2-1	Mali
4	F5.3 SSM10-20/2-1	Mali
5	F5.3 SSM10-31/6-3	Mali
6	F5.3 SSM10-1/3-3	Mali
7	F5.3 SSM10-1/4-1	Mali
8	F5.3 SSM10-9/1-3	Mali
9	F5.3 SSM10-7/3-4	Mali
10	F5.3 SSM10-31/5-1	Mali
11	F5.3 SSM10-8/2-2	Mali
12	F5.3 SSM10-1/1-3	Mali
13	F5.3 SSM10-1/1-8	Mali
14	F5.3 SSM10-31/2-3	Mali
15	F5.3 SSM10-15/5.1	Mali
16	F5.3 SSM10-13/6-1	Mali
17	F7.5 SSM09-5-3/3-2-1-1	Mali
18	F7.5 SSM09-6-2/4-1-1-2	Mali
19	F7.5 SSM09-1-1/2-2	Mali
20	F7.5 SSM09-5-3/3-2-1-2	Mali
21	F7.5 SSM09-5-3/3-2-1-4	Mali
22	F7.5 SSM09-5-3/3-2-2-1	Mali
23	F7.5 SSM09-5-3/3-2-2-2	Mali
24	F7.5 SSM09-1-1/9-2	Mali
25	F7.5 SSM09-1-1/7-1	Mali
26	F7.5 SSM09-6-2/3-1-2-PL	Mali
27	F7.5 SSM09 -5-3/3-1-1-2	Mali
28	IS23519	Mali
29	IS23525	Mali
30	IS23562	Mali
31	S 35	Mali
32	SAMSORG 44	Nigeria
33	SAMSORG 14	Nigeria
34	SPV 422	Kenya
35	ICSV 93046	Kenya
36	ICSR 93034	Kenya
37	ICSV 700	Kenya
38	SERENA	Kenya
39	SEREDO	Kenya
40	ICSB 324	Kenya
41	ICSB 654	Kenya
42	IESV 91104 DL	Kenya
43	IESV 92001 DL	Kenya
44	IESV 92008 DL	Kenya
45	IESV 92021 DL	Kenya
46	IESV 92028 DL	Kenya
47	IESV 92165 DL	Kenya
48	Kari Mtama 1	Kenya
49	IESV 91018 LT	Kenya
50	IESV 93042 SH	Kenya
51	IESV 92038/2 SH	Kenya
52	SDSL 90167	Kenya
53	IS 2331	Kenya
54	SPV 1411	Kenya
55	E 36-1	Kenya
56	104GRD	Kenya
57	DTN	Kenya
58	NTJ 2	Kenya
59	CRS-01	Kenya
60	NR 71151	Nigeria
61	SAMSORG 40	Nigeria
62	EX-DAC	Nigeria

3.3. Field Screening activities

3.3.1 Seed Bed Preparation and Sowing

Seed bed was prepared at a medium depth tillage and harrowing and seeds sown at 2 cm depth with a plant spacing of inter – and intra row spacing of 30 cm x 75 cm and a seed rate of 6kg seeds/ha. Four seeds were planted per hole and a two weeks after germination, it was thinned to two plants per stand. Each plot consists of 2 rows that were 5m each. Fertilizer was applied two weeks after planting. Fertilizer was applied at the rate of 90 Kg/ha N; 60 Kg/ha, P_2O_5; 60 K_2O. NPK was applied two weeks after planting. Second application was carried out four weeks later. At eight weeks after planting, urea was applied to fufiled the recommended agronomic practice. The Nitrogen fertilizer was split applied. The field was weeded as and when due to ensure the field was free of weeds at most times.

3.3.2 Stem Harvest, Juice Extraction and Brix Measurement

Each cultivar was harvested after the grain reached hard dough stage by cutting from the base and bundling plants from the plots. Bundles were transported to a work area where the fresh biomass weight was taken and then the panicle were cut and bagged after drying, and leaves were stripped from stems and weighed. Total biomass of all samples (10 stands/plot) harvested was weighed immediately after cutting, after which the leaves and panicles were removed and weighed as well. From the stripped stalks, the 2nd, 5th to the 8th internode were removed and cleaned with tissue. This is because the distribution of sugars is not uniform throughout the sweet sorghm stalk. The four top internode representing about 18% of the stalk weight are higher in sucrose than the remainder of the stalk. Internodes near the ground level in simple sugar.

The hand held refractometer was calibrated by adding distilled water on the sensitive surface and covered. This was cleaned with tissue paper to complete the calibration. Thereafter, the cut internodes were bent and the juice squeezed on the refractometer and covered to measure the brix. The fresh biomass was sun dried in the field and the dried weight was taken and duly recorded at maturity.

3.4 Population Development

The ten selected sorghum genotypes were used as parents in population development using North Carolina design II model I. The parents were crossed in a 3 x 7 North Carolina mating design II Model I, as described by Comstock and Robinson (1948) to generate 21 F_1 progenies (Table 3.2). These progenies were evaluated in the field in 2016 dry season under Irrigation.

Table 3.2: List of parental materials

	Genotype	Description	Characteristics
1	Samsorg 14	Female	Grain
2	Samsorg 40	Female	Grain
3	Samsorg 44	Female	Grain
4	F5.3ssm10-8/2-2	Male	Sweet sorghum
5	F5.3ssm10-1/1-8	Male	Sweet sorghum
6	F5.3ssm10-14/2-1	Male	Sweet sorghum
7	IESV92028DL	Male	Sweet sorghum
8	F5.3ssm10-31/2-3	Male	Sweet sorghum
9	F5.3ssm10-1/3-3	Male	Sweet sorghum
10	F5.3ssm10-31/5-1	Male	Sweet sorghum

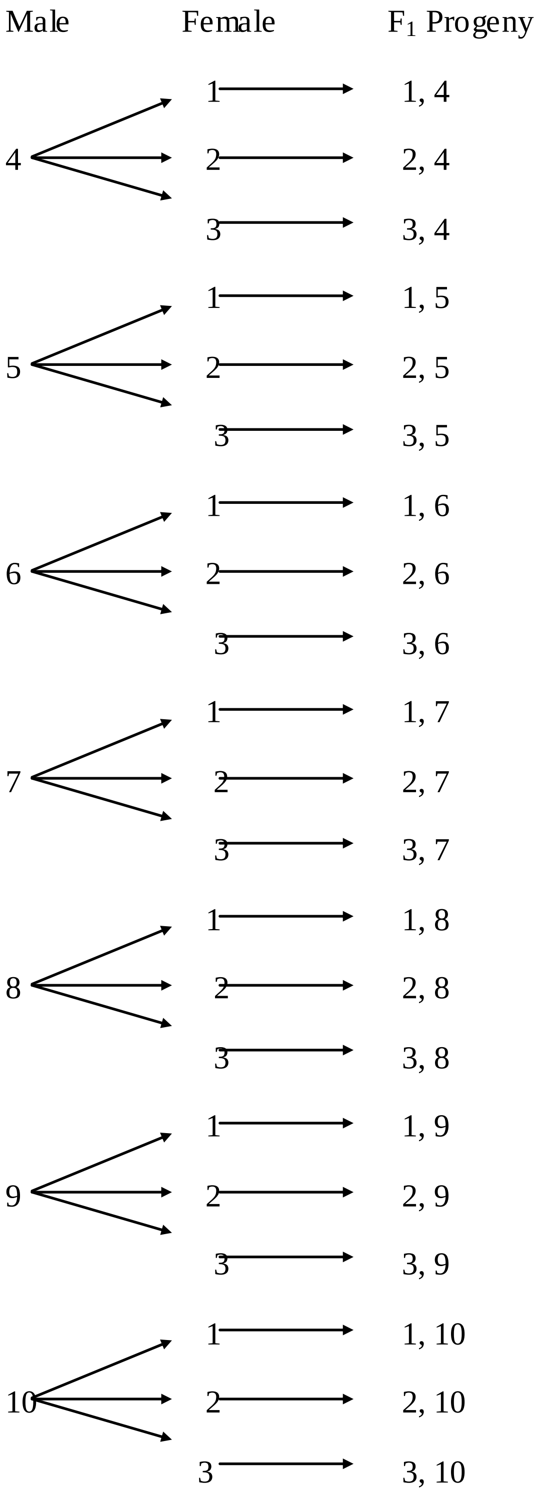

Fig 3.1 factorial design for North Carolina Design II

Key: 4-10 represents selected male sweet sorghum and 1-3 represents female grain sorghum.

3.4.1 Hybridization procedure

3.4.1.1 Hand emasculation

The male parent was sown in a plot side by side with the female parent. For every four rows of female parent, two rows of male parent were sown in a 0.2 ha. The Florets which are to be opened were selected before the anther dehiscence and the opened spikelets were removed with fine blade scissors. The awn was held between the finger and the forceps, the glumes were pressed laterally and the three stamens were removed. After the emasculation, the panicles were bagged with the date of bagging recorded on them.

3.4.1.2 Pollination

The pollination exercise was conducted with stigmas protruding out of the glumes after emasculation. The pollen was collected in the morning when anther dehiscence has taken place, usually between 7a.m and 10 am. Panicles flowering were used as source of pollen. The male parent was covered a day before crossing. The pollen was collected in the morning by tapping the bag with fingers on the panicle in which the anther shedding pollen grains lie. The collected pollen was transferred to the female head and the inflorescence was bagged with the same paper bag. The bag carried information on the date of the first bagging and pollination, and a crossing mark indicating the male parent it was pollinated with. At physiological maturity, the hybrids were harvested and the panicles in female lines were bulked and labelled clearly (Gupta, 2014).

3.5 Field Evaluation

The 10 parents, their 21F$_1$'s were evaluated at IAR research field Samaru in 2016 dry season for agronomic traits and sugar contents. The 32 genotypes were laid out in a randomized, 4 x 8 alpha lattice design with two replications. Each experimental unit consisted of two- rows plot of 3 m with inter – and intra row spacing of 30 cm x 75 cm. Each plot was sown by hand and later thinned to one plant per hole 3-4 weeks after planting. Fertlizers (12O kgN, 60 kg P_2O_5 and 60 kg K_2O per hectare) were applied in two split doses at planting and at 30 days after planting using NPK 15:15:15 and urea. Regular irrigation (during off season), pesticides, insecticides and other crop cultural management practices were applied to raise a successful crop.

3.6 Observations and Data Collection

Number of days to 50% flowering: Number of days from the date of sowing to the date of anthesis of 50% plants in a plot.

Plant height at maturity: The height was determined by carefully measuring from the base to the apex using a calibrated pole. All plants were measured from one row at maturity.

Number of internodes: Counted on 10 plants randomly selected per plot at maturity.

Panicle length: The distance (cm) between the base and the tip of the panicle, measured from 10 randomly selected stands per plot at maturity.

Panicle Exertion: Emergence of the panicle from the boot clearly above flag leaf measured in cm on 10 randomly selected stands per plot at maturity.

Panicle Weight: All panicles harvested in each plot were allowed to dry naturally and the weight recorded in Kg/ha.

Grain yield: Grain yield was measured on a per plot basis and converted into per hectare and dried to 12.5% grain moisture content.

1000- seed weight: 1000 seeds from each plot were sampled and weighed from the threshed panicle using a meter balance and recorded in grams.

Brix content determination: Ten plant stems were sampled per plot and juice extracted using a portable roller press. Juice yield per plot was recorded and brix content determined using a hand-held refractometer. Sugar content estimates were calculated based on an approach previously used by Wortmann (2010) that assumes 75% of Brix as fermentable sugars (Teetor, 2011). From the stripped stalks, the 2nd, 5th and 8th internode was removed and cleaned with tissue. The hand held refractometer was calibrated by adding distilled water on the sensitive surface and covered. This was cleaned with a tissue paper to complete the calibration. Thereafter, the cut internodes were blended and the juice squeezed on the refractometer and covered to measure the brix. The juice was extracted using a portable roller press and measured for weight and volume, and a 15 ml juice sample was collected. Juice samples were stored on ice as they were collected, pasteurized, and frozen for sugar analysis (Wortmann *et al.*, 2010).

3.7 Sugar concentration analyses

The concentrations of sugar was determined at the National Research Institute for Chemical Technology (NARICT) Zaria using a UV-2550 (UV-VIS) spectrophotometer shimadzu Ma. Reagents used are 80% ethanol, Fehling solution, and anthrone reagent. The extracted sugar was poured in a test tube each and 1.0 g was weighed. This was poured into a volumetric flask and mixed with 80% ethanol. The mixture was boiled for 15 minutes. It was cooled to 20^0C and diluted to 100ml with 80% ethanol. This was filtered through S&S 576 filter paper. To 1ml of the filtrate, 9ml of fehling solution was added in a test tube and heated in boiling water bath for 15minutes. This was cooled to 20^0C. to 1ml of this solution, 10ml of anthrone reagent was rapidly added and held for 30 minutes at 40^0C. the absorbance was read at 610 nm against a reagent blank. The percent total apparent sucrose was calculated as follows;

$$\text{Percent total apparent sucrose} = \frac{A_{sample}}{A_{s\tan dard}} x15$$

3.8 Data analysis

The data collected was subjected to analysis of variance using General Linear Model procedure of Statistical Analysis System (SAS) package (SAS, 2002) and significant difference between treatments means were compared using the Least Significant difference (LSD) test. The following linear model was used:

$$y_{ij} = \mu + r_i + g_j + e_{ij}$$

Where: y_{ij} = Observed effect for i^{th} replication and j^{th} genotypes

μ = grand mean of the experiment

r_i = effect due to the i^{th} replication

g_j = effect due to j^{th} genotype

e_{ij} = effects due to the residual or random error of the experiment

3.8.1 North Carolina II Analysis of Combining Ability and Gene Action

Analysis of variance for combining ability was carried out to partition mean squares into difference due to male parents and female parents, which was attributed to general combining ability (GCA), and differences due to male x female interaction, which was attributed to specific combining ability (SCA) (Comstock and Robinson, 1948). The genetic analyses of progenies from NCD II mating scheme was done according to the following linear model:

$$y_{ijk} = \mu + M_i + F_j + MF_{ij} + R_k + \ell_{ijk}$$

Where,

y_{ijk} = observed trait value,

μ = mean effect,

M_i = effect of the ith male,

F_j = effect of the jth female,

MF_{ij} = effect of interaction between ith male and jth female,

R_k = effect of kth replication

and ℓ_{ijk} = experimental error

Baker's ratio was used to determine the relative importance of additive and non-additive variances (Baker, 1978).

$$\text{Bakers ratio} = \frac{(K^2\text{gca}_{\text{m}} + K^2\text{gca}_{\text{f}})}{(K^2\text{gca}_{\text{m}} + K^2\text{gca}_{\text{f}} + K^2\text{sca})}$$

Where: K^2_{GCA} is the quadratic form (analogous to a variance component but referring to a fixed effect) derived from the mean square of GCA effect K^2_{SCA} is the quadratic form of SCA effects since the total genetic variation among single- cross progeny is equal to twice the GCA component plus the SCA component.

The closer this ratio is to unity, the greater the predictability of a specific hybrid's performance based on GCA alone.

The genetic variances were estimated by equating the variances to the respective mean squares from the ANOVA Table shown below.

Table 3.3: Form of Analysis of Variance for one environment for fixed model

Source of variation	df	MS	EMS
Replication	$(r-1)$	-	
Genotype	$(g-1)$	MS_2	$\sigma_e^2+\left[\frac{r}{(g-1)}\sum g^2\right]$
Error	$(r-1)(g-1)$	MS_1	σ_e^2

Where g= number of genotype, $\sum g^2$ =genotypic variance of effect, r= number of replication, σ_e^2 =error variance, df= degree of freedom, MS= observed mean squares, EMS= expected mean squares

Table 3.4: Form of ANOVA of NCD II for Model I (Comstock and Robinson, 1948).

Source.of Variation	df	MS	EMS
Replication	$(r-1)$		
Males (M)	$(m-1)$	MS_m	$\hat{\sigma}_e^2+\left[\frac{rf}{m-1}\right]K_{male}^2$
Females (F)	$(f-1)$	MS_f	$\hat{\sigma}_e^2+\left[\frac{rm}{f-1}\right]K_{female}^2$
M x F	$(m-1)(f-1)$	MS_{f*m}	$\hat{\sigma}_e^2+\left[\frac{r}{(m-1)(f-1)}\right]K_{crosses}^2$
Error	$(r-1)(mf-1)$	MS_e	$\hat{\sigma}_e^2$
Total	$mf(r-1)$		

K_{male}^2= is the quadratic form (analogous to a variance component but referring to a fixed effect) derived from the mean square of male GCA

K_{female}^2= is the quadratic form (analogous to a variance component but referring to a fixed effect) derived from the mean square of female GCA

$K^2_{crosses}$= is the quadratic form of SCA.

The components of gene effect for fixed model were calculated as follows (Hallauer *et al.*, 1988):

Males $$K^2_{male} = \frac{MS_m - MS_e}{rf/(m-1)}$$

Females $$K^2_{female} = \frac{MS_f - MS_e}{rm/(f-1)}$$

Male x female interaction $$K^2_{crosses} = \frac{MS_{f*m} - MS_e}{r/(m-1)(f-1)}$$

Estimation of general combining ability (GCA) and specific combining ability (SCA) effects

Estimation of GCA effects:

(a) **Females**: $g_i = \frac{x_i..}{rm} - \frac{x...}{rfm}$

Where, $x_i..$ = total of i^{th} females over males,

$x...$ = Grand total,

f = number of females

m = number of males

r = number of replications

(b) **Males**: $g_m = \frac{x_j..}{rf} - \frac{x...}{rfm}$

Where, $x_j..$ = Total of j^{th} males over females,

x ... = Grand total,

f = number of females,

m = number of males,

r = number of replications

Estimation of SCA effects:

$$s_{ij} = \frac{x_{ij}}{r} - \frac{x_{i}..}{rf} - \frac{x._{j}.}{rm} - \frac{x...}{rfm}$$

Where, s_{ij} = Specific combining ability,

f = number of females,

m = number of males,

r = number of replications,

$x_{i}.$ = Total of all the hybrids containing i^{th} female,

$x_{.j.}$ = Total of all hybrids containing j^{th} male,

x_{ii} = Total of all hybrids containing an i^{th} female and j^{th} male

$x_{...}$ = Grand total of crosses

The significance of the GCA (male), GCA (female) and SCA effects were estimated on the method as described by Singh and Chaudhary (1985);

(a) Significance of GCA effects:

$$t = \frac{GCA}{SE_{gca}(female)} \qquad \text{Where, } SE_{gca(female)} = \left(\frac{M_e}{rxm}\right)^{1/2}$$

$$t = \frac{GCA}{SE_{gca}(male)} \qquad \text{Where, } SE_{gca(male)} = \left(\frac{M_e}{rxf}\right)^{1/2}$$

Where; M_e = error mean square,
r = number of replications,

f= number of females,
m=number of males
and SE= Standard error

(b) Significance of SCA effects

$$t = \frac{SCA}{SE_{sca}\left(femalesxmales\right)} \qquad \text{Where, } SE_{sca} = \left(\frac{M_e}{r}\right)^{1/2}$$

Where; M$_e$= error mean square
r= number of replications
SE= Standard error

3.9 Heritability

A model with all terms considered random was fitted for the purpose of estimating entry mean heritability for each character. The GCA and SCA variances were estimated as described by Singh and Chaudhrary (1985) and Hallauer *et al.* (1988) as follows:

$$\sigma^2_{GCA_f} = \frac{MS_f - MS_{f*m}}{rm}$$

$$\sigma^2_{GCA_m} = \frac{MS_m - MS_{f*m}}{rf}$$

$$\sigma^2_{SCA} = \frac{MS_{f*m} - MS_e}{r}$$

Therefore, the broad-sense heritability was estimated by the formulae suggested by (Ruming, 2004) as follows:

Broad-sense heritability $$H_b = \frac{\hat{\sigma}^2_{GCA_f} + \hat{\sigma}^2_{GCA_m} + SCA_{fm}}{\hat{\sigma}^2_{GCA_f} + \hat{\sigma}^2_{GCA_m} + SCA_{fm} + \hat{\sigma}^2_e}$$

The heritability percentage was categorized following Robinson *et al.* (1949) method being Low (0-30%), Moderate (30-60%), and High (>60%).

3.10 Heterosis

is the superiority of a hybrid over its parents and can be defined as mid-parent heterosis which is hybrid performance superior to the mean performance of the two parents, or high parent heterosis, hybrid performance superior to the better performing parent. Mid-parent and high-parent heterosis are calculated by the following formulae (Hallauer *et al.*, 1988):

$$\text{Mid-parent heterosis} \quad (\%) = \frac{F_1\left(\frac{P_1+P_2}{2}\right)}{\frac{P_1+P_2}{2}} * 100$$

Where F_1= hybrid performance and P_1 and P_2 = performance of parents

$$\text{High-parent heterosis } (\%) = \frac{F_1 - HP}{HP} * 100$$

Where F_1 = Hybrid performance and HP = performance of superior parent

3.11 Correlation

The correlation coefficients were estimated using the formula described by Singh and Chaudhary (1985) and Bozokalfa *et al.*, (2010).

$$r_{xy} = \frac{\operatorname{cov}(xy)}{\sqrt{\operatorname{var}(y)\operatorname{var}(x)}}$$

Where; cov(xy) = Covariance of traits x and y
Var(x) = Variance of x
Var(y) = Variance of y

CHAPTER FOUR

RESULTS

4.1 Mean Performance of growth, yield characters and Brix content For the crosses

The results of 62 elite, 5 grain sorghum genotypes and 57 sweet sorghum genotypes from Nigeria, Mali and Kenya were screened at the Institute for Agricultural Research (IAR) Farm for their sugar content are presented in Table 4.1. The Table showed the mean performance for 62 sorghum genotypes screened from which ten (10) genotypes where selected because of their high brix content and grain yield. 2016 under rain fed condition.

4.2 Mean Squares from ANOVA

The mean squares from the analysis of variance, of crosses and parents for the 10 characters of sorghum evaluated for sugar content, grain yield and other agronomic characters at Samaru are presented in Table 4.2. Results showed highly significant ($P \leq 0.01$) differences among the genotypes for all the characters studied except for panicle weight and sugar concentration which showed non-significant ($P > 0.05$) difference.

Table 4. 1: Mean performance for sugar content and some agronomic characters among 62 sweet sorghum genotypes screened under rainfed condition at Samaru in 2015.

Genotype	Panicle weight (kg/ha)	Grain weight (kg/ha)	Fresh Biomass(kg/ha)	Dry Biomass(kg/ha)	Brix content (%)
F5.3 SSM10-14/2-1	**0.3**	**0.2**	**3.9**	**0.8**	**18.0**
F5.3 SSM10-16/2-1	0.6	0.5	2.7	1.1	14.9
F7.5 SSM09-1-1/9-2	0.4	0.2	3.9	2.9	11.1
F7.5 SSM09-1-1/7-1	0.4	0.3	7.7	4.2	12.6
F5.3 SSM10-13/6-1	0.1	0.0	10.6	4.6	14.0
F5.3 SSM10-19/1-1	0.1	0.1	2.6	1.6	9.8
F5.3 SSM10-20/2-1	0.9	0.5	3.4	1.3	3.7
F7.5 SSM09-6-2/3-1-2-PL	1.2	0.7	0.8	0.6	8.1
F7.5 SSM09-6-2/4-1-1-2	0.7	0.5	6.8	3.5	8.5
F7.5 SSM09 -5-3/3-1-1-2	0.1	0.1	2.5	1.0	12.6
F7.5 SSM09-5-3/3-2-1-1	0.7	2.5	2.5	1.4	6.4
F7.5 SSM09-5-3/3-2-1-2	0.4	0.3	2.0	1.0	15.8
F7.5 SSM09-5-3/3-2-1-4	1.6	0.8	3.9	2.0	12.5
F7.5 SSM09-5-3/3-2-2-1	0.2	0.2	9.7	6.0	15.0
F7.5 SSM09-5-3/3-2-2-2	0.9	0.5	2.6	1.6	10.6
F5.3 SSM10-31/6-3	0.8	0.4	6.2	3.1	14.8
F5.3 SSM10-1/3-3	**1.9**	**0.9**	**5.9**	**2.3**	**18.9**
F5.3 SSM10-1/4-1	0.8	0.4	4.6	3.1	11.4
F5.3 SSM10-9/1-3	0.8	0.4	1.2	0.9	13.0
F5.3 SSM10-7/3-4	0.2	1.3	4.1	3.0	10.6
F5.3 SSM10-31/5-1	**0.9**	**0.6**	**2.7**	**1.0**	**18.9**
F5.3 SSM10-8/2-2	**0.8**	**0.4**	**7.5**	**4.2**	**18.8**
F5.3 SSM10-1/1-3	0.9	0.9	4.5	3.0	5.2
F5.3 SSM10-1/1-8	**1.0**	**0.9**	**3.3**	**2.0**	**19.4**
F5.3 SSM10-31/2-3	**0.8**	**0.4**	**4.0**	**2.1**	**18.9**
IS23519	1.2	0.9	6.8	3.1	11.7
IS23525	0.9	0.5	1.8	1.0	12.9
IS23562	1.1	0.9	3.4	2.0	13.8
F7.5 SSM09-1-1/2-2	0.5	0.3	2.2	1.0	14.6
F5.3 SSM10-15/5.1	0.7	0.4	7.0	4.5	15.8
SPV 422	0.2	0.1	0.6	0.2	6.2
ICSV 93046	0.3	0.2	2.1	1.0	14.2
ICSR 93034	0.7	0.4	1.3	0.9	14.2
ICSV 700	0.9	0.5	1.2	0.6	14.2
CSR-01	1.0	0.6	4.8	2.9	15.1
NR 71151	1.0	0.5	6.2	3.1	11.0

EX-DAC	0.7	0.4	1.5	0.8	11.0
SAMSORG 44	1.4	0.7	1.6	0.5	17.9
SAMSORG 14	0.9	0.5	5.4	3.2	11.3
SPV 422	1.6	0.9	7.3	3.2	12.6
S 35	1.0	0.5	1.9	1.0	10.8
ICSV 93046	1.6	0.8	9.5	6.3	15.5
ICSR 93034	1.4	0.7	2.7	1.2	10.9
ICSV 701	1.0	6.1	2.5	1.3	8.7
SERENA	1.0	0.5	2.0	1.0	10.4
SEREDO	1.4	0.6	6.1	3.6	6.8
ICSB 324	1.2	0.6	4.2	2.0	7.1
ICSB 654	1.0	0.5	1.9	1.1	17.5
IESV 91104 DL	1.7	0.8	10.0	8.4	12.6
IESV 92001 DL	1.9	0.7	4.1	2.0	12.8
IESV 92008 DL	1.6	0.8	6.1	4.6	17.5
IESV 92021 DL	1.2	0.6	6.5	4.4	13.4
IESV 92028 DL	**1.1**	**0.6**	**10.9**	**8.4**	**19.9**
IESV 92165 DL	1.2	0.9	3.9	2.1	4.4
Kari Mtama 1	0.8	0.4	1.9	1.0	5.7
IESV 91018 LT	1.1	0.6	7.8	5.6	10.0
IESV 93042 SH	0.3	0.2	2.0	0.9	9.3
IESV 92038/2 SH	1.0	0.6	8.1	6.3	10.2
SDSL 90167	1.0	0.5	5.2	3.1	7.1
IS 2331	1.0	6.1	4.3	0.1	14.5
SAMSORG 40	0.2	1.0	0.7	1.1	9.3
E 36-1	2.0	7.0	6.6	1.4	17.8
Mean	1.0	1.1	4.2	2.3	12.0
%CV	18.8	22.1	16.8	18.4	23.0
LSD	2.9	2.2	2.0	2.8	8.6

Table 4. 2: Mean squares of analysis from variance for sugar content and some agronomic characters among 32 sorghum genotypes evaluated at Samaru in 2016 under irrigation.

Sources of Variation	Degree of freedom	Grain yield (kg/ha)	Days to 50% flowering	Plant Height (cm)	Number of Internodes	Panicle Length (cm)	Panicle Exertion	Panicle Weight (g)	1000-Grain Weight (g)	Brix content(%)	Sugar Concentration (g/L)
Replication	1	73707.50	123.77	346.89	2.44	0.46	97.52	61857.91	2.14	0.57	0.05
Block	3	8783.58	6.44	205.16	5.26	22.84	45.45	16161.73	3.71	0.91	15.03
Rep(Block)	3	1347.90	74.80	80.62	2.06	19.15	71.19	15560.99	0.39	0.09	2.84
Genotypes	31	13512.85*	1629.02**	3798.84**	20.27**	54.90**	61.78**	21119.36	15.24**	3.81**	24.02
Error	25	12552.75	44.52	86.83	2.00	17.44	23.58	13743.14	5.60	1.40	16.57

** Highly Significant and * Significant at 0.01% and 0.05% levels of probability, respectively

4.3 Mean Performance of growth, yield characters and Sugar content for crosses and parents

The mean for the ten characters estimated among the 32 sorghum genotypes is given in Table 4.3. There were significant differences among genotypes for many of the traits measured. Grain yield ranged from 855.5 kg/ha for F5.3ssm10-31/2-3 to 3106.8 kg/ha for IESV92028DL among the male and female parents with a mean grain yield value among the parents was 2499.6 kg/ha. The grain yield value among the hybrids ranged from 1031.5 kg/ha for Samsorg 14 x F5.3ssm10-14/2-1 to 3938.6 kg/ha for Samsorg 40 x F5.3ssm10-31/2-3. Mean grain yield of hybrids was 2367.6 kg/ha. The plant height ranged from 135.70 cm for F5.3ssm10-14/2-1 and 244.9 cm for Samsorg 14 with a mean height of 185.1 cm. For the hybrids, plant height ranged from 137.7 cm for Samsorg 40 x F5.3ssm10-31/2-3 to 269.83 cm for Samsorg 44 x F5.3ssm10-31/2-3 among the mean height of Hybrids was 213.7 cm. Hybrids, Samsorg 44 x F5.3ssm10-31/2-3 (269.8 cm), Samsorg 44 x F5.3ssm10-1/3-3 (269.1 cm) and Samsorg 44 x F5.3ssm10-1/1-8 (267.2 cm) were among the tallest. Whereas, F5.3ssm10-14/2-1 (135.7 cm), Samsorg 40 x F5.3ssm10-31/2-3 (137.7 cm) and Samsorg 40 x F5.3ssm10-14/2-1 (148.9 cm) were some of the shortest plants.

Panicle length varied from 18.6 cm for IESV92028DL to 36.3 cm for Samsorg 14 among the parents with a mean of 26.0 cm while among the hybrids, the panicle length varied from 17.9 cm for Samsorg 14 x F5.3ssm10-31/2-3 to 42.79 cm for Samsorg 14 x F5.3ssm10-31/5-1 with a mean of 26.7 cm. The hybrid Samsorg 14 x F5.3ssm10-31/5-1 (42.8 cm) recorded the highest panicle length followed by Samsorg 14 (36.3 cm). The shortest panicle was recorded in Samsorg 14 x F5.3ssm10-31/2-3 (17.9 cm) followed by Samsorg 40 x F5.3ssm10-8/2-2 (18.6 cm). The values for panicle weight ranged from 183.78 g for Samsorg 44 x F5.3ssm10-14/2-1 and 663.45 g for Samsorg 40 x F5.3ssm10-31/2-3, with a mean of 369.93 g. Across the 32 genotypes, brix content value ranged from 2.49 % for Samsorg 14 x F5.3ssm10-31/5-1 to 8.44 % for Samsorg 40 x F5.3ssm10-1/1-8 with a mean value of 6.2 % among the hybrids while the brix values among the parents ranged from F5.3ssm10-31/2-3 (4.0 %) to IESV92028DL (8.0 %) with a mean of 6.5 %. High brix greater than the mean was observed in Samsorg 40 x F5.3ssm10-1/1-8 (8.4 %), Samsorg 40 x F5.3ssm10-31/2-3 (8.2 %) and Samsorg 14 x IESV92028DL (8.2 %) genotypes. The genotypes Samsorg 14 x F5.3ssm10-31/5-1 (2.5 %), Samsorg 44 x F5.3ssm10-31/5-1 (3.5 %), Samsorg 44 x F5.3ssm10-31/2-3 (4.0 %) and F5.3ssm10-31/2-3 (4.3%) had low brix. The mean sugar concentration was 6.0 g/l and ranged from 1.5 g/l for F5.3ssm10-31/2-3 to 10.9 g/l for IESV92028DL among the parents. Among the hybrids, the sugar concentration ranged from 5.6 g/l for Samsorg 14 x F5.3ssm10-1/1-8 to 15.04 g/l for Samsorg 44 x F5.3ssm10-31/2-3 with a mean value of 9.6 g/l. Genotype Samsorg 44 x F5.3ssm10-31/2-3 (15.04 g/l) gave the highest sugar yield followed by Samsorg 40 x F5.3ssm10-1/3-3 (13.8 g/l), Samsorg 14 x F5.3ssm10-31/5-1 (13.2 g/l) and Samsorg 40 x F5.3ssm10-31/5-1 (13.2 g/l), while genotype Samsorg 14 x F5.3ssm10-1/1-8 (5.6

g/l) had the lowest sugar yield followed by F5.3ssm10-31/2-3 (1.5 g/l) and F5.3ssm10-1/1-8 (2.4 g/l).

Table 4. 3: Mean performance for sugar content and some agronomic characters among parents and F_1 hybrids of grain and sweet sorghum evaluated at Samaru in 2016.

Genotype	Grain yield (kg/ha)	Days to 50% flowering	Plant Height (cm)	Number of Internodes	Panicle Length (cm)	Panicle Exertion	Panicle Weight (g)	1000-Grain Weight (g)	Brix content (%)	Sugar Concentration (g/L)
Parents										
Female(Grain Sorghum)										
Samsorg 14 (P1)	2584	163.1	244.9	15.7	36.3	7	366	12.3	6.3	6.7
Samsorg 40 (P2)	2680.2	101.1	167.9	8.3	20.8	15.2	515.5	14.5	7.4	6.3
Samsorg 44 (P3)	2797.8	150.9	160.3	11.2	31.3	5.5	421.7	11.4	5.9	2.4
Male(Sweet Sorghum)										
F5.3ssm10-8/2-2 (P4)	2419.2	91.4	187.2	8.3	29.9	16.9	359.1	13.3	6.8	1.5
F5.3ssm10-1/1-8 (P5)	2630.6	163.8	243.9	15.1	30.2	14.2	328.9	10.8	5.6	7.1
F5.3ssm10-14/2-1 (P6)	2787.8	94.6	135.7	8.6	19.9	12	418.8	12.8	6.5	4.8
IESV92028DL (P7)	3106.8	104.9	151.3	7.3	18.6	11.5	448.8	15.8	8	8.6
F5.3ssm10-31/2-3 (P8)	855.5	93.3	189.2	7.4	23.1	7.7	203.7	7.8	4	10.9
F5.3ssm10-1/3-3 (P9)	2303.8	160.6	202.2	13.9	30.6	7.8	429	12.7	6.5	7.6
F5.3ssm10-31/5-1 (P10)	2829.8	91.2	168.5	7.8	19.2	28.8	401.8	15.4	7.9	4.2
Mean	2499.6	121.5	185.1	10.4	26	12.7	389.3	12.7	6.5	6
Range	855.5 - 3105.8	91.2 - 163.8	135.7 - 244.9	7.3 - 15.7	18.6 - 36.3	7.0 - 28.8	203.7 - 515.5	7.8 - 15.8	4.0 - 7.9	1.5 - 10.9
F_1 Hybrids										
Samsorg 14 xF5.3ssm10-8/2-2	2942.3	161.4	200.5	16	23.6	12	435.3	13.7	7	7.2
Samsorg 14 x F5.3ssm10-1/1-8	1664.1	181.8	256.8	12.8	19.4	23.5	316	11.3	5.8	5.6
Samsorg 14 x F5.3ssm10-14/2-1	1031.5	109.6	204.5	7.6	27.9	15.2	229.2	12.7	6.5	6.3
Samsorg 14 x IESV92028DL	2656.5	112.5	246.6	9.1	27.2	6.8	441.5	16	8.2	6.9
Samsorg 14 x F5.3ssm10-31/2-3	2713.8	138.6	265	9.1	17.9	3.4	410.9	14.3	7.3	11.3
Samsorg 14 x F5.3ssm10-1/3-3	2747	171.8	259.4	14.7	34.2	10.2	332.9	11.9	6.1	10.7

Samsorg 14 x F5.3ssm10-31/5-1	3086.4	165.6	249.9	15.3	42.8	2.5	395.2	4.7	2.5	13.2
Samsorg 40 x F5.3ssm10-8/2-2	2617.4	98.6	159.3	7.3	18.6	22.5	441.7	15.9	8.1	10.5
Samsorg 40 x F5.3ssm10-1/1-8	3000.2	95.9	206.1	10.2	24.3	15.3	484.6	16.6	8.4	12.5
Samsorg 40 x F5.3ssm10-14/2-1	2875.6	97.9	148.9	8.5	24.6	11	425.9	12.9	6.6	6.6
Samsorg 40 x IESV92028DL	2565.8	94.8	161.9	8.3	23	11	341.2	14.1	7.2	10.3
Samsorg 40 x F5.3ssm10-31/2-3	3938.6	80.1	137.7	5.7	20.8	11.2	663.5	16.1	8.2	11.4
Samsorg 40 x F5.3ssm10-1/3-3	2676.7	106.9	200.8	9	26.6	12	399.1	12.2	6.2	13.8
Samsorg 40 x F5.3ssm10-31/5-1	2755.5	86.3	150.8	9.6	24.1	13.8	465.2	11.5	5.9	12.7
Samsorg 44 x F5.3ssm10-8/2-2	2900.2	154.6	263.8	15.9	30.4	4.5	450.7	13	6.7	8.6
Samsorg 44 x F5.3ssm10-1/1-8	2252.6	124.2	267.2	14.8	29.2	10.2	192.6	8.2	4.3	5.8
Samsorg 44 x F5.3ssm10-14/2-1	1068.7	124.4	207.2	10.2	29	13.2	183.8	9.9	5.1	8.1
Samsorg 44 x IESV92028DL	1481.7	112.8	196	8.1	29.6	14	256.2	11.9	6.1	7.2
Samsorg 44 x F5.3ssm10-31/2-3	1379.9	156.1	269.8	16.4	28.1	10.3	245.7	7.7	4	15
Samsorg 44 x F5.3ssm10-1/3-3	2151.3	143	269.1	16.4	30.7	14.7	291.2	11.3	5.8	12.3
Samsorg 44 x F5.3ssm10-31/5-1	1702.2	128.1	230	14.1	31.9	11.4	208.5	6.8	3.5	6.5
Samsorg 38 (Check)	1878.1	93.8	150.3	9.3	23.2	18.5	333.7	12.6	6.4	9.2
Mean	2367.6	124.5	213.7	11.3	26.7	12.1	361.1	12.1	6.2	9.6
Range	1031.5 - 3938.6	80.1 - 181.8	137.7 – 269.8	5.7 - 16.4	17.9 - 42.8	2.5 - 23.5	183.8 - 663.5	4.7 - 16.6	2.5 - 8.4	5.6 - 15.0
%CV	37.2	5.4	4.6	12.9	15.8	40.6	31.7	19.3	18.8	50.3
LSD	830.8	13.7	19.2	2.9	8.6	10	241.4	4.9	2.4	8.4

4.4 Combining Ability

The mean squares for combining ability for the 32 sorghum genotypes evaluated at Samaru under irrigation in 2016 are presented in Table 4.4. The mean squares due to female were highly significant ($P \leq 0.01$) for all the characters under study except panicle exertion and sugar concentration. Mean squares due to male were highly significant ($P \leq 0.01$) for days to 50% flowering, plant height, number of internodes, 1000-grain weight, brix content and sugar concentration. The mean squares for the female x male interaction were highly significant ($P \leq 0.01$) for days to 50% flowering, plant height and number of internodes whereas it was non-significant for the rest of the traits.

4.5 Heritability Estimates

High Baker's ratio (close to unity) was recorded for grain yield (0.53), plant height (0.70), panicle weight (0.78), 1000-grain weight (0.79), brix content (0.79) and sugar concentration (0.95). Low Baker's ratio was recorded for panicle exertion (0.22).

High broad-sense heritability estimates were recorded for days to 50% flowering (95.3%), plant height (84.0%), 1000-grain weight (66.7%) and brix content (66.4%). Moderate broad-sense heritability estimates were recorded for grain weight (34.8%), panicle weight (48.9%), sugar concentration (39.3%), while low values were recorded for panicle exertion (16.8%).

4.6 Proportional Contributions of Females, Males and their Interactions to total variance

The proportional contribution of females, males and their interactions to the variations in total sum of squares of progenies for sugar content and agronomic traits is presented in Table 4.5. Both parents contributed significantly to variations for most of the characters studied.

Table 4.4: Mean squares for combining ability for sugar content and other agronomic characters among 32 sorghum genotypes evaluated at Samaru in 2016. Under Irrigation

Sources of Variation	Degree of freedom	Grain yield (kg/ha)	Days to 50% flowering	Plant Height (cm)	Number of Internodes	Panicle Length (cm)	Panicle Exertion	Panicle Weight (g)	1000-Grain Weight (g)	Brix content (%)	Sugar Concentration(g/L)
Replication	1	18606.00	144.85714	81.98	5.84	5.40	88.64	6642.75	4.21	1.07	0.68
Female	2	60403.48*	11200.60**	27552.17**	112.16**	175.79**	76.87	131559.11**	65.95**	16.55**	3.67
Male	6	16734.75	1113.88**	2657.48**	26.01**	66.23	47.89	28377.81	25.63**	6.40**	56.37**
Female x Male	12	15115.24	642.43**	990.69**	11.58**	45.76	55.68	17575.62	7.95	1.99	9.32
Error	21	11563.98	67.05	72.37	2.99	26.04	40.25	14752.90	5.46	1.36	14.17
$K^2_{GCA_{female}}$		6977.07	1590.51	3925.69	15.60	21.39	5.23	16686.60	8.64	2.17	-1.50
$K^2_{GCA_{male}}$		5170.77	1046.83	2585.11	23.02	40.20	7.64	13624.91	20.17	5.04	42.20
$K^2_{SCA_{femXmal}}$		21307.54	3452.29	5509.94	51.55	118.34	92.61	16936.33	14.95	3.75	-29.05
Baker's ratio		0.53	0.60	0.70	0.60	0.51	0.22	0.78	0.79	0.79	0.95
Broad-sense heritability (%)		0.34	0.95	0.98	0.84	0.50	0.16	0.48	0.66	0.66	0.39

** Highly Significant and * Significant at 0.01% and 0.05% levels of probability, respectively, K^2_{GCA} is the quadratic form derived from the mean square of GCA effect and K^2_{SCA} is the quadratic form of SCA effects

For grain yield, the contributions of the female parent (30.01 %) was greater than that of the male parent (24.94 %). For most of the traits where female parents exhibited higher contribution over the male parent, it was with a wide margin. The male parent showed more contribution to the total variance over the female parent for panicle length (27 % for the female to 30 % for the male), panicle exertion (14 % for the female to 26 % for the male), brix content (35 % for the female to 40 % for the male) and sugar concentration (2 % for the female to 74 % for the male).The sum of contributions of both male and female parents were greater than the contributions of the progenies in the variations observed for grain weight (54.9%), days to 50% flowering (79.0%), plant height (85.7%), number of internodes (73.2%), brix content (75.0%) and sugar concentration (75.5%) and all other characters except for panicle exertion (60.2%) in which the progenies contributed more than the parents for such character.

4.7 Combining Ability Effects

4.7.1 General combining ability effects

Estimates of general combining ability effects of each parent for all studied traits are presented in Table 4.6. From the table it was observed that the high negative values were required to develop earlier varieties. Results showed that the parent Samsorg 40 (539.19) had the highest positive GCA value for grain yield while F5.3ssm10-14/2-1 (-209.86) had the highest negative GCA value for grain yield; however, none of them was significant. All the male parents expressed highly significant ($P \leq 0.01$) and negative effects for flowering date while the female parents expressed highly significant ($P \leq 0.01$) but positive GCA effects for flowering date.

Table 4. 5: Proportional contribution of females, males and their interaction to total variance of effects of sorghum genotypes evaluated at Samaru in 2016.

Character	Contribution (%) due to:		
	Female	Male	Interaction
Grain yield (kg/ha)	30.01	24.94	45.05
Days to 50% flowering	60.88	18.16	20.95
Plant Height (cm)	66.44	19.23	14.33
Number of Internodes	43.20	30.04	26.76
Panicle Length (cm)	27.09	30.61	42.30
Panicle Exertion	13.86	25.90	60.24
Panicle Weight (g)	40.84	26.43	32.73
1000-Grain Weight (g)	34.61	40.36	25.03
Brix content (%)	34.69	40.29	25.02
Sugar Concentration(g/L)	1.60	73.94	24.46

Table 4.6: General combining ability effects of parents for sugar content and some agronomic traits among sorghum parent genotypes evaluated at Samaru in 2016. Under Irrigation

	Grain yield (kg/ha)	Days to 50% flowering	Plant Height (cm)	Number of Internodes	Panicle Length (cm)	Panicle Exertion	Panicle Weight (g)	1000-Grain Weight (g)	Brix content (%)	Sugar Concentration (g/L)
FEMALE										
Samsorg 14 (P1)	421.11	221.76**	347.59**	17.02**	37.42**	19.65**	518.73	16.27**	8.34**	10.71**
Samsorg 40 (P2)	539.19	94.26**	169.48**	7.91**	27.04**	18.87**	689.13	20.91**	10.65**	13.03**
Samsorg 44 (P3)	235.18	187.60**	349.92**	20.75**	43.37**	13.98**	241.01	10.79**	5.58**	12.36**
S.E±	825.99	4.78	5.16	0.21	1.86	2.87	1053.77	0.39	0.10	1.01
MALE										
F5.3ssm10-8/2-2 (P4)	-142.27	-66.69**	-126.87	-5.68**	-16.29**	-6.46	-168.45	-5.98**	-3.07**	-5.37*
F5.3ssm10-1/1-8 (P5)	-181.01	-68.48**	-113.41	-6.09**	-16.53**	-7.39	-229.93	-6.91	-3.54**	-7.27**
F5.3ssm10-14/2-1 (P6)	-209.86	-78.62**	-136.44	-7.63**	-15.29**	-7.27	-237.49	-6.87	-3.52**	-6.11*
IESV92028DL (P7)	-184.46	-80.62**	-131.39	-7.78**	-15.65**	-7.79	-223.55	-5.97	-3.07**	-5.58*
F5.3ssm10-31/2-3 (P8)	-153.74	-72.48**	-120.08	-6.83**	-17.03**	-8.51	-163.91	-6.59	-3.38**	-3.74
F5.3ssm10-1/3-3 (P9)	-161.59	-65.26**	-112.29	-5.71**	-13.89**	-7.82	-218.84	-7.05	-3.61**	-3.75
F5.3ssm10-31/5-1 (P10)	-162.56	-71.48**	-126.51	-5.97**	-13.15**	-7.27	-206.71	-8.60	-4.38**	-4.28
S.E±	1927.330	11.175	12.061	0.498	4.339	6.708	2458.817	0.909	0.227	2.361

** Highly Significant and * Significant at 0.01% and 0.05% levels of probability, respectively

The male parent F5.3ssm10-14/2-1 (-136.44) had the highest negative GCA for plant height although it was non-significant. With number of internodes, highly significant and positive GCA effects were shown by the female parents while significant negative effects were shown by the male parents. The parent Samsorg 44 (20.75) recorded the highest positive effect for number of internodes while the parent IESV92028DL (-7.78) recorded the highest negative effect for number of internodes. The high positive GCA effects for panicle length was contributed by Samsorg 44 (43.37) followed by Samsorg 14 (37.42) while high negative GCA effect were displayed by F5.3ssm10-31/2-3 (-17.03), F5.3ssm10-1/1-8 (-16.53) and F5.3ssm10-8/2-2 (-16.29). Parents Samsorg 40 (20.91) and Samsorg 14 (16.27) showed highly significant ($P \leq 0.01$) and positive GCA effects for 1000-grain weight while F5.3ssm10-31/5-1 (-8.60) and F5.3ssm10-1/3-3 (-7.05) contributed highly significant but negative GCA effects for 1000-grain weight. For brix content, highly significant and positive GCA effects were shown by male parents and Samsorg 40 (10.65) recorded the highest positive effect for brix content while F5.3ssm10-31/5-1 (-4.38) recorded the highest negative effect for brix content. The most significant and positive GCA effects for sugar concentration were contributed by Samsorg 40 (13.30) and Samsorg 44 (12.36) while F5.3ssm10-1/1-8 (-7.27) contributed the most significant and negative GCA effects for sugar concentration.

4.8 Specific combining ability effects

The mean and SCA of some cross combinations in desirable direction are given in Table 4.7. Results showed that the crosses, Samsorg 14 xF5.3ssm10-8/2-2 (142.09) and Samsorg 44 x IESV92028DL (131.05) had the highest positive SCA value for grain yield while Samsorg 44 x F5.3ssm10-8/2-2 (-114.38) and Samsorg 14 x IESV92028DL (-82.98) had the highest negative GCA value for grain yield`. For days to 50% flowering, many cross combinations have shown significant positive/negative SCA. Highly significant ($P \leq 0.01$) and positive SCA effects were shown by the crosses Samsorg 44 x F5.3ssm10-31/2-3 (41.45) and Samsorg 44 x F5.3ssm10-1/1-8 (36.29) for days to flowering while Samsorg 44 x F5.3ssm10-8/2-2 (-40.55) exhibited highly significant but negative SCA effects for days to flowering. For plant height only a few crosses exhibited significant SCA effects. Concerning panicle length, significant negative SCA effects were exhibited by cross Samsorg 14 xF5.3ssm10-8/2-2 (-2.24) while no cross showed significant SCA effects. The top performers for 1000-grain weight were found in crosses Samsorg 44 x F5.3ssm10-14/2-1 (3.35), Samsorg 14 x F5.3ssm10-1/1-8 (2.83) and Samsorg 14 xF5.3ssm10-8/2-2 (2.42) although none of the crosses showed significant values. Moreover, the crosses Samsorg 44 x F5.3ssm10-14/2-1 (1.66) and Samsorg 14 x F5.3ssm10-1/1-8 (1.42) recorded non-significant and highest positive SCA effect values for brix content while for sugar concentration, the crosses Samsorg 14 x F5.3ssm10-14/2-1 (3.62) and Samsorg 44 x IESV92028DL (3.30) contributed non-significant and positive SCA values.

Table 4.7: Specific combining ability effects for sugar content and other agronomic characters among the F_1 of some sorghum crosses evaluated at Samaru in 2016. Under irrigation

Crosses	Grain yield (kg/ha)	Days to 50% flowering	Plant Height (cm)	Number of Internodes	Panicle Length (cm)	Panicle Exertion	Panicle Weight (g)	1000-Grain Weight (g)	Brix content (%)	Sugar Concentration (g/L)
Samsorg 14 xF5.3ssm10-8/2-2	142.09	8.24	-24.42*	1.95	-2.24*	1.42	163.9	2.42	1.21	1.16
Samsorg 14 x F5.3ssm10-1/1-8	-28.3	-34.93*	-22.03	-3.16	-1.19	4.14	0.68	2.83	1.42	-3.30
Samsorg 14 x F5.3ssm10-14/2-1	27.86	39.40*	39.63*	3.12	11.14	-1.3	2.55	-5.68	-2.83	3.62
Samsorg 14 x IESV92028DL	-82.98	0.90	-15.64	-1.16	-2.03	2.37	-103.82	-0.08	-0.04	-2.80
Samsorg 14 x F5.3ssm10-31/2-3	-34.66	-15.26	-12.64	-3.21	0.03	-3.41	-22.39	0.48	0.24	1.34
Samsorg 14 x F5.3ssm10-1/3-3	35.81	-2.76	30.47*	2.06	-2.14	0.59	-29.47	-0.43	-0.21	-1.34
Samsorg 14 x F5.3ssm10-31/5-1	-59.81	4.40	4.63	0.40	-3.58	-3.80	-11.44	0.47	0.22	1.32
Samsorg 40 x F5.3ssm10-8/2-2	-27.7	32.31*	39.20**	1.36	-1.60	-1.22	-45.65	-1.91	-0.96	-2.15
Samsorg 40 x F5.3ssm10-1/1-8	12.46	-1.36	14.09	-0.92	-3.52	-3.17	56.49	-0.35	-0.17	1.42
Samsorg 40 x F5.3ssm10-14/2-1	-32.49	-20.52	-40.91**	-2.14	-4.85	1.56	-6.20	2.34	1.18	0.85
Samsorg 40 x IESV92028DL	-48.07	2.98	18.81	2.08	4.48	-3.61	-108.86	-0.41	-0.21	-0.5
Samsorg 40 x F5.3ssm10-31/2-3	12.10	-26.19	-49.36**	-1.81	-1.63	1.94	11.32	-1.00	-0.5	0.17
Samsorg 40 x F5.3ssm10-1/3-3	1.91	8.31	-1.75	0.13	3.87	1.44	56.34	-0.61	-0.32	0.05
Samsorg 40 x F5.3ssm10-31/5-1	81.80	4.48	19.92	1.30	3.26	3.06	36.57	1.94	0.98	0.15
Samsorg 44 x F5.3ssm10-8/2-2	-114.38	-40.55**	-14.78	-3.31	3.83	-0.20	-118.25	-0.50	-0.25	0.98
Samsorg 44 x F5.3ssm10-1/1-8	15.84	36.29**	7.94	4.08	4.71	-0.98	-57.16	-2.49	-1.24	1.88
Samsorg 44 x F5.3ssm10-14/2-1	4.63	-18.88	1.28	-0.98	-6.29	-0.25	3.65	3.35	1.66	-4.47
Samsorg 44 x IESV92028DL	131.05	-3.88	-3.17	-0.92	-2.45	1.25	212.69	0.50	0.25	3.30
Samsorg 44 x F5.3ssm10-31/2-3	22.57	41.45**	62.00**	5.02*	1.60	1.47	11.07	0.51	0.26	-1.51
Samsorg 44 x F5.3ssm10-1/3-3	-37.72	-5.55	-28.72*	-2.20	-1.73	-2.03	-26.86	1.05	0.53	1.29
Samsorg 44 x F5.3ssm10-31/5-1	-21.98	-8.88	-24.56*	-1.70	0.32	0.75	-25.13	-2.40	-1.19	-1.47
S.E±	152.08	11.58	12.03	2.44	7.22	8.97	171.77	3.30	1.65	5.32

** Highly Significant and * Significant at 0.01% and 0.05% levels of probability, respectively

4.9 Heterosis

For each F_1 cross, percent heterosis for a particular trait was calculated and shown in Table 4.8. For grain yield, the crosses Samsorg 40 x F5.3ssm10-31/2-3 (46.95%), Samsorg 14 xF5.3ssm10-8/2-2 (13.87%) and Samsorg 40 x F5.3ssm10-1/1-8 (11.94%) showed high significant heterosis over the mid and better parent. Samsorg 40 x F5.3ssm10-1/3-3 (-33.4%) and Samsorg 14 x F5.3ssm10-14/2-1 (-32.8%) showed non-significant and negative heterosis over the better parent for days to flowering. For plant height, the cross Samsorg 40 x F5.3ssm10-31/2-3 (-27.2%) showed significant and negative heterosis over the better parent. Highly significant ($P \leq 0.01$) and positive better parent heterosis was recorded for 1000-grain weight and brix content by the crosses Samsorg 14 x F5.3ssm10-31/2-3 (15.85%, 16.25), Samsorg 40 x F5.3ssm10-1/1-8 (14.40%, 13.86%), and Samsorg 40 x F5.3ssm10-31/2-3 (10.36%, 10.20%). The crosses, Samsorg 44 x F5.3ssm10-8/2-2 (262.58%), Samsorg 40 x F5.3ssm10-31/5-1 (101.22%), and Samsorg 14 x F5.3ssm10-31/5-1 (97.09%) exhibited highly significant ($P \leq 0.01$) and positive better parent heterosis for sugar concentration. Highly significant but negative better parent heterosis was recorded for brix content by Samsorg 14 x F5.3ssm10-1/3-3 (-5.80), Samsorg 14 x F5.3ssm10-31/5-1 (-68.36), . However these hybrids exhibited a highly significant and positive better parent heterosis for sugar concentration with values of 39.79 and 97.09 respectively. Other hybrids similarly recorded negative values for brix content and positive values for sugar concentration. However, in some hybrids such trend is reversed as the hybrid, Samsorg 40 x F5.3ssm10-1/1-8 exhibited a highly significant positive better parent heterosis for brix content (13.86) and a negative value for sugar concentration (-107.41). The values for mid-parent heterosis (heterobeltiosis) are shown in Tables 4.8.

Table 4.8: Mid- and High Parent Heterosis for grain yield, sugar content and other agronomic traits among 21 sorghum genotypes evaluated at Samaru in 2016. Under irrigation

Genotype	Grain yield (kg/ha)		Days to 50% flowering		Plant Height (cm)		Number of Internodes		Panicle Length (cm)	
	MPH	HPH	MPH	HPH	MPH	HPH	MPH	HPH	MPH	HPH
Samsorg 14 xF5.3ssm10-8/2-2	17.62	13.87	26.84*	-1.03	-7.20	-18.13	33.83**	2.26	-28.59**	-34.90**
Samsorg 14 x F5.3ssm10-1/1-8	-36.18	-36.74	11.24	11.03	5.08	5.31	-16.76**	-18.34**	-41.56**	-46.48**
Samsorg 14 x F5.3ssm10-14/2-1	-61.59	-63.00	-14.92	-32.80	7.45	-16.51	-37.29**	-51.50**	-0.64	-23.03**
Samsorg 14 x IESV92028DL	-6.64	-14.49	-16.06	-31.03	24.49*	0.68	-20.91**	-42.06**	-0.79	-24.97**
Samsorg 14 x F5.3ssm10-31/2-3	57.80	5.03	8.09	-15.06	22.07	8.17	-21.05**	-41.93**	-39.88**	-50.80**
Samsorg 14 x F5.3ssm10-1/3-3	12.40	6.31	6.16	5.33	16.05	5.92	-0.39	-6.18**	2.13	-5.90
Samsorg 14 x F5.3ssm10-31/5-1	14.02	9.07	30.25*	1.53	20.91	2.04	30.64**	-2.13	54.32**	17.91**
Samsorg 40 x F5.3ssm10-8/2-2	2.66	-2.34	2.40	-2.47	-10.31	-14.92	-11.72**	-12.00**	-26.60**	-37.82**
Samsorg 40 x F5.3ssm10-1/1-8	12.98	11.94	-27.59*	-41.45	0.09	-15.50	-12.81**	-32.32**	-4.78	-19.67**
Samsorg 40 x F5.3ssm10-14/2-1	5.18	3.15	0.13	-3.09	-1.94	-11.35	-0.06	-1.46	20.67**	18.32**
Samsorg 40 x IESV92028DL	-11.32	-17.41	-8.01	-9.71	1.43	-3.61	5.60*	-1.00	17.02*	10.97*
Samsorg 40 x F5.3ssm10-31/2-3	122.79	46.95**	-17.59	-20.78	-22.87	-27.20*	-26.97**	-31.13**	-5.27	-10.12
Samsorg 40 x F5.3ssm10-1/3-3	7.41	-0.13	-18.25	-33.40	8.48	-0.70	-19.25**	-35.34**	3.64	-13.02
Samsorg 40 x F5.3ssm10-31/5-1	0.02	-2.62	-10.27	-14.66	-10.33	-10.47	18.32**	14.63**	20.81*	16.21*
Samsorg 44 x F5.3ssm10-8/2-2	11.18	3.66	27.57*	2.44	51.86**	40.93**	62.69**	41.45**	-0.48	-2.67
Samsorg 44 x F5.3ssm10-1/1-8	-17.01	-19.49	-21.06	-24.16	32.21*	9.54	12.68**	-1.80	-5.05	-6.67
Samsorg 44 x F5.3ssm10-14/2-1	-61.73	-61.80	1.40	-17.52	40.01**	29.29*	3.11	-9.01**	13.15	-7.33
Samsorg 44 x IESV92028DL	-49.81	-52.31	-11.80	-25.23	25.84*	22.31	-12.05**	-27.42**	18.86*	-5.20
Samsorg 44 x F5.3ssm10-31/2-3	-24.46	-50.68	27.91*	3.48	54.45**	42.64**	76.81**	46.65**	3.39	-10.08
Samsorg 44 x F5.3ssm10-1/3-3	-15.66	-23.11	-8.17	-10.94	48.51**	33.11*	31.01**	18.50**	-0.61	-1.67
Samsorg 44 x F5.3ssm10-31/5-1	-39.50	-39.84	5.81	-15.12	39.91**	36.49**	48.30**	25.84**	26.36*	1.93
SE	152.08	152.1	11.58	11.58	12.03	12.03	2.44	2.44	7.22	7.22

** Highly Significant and * Significant at 0.01% and 0.05% levels of probability, respectively

Table 4.8: Mid- and High Parent Heterosis for grain yield, sugar content and other agronomic traits among 21 sorghum genotypes evaluated at Samaru in 2016 (Continued).

Genotype	Panicle Exertion		Panicle Weight (g)		1000-Grain Weight (g)		Brix content (%)		Sugar Concentration (g/L)	
	MPH	HPH	MPH	HPH	MPH	HPH	MPH	HPH	MPH	HPH
Samsorg 14 xF5.3ssm10-8/2-2	0.61	-28.80**	20.08	18.96	7.06*	2.91	6.85**	2.80	75.27**	7.26
Samsorg 14 x F5.3ssm10-1/1-8	121.83**	65.64**	-9.06	-13.67	-2.06	-7.74*	-2.13	-7.65**	-18.60**	-20.99**
Samsorg 14 x F5.3ssm10-14/2-1	59.82**	26.61**	-41.59	-45.27	1.62	-0.29	1.59	-0.24	9.02	-6.23
Samsorg 14 x IESV92028DL	-26.35*	-40.76**	8.37	-1.63	14.08**	1.39	13.94**	1.68	-10.05	-20.15**
Samsorg 14 x F5.3ssm10-31/2-3	-54.26**	-56.25**	44.27	12.29	41.96**	16.25**	41.10**	15.85**	28.10**	3.31
Samsorg 14 x F5.3ssm10-1/3-3	-102.25**	-102.13**	-16.25	-22.4	-4.76	-6.27	-4.51*	-5.80**	48.93**	39.79**
Samsorg 14 x F5.3ssm10-31/5-1	-86.05**	-91.33**	2.96	-1.63	-66.28**	-69.73**	-64.84**	-68.36**	141.57**	97.09**
Samsorg 40 x F5.3ssm10-8/2-2	40.49**	33.37**	1.01	-14.31	14.16**	9.28*	13.80**	9.10**	168.04**	65.75**
Samsorg 40 x F5.3ssm10-1/1-8	4.55	1.24**	14.79	-5.98	31.07**	14.40**	29.97**	13.86**	-107.84**	-107.41**
Samsorg 40 x F5.3ssm10-14/2-1	-18.74*	-27.24**	-8.82	-17.37	-5.47	-11.30**	-5.25**	-10.96**	18.37**	4.25
Samsorg 40 x IESV92028DL	-17.28*	-27.24**	-29.23	-33.80	-6.72*	-10.38**	-6.30**	-9.79**	38.04**	19.64**
Samsorg 40 x F5.3ssm10-31/2-3	-2.28	-26.41**	84.51	28.71	43.50**	10.36**	42.70**	10.20**	31.95**	4.22
Samsorg 40 x F5.3ssm10-1/3-3	4.44	-20.77**	-15.49	-22.58	-10.47**	-16.24**	-10.11**	-15.89**	97.61**	80.78**
Samsorg 40 x F5.3ssm10-31/5-1	-37.09**	-52.02**	1.43	15.78	-23.09**	-25.28**	-22.60**	-24.80**	141.28**	101.22**
Samsorg 44 x F5.3ssm10-8/2-2	-59.74**	-73.30**	15.45	6.88	5.26	13.83**	5.15*	-2.07	343.85**	262.58**
Samsorg 44 x F5.3ssm10-1/1-8	3.28	-28.34**	-48.69	-54.34	-26.17**	-28.09**	-25.53**	-27.37**	23.21**	-17.91**
Samsorg 44 x F5.3ssm10-14/2-1	50.66**	9.91	-56.27	-56.42	-18.24**	-22.45**	-18.18**	-22.28**	126.10**	68.51**
Samsorg 44 x IESV92028DL	64.71**	21.74**	-41.14	-42.92	-12.42**	-24.48**	-12.02**	-23.79**	31.44**	-16.28**
Samsorg 44 x F5.3ssm10-31/2-3	56.96**	34.78**	-21.42	-41.73	-19.92**	-32.57**	-19.62**	-32.16**	126.54**	37.80**
Samsorg 44 x F5.3ssm10-1/3-3	119.69**	86.97**	-31.55	-32.13	-6.66*	-11.20**	-6.39**	-10.69**	146.51**	61.45**
Samsorg 44 x F5.3ssm10-31/5-1	-33.86**	-60.62**	-49.35	-50.55	-49.65**	-56.16**	-48.52**	-55.05**	95.91**	52.73**
SE	8.97	8.97	171.77	171.77	3.30	3.30	1.65	1.65	5.32	5.32

** Highly Significant and * Significant at 0.01% and 0.05% levels of probability, respectively

4.10 Correlation

Table 4.9 presents correlation coefficient among 10 characters of Sorghum genotypes evaluated at Samaru during the 2016/2017 dry season. Grain yield showed highly significant and positive correlation with panicle weight (0.88) among the hybrids while among the parents, grain yield showed significant and positive correlation with panicle weight (0.80), 1000- grain weight (0.79) and brix content (0.81). Days to flowering exhibited significant and positive correlation among the hybrids for plant height (0.78) and number of internodes (0.80). Among the parents, days to flowering showed significant and positive correlation with plant height (0.68), number of internodes (0.95) and panicle length (0.79). Among the hybrids, number of internodes exhibited significant and positive correlation with days to flowering (0.80) and plant height (0.73) while among the parents number of internodes showed significant and positive correlation for days to flowering (0.95) and plant height (0.81). Panicle weight had significant positive correlation with grain weight (0.88) and significant negative correlation with plant height (-0.46). Brix content showed significant positive correlation with panicle weight (0.63) and 1000- grain weight (0.99) but showed negative significant correlation with days to flowering (-0.48), plant height (-0.44), number of internodes (-0.61) and panicle length (-0.71).

Table 4.9 Correlation coefficient of hybrids (Upper diagonal) and Parents (Lower diagonal) among 10 characters of Sorghum genotypes evaluated at Samaru during the 2016/2017 dry season.

Correlation	Grain yield (kg/ha)	Days to 50% flowering	Plant Height (cm)	Number of Internodes	Panicle Length (cm)	Panicle Exertion	Panicle Weight (g)	1000-Grain Weight (g)	Brix content (%)	Sugar Concentration (g/L)
Grain yield (kg/ha)		-0.21	-0.29	-0.12	-0.14	-0.35	0.88**	0.42	0.43	0.33
Days to 50% flowering	0.15		0.78**	0.80**	0.39	-0.28	-0.34	-0.48*	-0.48*	-0.07
Plant Height (cm)	-0.24	0.68*		0.73**	0.43	-0.38	-0.46*	-0.44*	-0.44*	-0.01
Number of Internodes	0.11	0.95**	0.81**		0.55*	-0.30	-0.36	-0.61**	-0.61**	0.07
Panicle Length (cm)	-0.08	0.79**	0.75*	0.83**		-0.53*	-0.38	-0.70**	-0.71**	0.09
Panicle Exertion	0.30	-0.52	-0.18	-0.40	-0.49		-0.09	0.22	0.21	-0.20
Panicle Weight (g)	0.80**	0.02	-0.43	-0.06	-0.23	0.16		0.63**	0.63**	0.33
1000-Grain Weight (g)	0.79**	-0.27	-0.40	-0.27	-0.40	0.56	0.80**		0.99**	-0.04
Brix content (%)	0.81**	-0.26	-0.39	-0.27	-0.40	0.56	0.85**	0.99**		-0.04
Sugar Concentration (g/L)	-0.51	0.07	0.24	0.05	-0.21	-0.33	-0.36	-0.34	-0.35	

** Highly Significant and * Significant at 0.01% and 0.05% levels of probability, respectively

CHAPTER FIVE

DISCUSSIONS

It is well known that progress in plant breeding depends on the extent of genotypic variability existing in a population. Sorghum genotypes and their hybrids were studied for their sugar content and grain yield at Samaru during 2016 dry season under irrigation. The sorghum genotypes were chosen from diverse grain sorghum and sweet sorghum groups and most of the measured traits exhibited extensive variability. Variability in the parent sorghum genotypes varied for grain yield from 855.5 to 3106.6 kg/ha and from 1031.5 to 3938.6 kg/ha among the progenies. The presence of variability in grain yield suggests improvement can be made through selection for high grain yield. However, planting during the dry season under irrigation significantly affected the yield. This was because the growing season from planting to flowering was long and assimilates were used largely for vegetative growth. Physiological mechanisms in plants are capable of sensing differences in day length. Under most conditions, late planting is associated with a reduction in number of days to panicle initiation and flowering, which in turn is affected by temperature and the photoperiod (Balole, 2001). Genetic variability for grain yield in sweet and grain sorghum was also reported by Hunter and Anderson, 1997. There were large variations for days to flowering, plant height, number of internodes, panicle length, panicle weight and brix content among the sweet and grain sorghum genotypes. Significant genotypic variability for plant height and juice brix among sweet sorghum germplasm were also reported by Murray *et al.,* (2009). Plants with greater plant height, brix content and juice yield also produced greater sugar yields. Higher mean values for time to flowering and plant height indicated that good options exist for selecting the genotypes with different maturity levels that can be suitable for cultivation in the dry savannah ecologies with marginal rainfall. The clear discrimination among average performance values for height and days to flowering has practical implications for potential use of the parents for hybrid production. Samsorg 14, F5.3ssm10-1/3-3 and F5.3ssm10-1/1-8 would be expected to produce longer-season and taller hybrids than the other parents. F5.3ssm10-14/2-1 would be expected to produce shorter-stature and shorter-season hybrids. In some cases, tallness of the plant favoured production of sugar. Earlier studies involving sweet sorghum hybrids also brought out a significant role of plant height in contributing to total biomass (Pfeiffer *et al.,* 2010). It is also noticed that high sugar yielders and late maturing enabled the plant to maintain an adequate supply of photoassimilates for a longer duration than in the case of low sugar yielders. This suggests that earliness does not favour higher accumulation of sugar in sweet sorghum. Taking advantage of a great variability on days to flowering that existed in this population; breeders will be able to develop varieties with higher biomass by selecting the genotypes with longer vegetative growth phase. On the other hand, genotypes with early maturity can be also developed for the areas where the growing season is limited by rainfall, temperature or other environmental factors.

The low sugar yielding genotypes contained fewer number of internode which restricted its assimilate production. The high sugar yielding F_1 hubrids genotype, Samsorg 44 x F5.3ssm10-31/2-3, produced the maximum number of internodes, also accumulated the greatest amount of sugar. In sweet sorghum, the most useful traits for selection are plant height, stem diameter, brix and juice yield (Ali *et al.,* 2008; Murray *et al.,* 2009). The F_1 hybrids in this study were significantly different from the paprental cultivars for total sugar concentration in the juice. Hybrids had a greater total sugar concentration than most of the parent types. Sweet sorghum varieties differ in their ability to produce and store sugar in stem (Ali *et al.,* 2008). Mostly, sugar accumulation in stems takes place during inflorescence development (McBee and Miller, 1982) and is accelerated after post anthesis (Prasad *et al.,* 2007; Almodares *et al.,* 2008). Environmental factors such as temperature and water level may greatly determine juice quality and amount. Among the sweet sorghum genotypes studied, the hybrids Samsorg 44 x F5.3ssm10-31/2-3 and Samsorg 40 x F5.3ssm10-1/3-3 had the highest sugar concentration which was attributed to increased juice and moderate brix. This indicates that Samsorg 44 x F5.3ssm10-31/2-3 and Samsorg 40 x F5.3ssm10-1/3-3 have greater potential for grain yield compared with other F_1 hybrid genotypes. Genotypes with moderate brix and high juice yield produced high sugar yields. The sugar quality and yield traits in sweet sorghum are the outcome of interaction between genotypes and environmental factors. Makanda *et al.* (2009) suggested genotypes with higher juice yield and lower brix were considered better stem sugar yielder than those genotypes with lower juice yield and higher brix. Brix values are known to be highly dependent on temperature, environment, and agronomic practices. The highest performing genotypes also confirmed in the present study that the juice yield is an important trait for selection for higher sugar yield. Genetic differences for growth attributes, juice and sugar yield were reported earlier in sweet sorghum (Blum *et al.,* 1990), under normal growing conditions.

Genetic variability among genotypes for desirable traits plays crucial role for proficient selection. In the present investigation significant mean squares for genotypes for almost all the quality traits pointed out the presence of genetic variability to be evaluated for the improvement in brix, sugar yield and other agronomic traits.

Existence of both additive and non-additive type of gene action was observed due to significant mean squares for general combining ability and specific combining ability. Kamdi *et al.,* (2009) reported significant general combining ability and specific combining ability for different characters in sweet sorghum. The Baker's ratio was close to unity for most of the traits measured especially for brix content and sugar concentration. This indicates the predominance of additive gene in the governance of these traits. Additive genetic variance is associated with homozygosity and also fixable in nature. Therefore, selection for brix content and sugar concentration governed by additive genetic variance will be very effective. Existence of additive genetic variance is prerequisite for improvement through selection because this is the only variance that responds to selection. Additive genetic variance is a measure of additive gene action and this gene action is the chief cause of resemblance between relatives and progress by selection is directly proportional to the degree of resemblance between parents and progeny. Thus additive gene action is a measure of breeding value of a genotype. Hence, for the traits like brix content and sugar concentration which showed preponderance of additive gene action, reliance should be placed on pure line selection, mass selection and or progeny selection. Premalatha *et al.* (2006) reported high Baker's ratio and described the additive type of gene actions for different traits in sweet sorghum. Further, brix content and sugar concentration could be improved by hybridization and selection.

The trait with high heritability could be brought into appropriate selection programmes. Panicle exertion had the lowest heritability, indicating that this trait was more easily affected by environment than traits such as days to flowering and plant height.

The mean performance of parents and their hybrids is believed to be one of the essential events for their appraisal. The parents with high mean value may or may not converse their high performance to their hybrids. This parental aptitude is expected in terms of general combining ability effects. The general combining ability effects in the desired direction provide a support in selection system. The parents having greater general combining ability effects in most wanted direction for traits of attention can be selected for further hybridization and assessment programmes. In this study the parent Samsorg 40 had highest positive general combining ability effects for 1000-grain weight, brix content and sugar concentration. Samsorg 44 parent had the highest significant positive general combining ability effects for days to flowering and plant height indicating the presence of alleles with additive effects on lateness while parent IESV92028DL recorded negative values. Samsorg 44 can be used to develop tall hybrids that are late in maturity while IESV92028DL can be exploited in producing early maturing hybrids. Determination of the significant effects is of importance in sorghum breeding programme where the hybrid is the ultimate product. Significant SCA effects denote the importance of non-additive effects such as dominance. The SCA effects for grain yield were not significant in all cross combinations. This implies that there are no suitable specific combiners for grain yield among the different cross combinations. For time to flowering, many cross combinations have shown significant positive/negative SCA. These crosses mostly are low x high GCA combinations. For number of internodes, only Samsorg 44 x F5.3ssm10-31/2-3 exhibited significant SCA effects and hence, it appears that these traits are predominantly governed by non-additive gene effects

The degree of heterosis in the hybrids varied from character to character and cross to cross. The magnitude of the 2 types of heterosis i.e., heterosis over mid parent and heterosis over better parent as shown by different crosses for the traits under estimation indicated sufficient departure from parental material for these parameters. In this study both positive and negative heterotic values were recorded in the traits studied indicating the presence of non-additive gene action (dominance and epistasis). The study showed that great potentials for increased grain yield and sugar content exists because of the high level of heterosis observed. The hybrids, Samsorg 40 x F5.3ssm10-31/2-3 and Samsorg 14 xF5.3ssm10-8/2-2 had the highest levels of hetrotic effects for grain yield. High heterosis estimates are desirable for grain yield in sorghum. These findings are in agreement with that of Reddy *et.al*, 2005 who reported greater levels of heterosis for grain yield. The hybrids, Samsorg 40 x F5.3ssm10-1/1-8 and Samsorg 40 x F5.3ssm10-1/3-3 recorded negative heterotic values for days to flowering. Negative heterosis is desirable for earliness implying that these hybrids would mature early. These findings are in conformity with Meshram *et. al*, 2005 who reported negative heterosis for days to flowering in sorghum crosses. The hybrids, Samsorg 44 x F5.3ssm10-8/2-2, Samsorg 44 x F5.3ssm10-14/2-1 and Samsorg 44 x F5.3ssm10-31/2-3 were taller considering their superioty in heterotic values. In sweet sorghum taller plants are preferred over short types and therefore positive heterosis is considered desirable for plant height. In sweet sorghum, moderate values of high parent heterosis have been observed for plant height by Meshram *et. al*, 2005. The hybrids, Samsorg 14 x F5.3ssm10-31/2-3, Samsorg 40 x F5.3ssm10-8/2-2 and Samsorg 44 x F5.3ssm10-8/2-2 had significant and positive heterotic values for 1000-grain weight, brix content and sugar concentration. High heterotic values could be attributed to the greater diversity due to geographical distance in the origin of the parents used in this study. The findings of the present investigation on the magnitude of heterosis for brix content and sugar concentration are in agreement with that of

Reddy *et.al*, 2005 but are not entirely in agreement with the findings of Mohanraj *et al.*, (2006) who identified hybrids with significant negative heterosis for brix content and sugar concentration in sorghum. These parents could therefore be utilized for the development of varieties by allowing thorough recombinations among them to achieve desirable genetic population which could be further subjected to recurrent selection.

The correlation study has demonstrated important relationships between brix content and other agronomic traits association in sweet sorghum. The first and surprising result was the positive and significant correlation coefficient between grain yield and brix content both at grain maturity. This implied that breeding for high brix content will not compromise grain yield. The significance of this observation contradicts the general notion that the two traits are inversely related; and suggests that breeding can improve both traits simultaneously in one cultivar, using conventional plant breeding. This is consistent with the findings of Gutjahr *et al.* (2013), who reported that change in sugar concentration was not negatively correlated with grain yield. Therefore, it is possible to breed dual purpose sorghum cultivars and the identification of genotypes combining the desirable traits is prudent in addition to general relationships information.

The observed positive correlation coefficient between brix content and panicle weight and 1000 grain weight could be attributed to the fact that panicle weight and 1000 grain weight are major components contributing to the overall plant biomass. The findings are consistent with earlier reports in sorghum (Ezeaku and Mohammed, 2006) that the traits are major contributing components to plant stem biomass. The positive correlation coefficients between plant height and days to flowering suggests that the height increases as plant height increases, which is consistent with earlier reports in sorghum by Alam *et al.* (2001) and in other crops like rice by Babar *et al.* (2007). Most tall plants have longer heads than their shorter counterparts, a phenomenon that was given as one of the explanations for heterosis in sorghum (Patanothai and Atkins, 1971) and can explain the positive correlation coefficient between the panicle length and plant height. However, this relationship can be altered by growing conditions and through breeding for improved harvest index in grain sorghum, as it ensures larger heads relative to the plant height. Therefore, this has to be taken in context of growing crops and breeding history of the reference sorghum base population.

However, the negative correlation between panicle length and grain weight implies that plants with heavier grains have smaller heads, and *vice versa*. The reason for this observation is not clear as both traits are genetically controlled, although the panicle length can be influenced by the environment. This could mean that the bigger grains were competing with the head for photo-assimilates and implies that breeding for high grain yield can be achieved indirectly through breeding for reduced panicle length to optimum levels.

However, these optimum levels have to be established for each cultivar because it is logical that differences in plant architecture (including height) and environmental conditions result in varying photosynthetic levels and efficiencies (Sarlikioti *et al.*, 2011).

CHAPTER SIX

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

6.1 SUMMARY

This research was conducted to study heterosis and inheritance of sugar, grain yield and other agronomic traits in sweet sorghum under irrigation. The parental materials used in this study comprised ten parents (seven males and three females) selected based on their sugar level and agronomic qualities. The parents were mated in a North Carolina mating design II Model I in IAR Samaru field, generating 21 F_1s. The 10 parents and their 21 F_1 progenies were evaluated at the Institute for Agricultural Research (IAR) Samaru, Ahmadu Bello University Zaria irrigation field during the 2015/2016 dry season. The experiment was laid out in a randomized, 4 x 8 alpha lattice design with two replications. Data were collected on some agronomic traits along with brix content and sugar yield. Significant genetic variations were observed for most of the characters studied indicating the presence of appreciable variability among the genotypes which is a pre-requisite for any crop improvement programme. The broad-sense heritability estimates were moderate to high for most studied characters. This gave an indication that the environment has less influence in the exhibition of these characters and selection for genetic improvement would be worthwhile. Panicle exertion had the lowest heritability, indicating that this trait was more easily affected by environment than traits such as days to flowering and plant height. Hybrids developed by crossing grain-type seed parents and sweet-type pollen parents had resulted in higher grain yields and sugar content when compared to the original grain-type parents. Combining ability made significant and important contributions to hybrid variations for grain yields and sugar content. The analysis revealed that additive and non-additive gene actions were important for the inheritance of grain yields, sugar content and improved agronomic characters. This was further confirmed by Baker’s ratio which was less than unity for some characters and close to unity for others. Hence, for the traits like brix content and sugar concentration which showed preponderance of additive gene action, effort should be placed on pure line selection, mass selection and or progeny selection. Furthermore, brix content and sugar concentration could be improved by pedigree breeding method while going for hybridization and selection.

IESV92028DL and F5.3ssm10-31/2-3 were good general combiners for earliness. Samsorg 14, Samsorg 40 and Samsorg 44 were good general combiners for brix content and sugar concentration. The crosses Samsorg 44 x F5.3ssm10-14/2-1 (1.66) and Samsorg 14 x F5.3ssm10-1/1-8 (1.42) recorded non-significant and highest positive SCA effect values for brix content while for sugar concentration, the crosses Samsorg 14 x F5.3ssm10-14/2-1 (3.62) and Samsorg 44 x IESV92028DL (3.30) contributed non-significant and positive SCA values. The study has identified the specific crosses with high SCA effects and involved good x good GCA parents for exploitation by pedigree selection to isolate high-yielding pure lines. Specific crosses with high SCA effects and parents involving good x poor general combiners can be exploited directly for heterosis breeding. Parents that exhibited combining abilities in the desired direction could be useful in hybridization programmes. The degree of heterosis in the hybrids varied from character to character or from cross to cross. The hybrids, Samsorg 40 x F5.3ssm10-31/2-3 and Samsorg 14 xF5.3ssm10-8/2-2 had the highest levels of hetrotic effects for grain yield. High heterosis estimates are desirable for grain yield in sorghum. The hybrids, Samsorg 40 x F5.3ssm10-1/1-8 and Samsorg 40 x F5.3ssm10-1/3-3 recorded negative heterotic values for days to flowering.

Negative heterosis is desirable for earliness implying that these hybrids would mature early. The hybrids, Samsorg 44 x F5.3ssm10-8/2-2, Samsorg 44 x F5.3ssm10-14/2-1 and Samsorg 44 x F5.3ssm10-31/2-3 were taller considering their superioty in heterotic values. In some cases, sweet sorghum taller plants are preferred over short types and therefore positive heterosis is considered desirable for plant height. The hybrids, Samsorg 14 x F5.3ssm10-31/2-3, Samsorg 40 x F5.3ssm10-8/2-2 and Samsorg 44 x F5.3ssm10-8/2-2 had significant and positive heterotic values for 1000-grain weight, brix content and sugar concentration. The crosses Samsorg 14 x F5.3ssm10-31/2-3, Samsorg 44 x F5.3ssm10-14/2-1, Samsorg 40 x F5.3ssm10-8/2-2, Samsorg 44 x F5.3ssm10-8/2-2 and Samsorg 14 x F5.3ssm10-1/1-8 were identified as the best hybrids on the basis of per se performance, high heterosis and combining ability effects. High heterotic values could be attributed to the greater diversity due to geographical distance in the origin of the parents used in this study.

6.2 CONCLUSIONS

The conclusions of the present study are:

1. Sufficient genetic variability exists for brix content, plant height, number of internodes and 1000-grain weight among the sorghum genotypes used.

2. High heritability was observed in days to 50% flowering, plant height and brix content while panicle exertion recorded the lowest heritability, indicating that the expression of most of the trait is not easily affected by environment. There was preponderance of additive gene action for the inheritance of sugar concentration, brix content, plant height and 1000-grain weight.

3. The crosses among Samsorg 14 x F5.3ssm10-31/2-3, Samsorg 44 x F5.3ssm10-14/2-1, Samsorg 40 x F5.3ssm10-8/2-2, Samsorg 44 x F5.3ssm10-

8/2-2 and Samsorg 14 x F5.3ssm10-1/1-8 were identified as the best hybrids on the basis of per se performance, high heterosis and combining ability effects for 1000-grain weight, brix content and sugar concentration

4. Brix content showed significant positive correlation with panicle weight and 1000- grain weight but showed negative significant correlation with days to flowering, plant height, number of internodes and panicle length.

6.3 RECOMMENDATION

From the study, it is recommended that:

i. The materials evaluated were at the F_1. The F_1 populations (Samsorg 14 x F5.3ssm10-31/2-3, Samsorg 44 x F5.3ssm10-14/2-1, Samsorg 40 x F5.3ssm10-8/2-2, Samsorg 44 x F5.3ssm10-8/2-2 and Samsorg 14 x F5.3ssm10-1/1-8) of the fairly high brix/sugar concentration should be advanced to F_2/ F_3; perhaps transgressive segregants may produce lines that are far superior to the male parents in their sugar content.

ii. Re- validation of the sweet sorghum parental genotypes should be carried out to ascertain their sugar content across diverse growing environments to identify stable sweet sorghum genotypes.

iii. The use of biotechnology to understand the mechanisms governing the inheritance of sugar should be harnessed and the information should be used in breeding programs.

iv. Revalidation of the present findings, especially with respect to sugar concentration. The true results of this findings could have been altered because of the outage of light during the period of storage of the extracted juice and laboratory analysis for the sugar concentration. Part of the sugar could have been fermented.

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