HETEROSIS AND COMBINING ABILITY OF DROUGHT TOLERANT SORGHUM [*Sorghum bicolor (*L.) Moench] GENOTYPES USING LINE X TESTER ANALYSIS

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HETEROSIS AND COMBINING ABILITY OF DROUGHT TOLERANT SORGHUM [*Sorghum bicolor (*L.) Moench] GENOTYPES USING LINE X TESTER ANALYSIS

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APPROVAL SHEET

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A thesis research advisor we hereby certify that we have read and evaluated the thesis prepared by Solomon Assefa under our direction, entitled ‘‘**HETEROSIS AND COMBINING ABILITY OF DROUGHT TOLERANT SORGHUM [*Sorghum bicolor* (L). Moench] GENOTYPES USING LINE X TESTER ANALYSIS**’’. We recommend that it accepted as fulfilling the thesis requirement for the degree of Master of Science in Agriculture (Plant Breeding).

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As a members of Board of Examiners of the M.Sc. thesis open defense examination, We certify that we have read and evaluated the thesis prepared by Solomon Assefa and examined the candidate. We recommended that the thesis accepted as fulfilling the thesis requirement for the Degree of Master of Science in Agriculture (Plant Breeding).

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DEDICATION

This manuscript is dedicated to **W/ro Meseret Gashaw** who unite my heart for adore and our baby **Tebibu Solomon**, my mother **W/ro Demekech Shibeshi**, my father **Ato Assefa Derese**, and to my Brothers and Sisters.

STATEMENT OF THE AUTHOR

First, I declare that this thesis is my original work and that all sources of materials used for the thesis have been duly acknowledged. This thesis has been submitted in partial fulfillment of the requirements for M.Sc. degree at Jimma University, College of Agriculture and Veterinary Medicine and is deposited at the University Library to be made available to borrowers under rules of the Library. I solemnly declare that this thesis is not submitted to any other institution anywhere for the award any academic degree, diploma or certificate.

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ACRONYMS AND ABBREVIATIONS

ANOVA	-	Analysis of variance
CER	-	Carbon exchange rate
cm	-	Centimeter
CMS	-	Cytoplasmic male sterility
CSA	-	Central Statistical Agency
CV	-	Coefficient of variation
DAP	-	Di ammonium Phosphate
EARO	-	Ethiopian Agricultural Research Organization
FAO	-	Food and Agriculture organization of united nation
GCA	-	General combining ability
GS	-	Growth stage
ha	-	Hectare
INTSORMIL	-	International Sorghum and Millets Research
LSD	-	List significant difference
MARC	-	Melkassa Agricultural Research Center
MPH	-	Mid-Parent heterosis
QTL	-	Quantitative trait loci
RCBD	-	Randomized Complete Block Design
SAT	-	Semi Arid Tropics
SAS	-	Statistical Analysis System
SCA	-	Specific combining ability
SC	-	Standard check
SE	-	Standard error
SED	-	Standard error of the difference
t ha^{-1}	-	Tones per hectare
USA	-	United States of America

BIOGRAPHICAL SKETCH

The author was born on November 10, 1982 in North Wollo Zone in the city of Sirinka. He completed his elementary and secondary school education at Sirinka Primary and Secondary School and Woldia Comprehensive Secondary School, respectively. He joined Jimma University, College of Agriculture and Veterinary Medicine (JUCAVM) and graduated on July 12, 2006 with a Bachelor of Science (B.Sc.) degree in Crop Production and Protection.

After Graduation, he served the Organization for Rehabilitation and Development in Amhara (ORDA) Wagehimera Zone, Dehana-RDIR Project as an Agronomist, Livelihood and Safety Net officer from October 14, 2006 to June, 2007. He joined the Amhara Regional Agricultural Research Institute in June 2007. This period, he was assigned as a junior researcher in the sorghum, tef, maize, millet and rice improvement program based at Sirinka Agricultural Research Center (SARC). After three years of service, he joined the School of Graduate Studies of Jimma University in September 2009 to pursue his Master of Science (M.Sc.) degree studies in Agriculture (Plant Breeding).

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HETEROSIS AND COMBINING ABILITY OF DROUGHT TOLERANT SORGHUM [*Sorghum bicolor (*L.) Moench] GENOTYPES USING LINE X TESTER ANALYSIS

ABSTRACT

Sorghum [Sorghum bicolor (L).Moench] is the leading crop in the arid and semiarid tropics, where drought significantly affects crop production. The use of improved cultivar, in particular hybrid, was found to be the major component as part of the integrated approach of extenuating the extreme effect of drought. A line x tester analysis involving 32 hybrids that resulted from crossing among eight lines and four testers along with two standard checks were studied for 16 characters to generate information on combining ability, gene action and heterosis with respect to growth, phenological and yield and yield components linked to drought tolerance. All 46 entries (32 F_1s, 12 parents and 2 checks) were evaluated at drought prone area, Sirinka Agricultural Research Center Kobo trial site, using randomized complete block design (RCBD) with three replications. AGROBASE 20 and SAS version 9.1 were used for analysis of variance (ANOVA) as well as for GCA and SCA analysis. In the analysis the total genotypic variances were partitioned into variation due to lines, testers and their interaction. The GCA and SCA effects were significant for most of the characters studied. The SCA effects were of greater magnitude than GCA effects, which showed greater manifestation of non-additive gene effects. The ratio of SCA to GCA also revealed predominance of non additive gene effects. Performances of M90950 and P-9529 among the CMS and PDL 984928, WSV 387 and ICSR 161 among the restorers were better for most of the traits. CMS lines P-851015, P-9532 and P-850341 and restorer ICSR 161 and WSV 387 were the best general combiners for most of the traits studied. Mean grain yield of crosses was 3.63 t ha^{-1} with a range of 2.73 to 5.51 t ha^{-1}. Cross combination P-851015xWSV 387 gave the maximum grain yield 5.51 t ha^{-1}. Not a single cross combination showed consistent promising results for all traits, however, the cross combinations P-9532 x PDL 984928, P-850341 x ICSR 161, P-851015 x WSV 387, P-9534 x WSV 387 and P- 851063 x WSV387 showed higher specific combining effects for grain yield, number of green leaves per plant and other yield components. Most of the crosses exhibited significant positive heterosis over the mid- parent and standard check value for all traits, however, some of the crosses also depicted negative but desirable heterosis for traits like days to 50% emergency, flowering, maturity and seedling vigor. Generally, this study gave valuable information on the effect of gene action on the performance of crosses as well as identified best general and specific combiners for drought tolerance. However, these should be confirmed further over many locations and seasons.

Key Words: Sorghum, drought, line x tester analysis, combining ability, heterosis

1. INTRODUCTION

Sorghum [*Sorghum bicolor* (L.) Moench] is a monocotyledon crop belonging to a tribe *Andropogoneae* of the family Poaceae (Gramineae). It is naturally self pollinated crop with the degree of spontaneous cross pollination, in some cases, reaching up to 30% depending on the panicle types (Poehlman and Sleper, 1995).

Sorghum is a crop of tropical origin and it is widely adapted to regions laying between 40^0 N and 40^0 S of the equator and it includes agronomically important grain races, that is, bicolor, caudatum, durra, guinea, and kafir, and several hybrid races (Doggett, 1988).

Sorghum is the fifth most important cereal crop after maize, rice, wheat, and barley in terms of production. The global production of sorghum is estimated at 61.69 million metric tones and the global average yield is 1.57 t ha^{-1} (FAOSTAT, 2011). It is estimated that more than 300 millions people from developing countries essentially rely on sorghum as source of energy (Godwin and Gray, 2000).

In Ethiopia Sorghum is grown over a wide range of ecological habitats, in the range of 400-3000 meters above sea level (Teshome *et al*., 2007). It ranks third after maize (*Zea mays* L.) and tef (*Eragrostis tef (Zucc*.) *Trotter*) in total production, after maize and wheat (*Triticum spp.)* in yield per hectare and after tef and maize in area harvested. The cultivated area covered by sorghum in Ethiopia is estimated at 1,903,022.97 ha and the national average yield is 1.680 t ha^{-1} (CSA, 2010/11). In Ethiopia, every part of sorghum is utilized, the grain for food; the leaf for feed; the sweet stalk for chewing; the dry stalk for construction; and the root and the dry stalk for fuel (Amsalu, 2001). Injera is local fermented pancake-like bread prepared in Ethiopia from sorghum (Yetneberk *et al*., 2004).

Sorghum was originated in Africa about 5000 years ago (Poehlman and Sleper, 1995). The greatest genetic diversity in sorghum is found in Ethiopia and adjacent areas of northeast Africa (Poehlman and Sleper, 1995). Hence wide genetic variations exist among sorghum germplasm for tolerance to drought indicating the potential to develop new sorghum cultivars that may be better adapted to drought condition. The ability of the crop to withstand drought stress and give reasonable yields under adverse environmental conditions has crowned its importance as a food security crop in arid and semi-arid lowlands. Sorghum is a good source of income for small scale farmers because of its wide range of uses. Despite the importance of the crop to many parts of the world, its productivity is very low (House, 1995). But experimental result indicated that yield of up to 3.5 t ha^{-1} is possible on farmers' fields in major sorghum growing regions of the country, Ethiopia, (Geremew *et al*., 2004). This still is very low when compared with the yield of 7 to 9 t ha^{-1} obtained under intensive management, indicating that drought is one of the prime factors reducing sorghum yield in semi arid regions (House, 1995). The low yields are attributable to various production constraints, which include biotic stresses (insects, diseases, birds and weeds), abiotic factors (drought, low soil fertility) and continued use of low yielding traditional cultivars (Wortmann *et al.,* 2006).

Drought stress contributes to poor crop performance and yield. Insufficient, unevenly distributed, and unpredictable rainfall are usually experienced in drier parts of Ethiopia. At one point rain may be abundant and perhaps wasted through runoff; in some years much rain may fall completely outside the growing season. In other years the amount of rain may be low, and after the crops have germinated, soil moisture may be severely depleted. Consequently, in almost all lowland areas crops are prone to periodic moisture stress in one way or another because of the above mentioned realities (EARO, 2001). The effect of drought on crop yield is dependent on the stage of plant development. Anthesis and grain filling stages appear to be more vulnerable; occurrence of drought at these stages may result in reduced yield and/or complete crop failure. Although drought stress at the beginning of the growing season (seedling stage) severely affects plant establishment, plants recover soon when the rain falls late.

In addition to its direct effect on yield, drought also predisposes the crop to other yield limiting factors such as pests and diseases (McBee, 1984). The federal and regional agricultural research centers of Ethiopia where sorghum is their mandate crop, have also recommended a number of soil and moisture conservation practices, which include tillage operations, tie-ridging and mulching to reduce the effect of drought (Teshome *et al*., 1995). Efforts have also been made to develop early maturing sorghum varieties that are adapted to areas where moisture scarcity is detrimental to sorghum production. Two early maturing hybrid sorghum varieties (Ethiopian Sorghum Hybrid I and Ethiopian Sorghum Hybrid II) are currently available for use under such environments. Wide genetic variations exist among sorghum germplasm for tolerance to drought indicating the potential to develop new sorghum cultivars that may be better adapted to drought condition.

Exploitation of heterosis primarily depends on screening and selection of available germplasm that could produce better combinations of important characters. Moreover, the discovery of cytoplasmic genetic male sterility system revolutionized sorghum improvement by making possible commercial production of hybrid cultivars (Stephenes and Holland, 1954). In sorghum 20-25 % hybrid vigor (heterosis) is common and thus use of hybrid cultivars improve yield proportionally. Besides grain yield, hybrid cultivars expressed their better drought tolerance and early maturity than their parental lines. This resulted in increased emphasis on hybrid breeding by several national programs in the semi arid tropics. Presently, commercial hybrids are being grown extensively in countries like Sudan (Dingkhun *et al*., 2005) and India (USDA, 1997), where drought is a dominant constraint. Field test in Ethiopia also showed that hybrid sorghum has excellent potential to enhance yield. Yield advantage of 50-80% over the best check is common when hybrids are planted in water deficit areas of Ethiopia (Brhane, 1980). With the goal of advancing hybrid sorghum production in Ethiopia, the national program began introducing and evaluating promising hybrid cultivars. The program continues to engage in hybrid research by evaluating parental lines and their hybrids for yield and suitability for commercial seed production.

In a systematic breeding program, it is essential to identify superior parents for hybridization and crosses to expand the genetic variability for selection of superior genotypes. One crucial step in hybrid development is testing of inbred lines for their general combining ability (GCA). The line x tester analysis is one of the efficient methods of evaluating large numbers of inbreeds as well as providing information on the relative importance of general combining ability and specific combining ability effects for interpreting the genetic basis of important plant traits. Therefore, this study was proposed with the following objectives:

1) To identify promising crosses for future use in drought prone areas of Ethiopia;
2) To determine the gene action operating for the inheritance of drought tolerance traits and
3) To estimate heterosis and combining ability of selected drought tolerant lines for yield and yield related traits

2. LITERATURE REVIEW

2.1. Drought as Major Constraint to Sorghum Production

Drought stress is a major constraint to sorghum production world wide, although sorghum is considered as a highly drought tolerant cereal. Sorghum is cultivated in rainfed environments. Drought at any stage of life cycle of a sorghum crop affects its growth and production, but mostly severely at the post flowering stage. Drought stress is the single most limiting factor in yield stability that can have a severe impact on agronomic and grain quality characteristics, as well as grain yield. Drought can occur at both pre-flowering and post-flowering stage of the development, and has the most adverse effect on yield during and after anthesis (Tuinstra *et al.,*1997; Kebede *et al.,* 2001). Drought stress usually coincides with periods of heat stress. Recent studies by Prasad *et al.* (2008) have shown that heat stress occurring at the pre-flowering, flowering and post flowering stages can affect sorghum plants. The authors concluded that most sensitive stages to be grain filling in sorghum were at flowering and ten days prior to flowering. It was noted that post-flowering heat stress caused yield losses up to 50% due to reduced seed filling duration

In most areas where crop production is dependent on rainfall there is always risk of crop failure or yield loss due to moisture stress. In the semi arid tropics, the loss mainly arises from availability of low moisture to support growth and development of crops (Boyer, 1982; Bohnet and Jensen, 1996; Rosenow *et al.*, 1996). In these areas moisture is always inadequate for crop growth because of low precipitation and erratic distribution and poor soil moisture storage capacity of soils. In severe cases the stress could lead to total crop loss (Sinha, 1986). Sorghum is mainly grown in areas of inadequate rainfall and is the principal source of food for millions of people living in these areas.

In Africa over 24 million hectares of land is allotted for sorghum production annually with mean yield of 0.8 tones/ha (Dingkuhn *et al*., 2005). Although several factors such as low soil fertility, poor pest and disease control and low yielding potential of local varieties contributed to low yield, much of the reduction in yield is thought to be due to severe drought stress (Boyer, 1982). Efforts have been underway to mitigate the effect of recurrent drought through soil and moisture conservation and tillage practices and development of varieties adapted to the dry land condition. Previous reports indicated that significant morphological and genetic variability attributes to drought tolerance were detected among African sorghums (Blum, 1979; Doggett, 1988).

2.1.1. Sorghum response to drought

Sorghum is considered the most drought tolerant cereal and a model crop for evaluation of drought tolerance mechanisms. Drought tolerance is a complex trait influenced by several plant factors. Pre-flowering and post-flowering responses to drought stress are generally distinguished in sorghum (Rosenow, 1993).

Even though sorghum possesses excellent drought resistance compared to most other crops, drought stress is the primary factor that reduces sorghum production world wide (Rosenow *et al*.,1997c). The crop is commonly grown in regions of the world where water is limiting and, therefore, the crop commonly experiences periods of extreme drought stress at some point within the growing season. Sorghum improvement programs have long realized that enhancing the drought tolerance of sorghum would improve the stabilize yield and increase the productivity of the crop.

Because genotypes respond differently to different types of drought stress, several general types of drought resistance mechanisms in sorghum must be considered. Early research in sorghum indicated that the most effective way to reduce loss due to water-stress was through the use of early maturing genotypes to avoid the late season water stress (Blum, 1979). While technically not a drought resistance mechanism, sorghum production and its growth as a crop in the Midwest US was based on the development of early maturing genotypes that avoided late season drought stress (Smith and Frederiksen, 2001). In many regions of the world, the use of specific maturity types to utilize seasonal rainfall is still a common practice and an important mechanism for controlling losses due to water stress.

While drought escape is desirable method of controlling losses due to water stress, it is not a feasible method in many areas of the world because of inconsistent weather patterns or the fact that unacceptable yield potential may be lost to avoid drought stress (Dalton, 1967). In these situations, the plant must have the morphological or genetic capability to tolerate the water stress. A significant effort to identify these characteristics, their expression and their genetic control has been undertaken so that the drought tolerance of the crop is further improved (Blum, 1979; Howarth *et al*.,1997; Rosenow *et al*.,1997 a-c).

Drought stress response in sorghum depends on the stage of growth in which the drought stress occurs. Pauli *et al*. (1964) divided sorghum growth in to three stages. Growth stage 1 (GS1) is the vegetative stage that begins with germination and ends at panicle differentiation. Growth stage 2 (GS2) is the pre-flowering or reproductive phase of growth ranging from panicle differentiation until the cessation of anthesis. Growth stage 3 (GS3) is the post-flowering or grain fill phase that begins immediately after anthesis and continues until physiological maturity of the grain. This division of growth stages is particularly useful in classifying drought reaction, as in each stage the drought resistance reaction is controlled by different genetic mechanisms (Rosenow *et al.,* 1997a-c).

Drought stress tolerance in GS1 is an important trait especially in the harsher production environments and the interaction between genotypes and environment begins at planting with the germination process. Sorghum germination is influenced by the amount of available soil water and the genotype of the seedling and the environment in which the seed was produced (Evans and Stickler. 1961; Howarth *et al.,* 1997). There have been relatively few reports on variation within sorghum for seedling drought tolerance. Differences in germination and emergence among genotypes were observed at different levels of soil water stress (Smith *et al.,* 1989; Gurmu and Naylor, 1991). Wenzel (1991) reported that additive effects controlled variation for seedling drought tolerance and that the trait was highly heritable. However, the relative magnitude of this effect was minimal compared to the variation observed for soil seedling temperature effects. Significant differences among hybrid genotypes for survivals have not been reported in the US (Rosenow *et al.,* 1997a-c). For these reasons, research to improve germination and seedling emergence has focused on tolerance has focused on tolerance to temperature extremes.

In later stages of growth, two distinct types of water stress reaction have been identified and characterized. Both reactions are based on growth stage and have distinct and different phenotypic expressions (Rosenow and Clark, 1981; Rosenow *et al.,*1983). The pre-flowering stress response occurs when the plant encounters significant drought stress during GS2 prior to anthesis.

Sorghum susceptible to pre-flowering drought stress will exhibit symptoms such as leaf rolling, leaf tip burn, delayed flowering, poor panicle exertion, panicle blasting, and reduced panicle size (Rosenow *et al.,* 1997a-c). In a breeding nursery, pre-flowering susceptibility is evident when characteristic ‘‘saddle effect’’ is observed where panicle development occurs only at the ends of a plot (presumably due to additional soil moisture available in the alleys between plots). Because pre-flowering stress occurs during panicle development, it affects yield potential by influencing panicle size and seed number.

Because of the importance of the trait and its impact on yield, sorghum improvement programs have identified and successfully used numerous source of resistance to pre-flowering drought stress. These sources of resistance have been utilized by breeders to develop inbred lines, hybrids, and cultivars that have excellent pre-flowering drought stress tolerance. While the physiological basis of pre-flowering drought stress is not well known, the genetics of pre-flowering drought stress have been evaluated. Because the evaluation of pre-flowering drought stress is primarily subjective and is related to numerous phenotypic characteristics, there has been relatively little research to determine the inheritance of the trait (Rosenow *et al.,* 1997a-c).

More recently, the development of molecular marker technology has allowed sorghum breeders to dissect the inheritance of pre-flowering drought tolerance. Tuinstra *et al.* (1996) evaluated a recombinant inbred line population and found six distinct genomic regions that were specifically associated with pre-flowering drought tolerance. These loci accounted for approximately 40% of the total phenotypic variation for yield under drought stress and most of these regions were detectable across environments. Kebede *et al.* (2001) identified four QTLs that controlled pre-flowering drought tolerance in sorghum, but non of the QTLs identified were consistent across all environments. They also noted a strong relationship between QTL for pre-flowering drought tolerance and days to flowering.

Post-flowering water stress results from drought stress that is encountered at GS3 during grain fill. Water stress encountered during GS3 can also result in significant reduction in yield, as the plant is unable to completely fill the grain. Sorghum susceptible to post-flowering drought stress will exhibit symptoms such as reduced kernel size, significant leaf and stem death and lodging (Rosenow *et al.,* 1997 a-c). the increase in lodging is due to the plant remobilizing carbohydrate from the stem in an attempt to complete the grain fill process. Once the stem is weakened, charcoal rot (caused by *M. phaxcoliiui*) invades and further weakens the plant, resulting in significant lodging.

Sources of resistance to post flowering drought stress are less common than those found for pre-flowering drought stress, but breeders have succeeded in identifying genetic resistance to post-flowering drought stress. Because sources of post-flowering drought resistance remain green while susceptible types do not, the resistance to post flowering drought stress is known as stay-green drought tolerance (Rosenow *et al.,* 1983). Stay-green genotypes are less susceptible to lodging, more resistant to charcoal rot, and they retain greater green leaf area and higher levels of stem carbohydrates than non stay-green genotypes (Mahalakshmi and Bidinger, 2002)

While sources of post-flowering drought stress are more limited than those for pre-flowering drought stress, there has been substantially more research on the heritability and physiology of post-flowering drought resistance. The genetic control of non-senescence in sorghum has been described both dominant and recessive in terms of inheritance Duncan, (1984). Tenkouano *et al.* (1994) determined that non-senescence was regulated by dominant and recessive epistatic interactions between two loci controlling non-senescence. In a diallel analysis, Van O0sterum *et al.*(1996) also found that stay-green was moderately heritable with dominant gene action.

Tuinstra *et al.* (1997) identified 13 regions of the genome associated with at least one measure of post-flowering drought tolerance, but only two of these QTLs were stable across environments with major effects on stay-green and yield. Crasta *et al.* (1999) identified seven genomic regions associated with stay green in line B35, but only three of these QTLs were stable across environments. These three QTLs also accounted for 42% of the total phenotypic variability for stay-green. Xu *et al.* (2000) also identified several genomic regions with major effects for stay green. Tao *et al.* (2000) identified two genomic regions that were consistently associated with stay-green response in Australia. These reports consistently indicate that at least two loci account for a significant amount of the variability associated with stay-green, but there is no way to know if the genomic regions were consistent across studies.

Visual scoring of stay green trait should be done at or right after physiological maturity. The scoring procedure is relatively easy and not time taking but it is subjected to individual biasness and difference in ratings among individuals (Rosenow, 1994). Visual ratings for percentage green leaf area and number of green leaves were highly correlated with measured green leaf area under drought stress (Wanous *et al*.,1991). Consequently breeding for stay green trait is becoming a fundamental strategy for increasing crop production in water-limited conditions (Rosenow, 1977; Borrell *et al*., 2004). Progresses have been made in genetic improvement of post-flowering drought tolerance of sorghum through manipulation of the stay green trait (Payne *et al*., 2005). Genotypes possessing the stay green trait maintain more photosynthetically active leaves than genotypes not possessing the trait (Rosenow *et al.,* 1983). The longevity and photosynthetic efficiency of the leaves of stay green plant was shown to be associated with the nitrogen status of the leaves (Thomas and Rogers, 1990; Borrell and Hammer, 2000); increased leaf area at maturity and higher transpiration efficiency (Borrel *et al.*, 2004). Retention of chloroplast protein up to the late onset of senescence have been reported in sorghum containing the KS19 source of stay green indicating that photosynthesis may be maintained for longer during senescence in these genotypes (De Villiers *et al.,* 1993). Plants with the stay green trait contain high content of cytokynins (McBee, 1984) and basal stem sugars (Duncan, 1984) than do senescent genotypes. Moreover, it has also an advantage to resist stalk rot disease (Ducan, 1983; Rosenow, 1984; McBee, 1984).

As cited by Nguyen *et al*. (1996) field performance evaluation containing hybrids derived from parental lines containing senescent and non senescent trait under severe post-flowering conditions revealed that hybrids from non stay green parents showed about 20-55% lodging percentage compared to less than 10% lodging in the hybrids with one stay green parent. The stalks of stay green genotypes have the capacity to transport water continuously under drought condition (Xu *et al*., 2000). He also reported that the relative water content in the apical leaves of sorghum lines containing stay green trait was about 81% whereas it was only 38% in the non-stay green lines. The accumulation of sugar is also associated with greater function of leaf area during grain filling period thereby reduce dependence on the stored sugar for grain filling (Duncan *et al*., 1981). Besides the grain, stalks of sorghum are sought for animal feed in developing countries. The stay green trait might add value to the stalks that may enhance the quality of stalk as feed sources. Results of some previous studies indicated that content and concentration of non structural carbohydrate in the stay green plant relatively after grain harvest has been higher than the non stay green types (McBee *et al*., 1983; Vietor and Miller, 1990; Tunistra *et al*., 1998).

The phenotypic manifestation of pre-or post-flowering drought tolerance is the result of several phenotypic and physiological traits that have been identified and characterized by sorghum physiologists. Traits that have been associated with drought resistance include heat tolerance, osmotic adjustment (Basnayake *et al.,* 1995), transpiration efficiency (Muchow *et al.,* 1996), rooting depth and patterns (Jordan and Miller, 1980), and epicuticular wax (Maiti *et al.,* 1984). The physiological basis of these and other traits associated with drought tolerance has been reviewed by Kreig (1993) and Ludlow (1993). While all of these traits have been associated with drought tolerance in sorghum, most have not been of any practical use in improvement programs because of the difficulty in evaluation and/or selection.

2.1.2. Sorghum research for stay-green trait in Ethiopia

Sorghum is one of the most widely grown cereal crops in Ethiopia. The crop is the fourth staple crop in terms of both in cultivated area and in total grain production among the major five cereal crops produced in Ethiopia, preceded by tef, maize, wheat and followed by barley (Asfaw Adugna, 2007). This author also indicated importance of sorghum is well recognized, particularly in the lowland areas where rainfall is unreliable and crop failures due to recurrent drought are common. Although several factors such as low soil fertility, poor pest and disease control and low yield potential of local cultivars contribute to low yield in sorghum, much of the reduction in yield is due to severe drought stresses (Simon, 2009). Moreover, the cultural aspect of sorghum in Ethiopia has been well addressed by Firew Mekbib (2009).

The crop has been grown in different agro-ecology zones of the country. Based on their adaptation zones within the country, cultivated sorghums are grouped into highland, intermediate and lowland sorghum (Alemayehu Bekelle, 2003). This classification has been made largely based on altitude, length of growing period and amount and distribution of rainfall (Yilma Kebede and Abebe Menkir, 1987). These authors indicated that intermediate zone sorghum grows at an altitude of 1600-1900masl and those of lowlands grow in areas of altitude less than 1600 m.a.s.l. Being an indigenous crop, sorghum exists in tremendous diversity throughout the growing areas, which contains pockets of geographical isolation, with extremely broad and valuable genetic base for potential breeding and improvement work in the country and the world at large (Asfaw Adugna, 2007). Moreover, in Ethiopia, many efforts have been made to address the drought problem in sorghum production. Breeding programme in Ethiopia has released a number of varieties for lowland areas which give reasonable yield in drought prone areas (Asfaw Adugna, 2007). Currently, sorghum breeding in Ethiopia is fully engaged in different research activities in sorghum drought tolerance. So far, two sources of stay-green, B-35 and E-36-1 were identified from the Ethiopian gene pools by ICRISAT and other scientists in the region and now in use in different part of the world to generate drought tolerance/resistance sorghum varieties (Borrell *et al*., 2001). In addition to these, the Ethiopian sorghum germplasm is also noted worldwide as a source for useful genes such as cold tolerance, good grain quality, and disease and insect resistance (Doggett, 1970; Yilma Kebede, 1991). Due to the increase in demand for searching additional sources of stay-green materials, in Ethiopia the BIO-EARN project has attempted to screen accessions for post flowering drought tolerance. Under this project, Dagnachew Bekelle (2008) and Zelalem Mengiste (2008) evaluated sorghum accessions genetic diversity and post-flowering drought tolerance using few morphological and agronomic criteria. Zelalem Mengiste (2008) has reported the presence of variation in stay-green property among 165 sorghum accessions evaluated. Since the accessions were evaluated using few morphological parameters, the author has suggested the need to include more physiological parameters to scrutinize approved stay-green materials. Moreover, Dagnachew Bekelle (2008) has indicated that estimation of genetic diversity in sorghum is very important in the evaluation of accessions as possible source of genes for a given trait of interest, for example drought resistance/ tolerance. This author has also noted that the presence of very high genetic diversity among Ethiopian sorghum germplasm accessions collected from the drought prone areas based on quantitative and qualitative morphological traits.

2.2. Hybrid Sorghum Development for Drought Prone Areas

Based on the success of hybrid corn, early sorghum breeders knew the potential of hybrids, but had no means by which to economically produce seed (Conner and Karper, 1927). However, Stephens and Holland (1954) identified a cytoplasmic male-sterility system that would allow the cost-effective production of F_1 sorghum hybrids in the USA and the rest of the world (Maunder, 1999). Once hybrid sorghum seed was produced, it was rapidly accepted by sorghum producers and replaced sorghum cultivars in a period of less than ten years.

The use of early maturing sorghum varieties is encouraged in SAT regions where either seasonal rainfall is short or its distribution is erratic to overcome the drastic effect of drought. These varieties may not be necessarily superior to long maturing cultivars, but give more stable yield under water stress environments. Though a number of early maturing varieties are now available for much of the SAT regions, their contribution to enhance total production was minimal. This might be because selections were made among traditional cultivars with major emphasis on maturity rather than combining early maturity with high yield potential (House, 1995). Therefore, much of the increase in total production in Africa come from increased land area. The situation is quite different in other part of the world. In India, the production area declined by 37%, but yield increased by 80% (USDA, 1997). Also in developed countries average production has been increasing and total area decreasing. This was perhaps due to increased development of hybrid cultivars that have much higher yielding potential than open pollinated varieties.

Globally estimated area planted with hybrid sorghum was 48% which contributed to a minimum of 40% yield advantage over open pollinated varieties (Duvick, 1999). Hybrid cultivars of sorghum are often preferred because they give higher yield and have more stable performance under a wide range of environmental conditions (Brhane, 1980). They have the advantage of giving higher grain yield than open pollinated varieties both under optimum and stress environments (Doggett, 1969) with the advantage being higher under stress environment (Quinby *et al.,* 1958; Doggett, 1970). In Kenya hybrid sorghum reported to give up to 50% yield advantage over open pollinated varieties under extreme drought situations (Karari *et al*., www.africancrops). The performance of hybrids tested for several years at MARC exhibited a consistent yield advantage of over 100 % compared to standard checks (Brhane, 1980). Commercial production of hybrid sorghum became only possible after the discovery of cytoplasmic male sterility system in the 1950s (Stephenes and Holland, 1954).

Different male sterility systems which include A1, A2, A3 and A4 have been identified in sorghum (Schertz, 1977; Schertz and Johnson, 1984; Worstell *et al*., 1984). But the A1 sterility system is widely used in hybrid sorghum program (Moran and Rooney, 2003). The A2 cytoplasm can be potentially useful for hybrid seed production provided that suitable A2 sterile females and corresponding restorer are identified. Whereas, the A3 system was kept out of use because of limited source of fertility restoration genes and the A4 cytoplasm is not sufficiently characterized (Moran and Rooney, 2003). Due to expanded use of hybrids, sorghum yield in the United States has improved over 300% between 1950 s and 1990s. Following the advent of hybrids in USA 35-40% genetic gain were estimated on grain sorghum (Duvick, 1999). Hybrid cultivars, besides their superior yielding potential over the pure line varieties, have magnificent role in motivating private seed growers to engage in commercial seed production (Kenga *et al*., 2004). In Sudan, there was significant turn around in seed production following the release of Hageen Dura-1 (HD-1), the first commercial hybrid released in 1983. This cultivar has excellent grain quality and stable performance in areas where moistures is limiting of production. Thus the acreage under this cultivar increased from year to year with the current statistics showing 1 million ha of land put to cultivation of this hybrid (Andrews *et al.*, 1996; Dingkhun *et al*., 2005). Considering the advantages of hybrid sorghum, several national programs in the semi arid regions have shown increased interest in hybrids (Axtell *et al*., 1999).

Research on sorghum hybrid development in Ethiopia began in the mid seventies, with an objective of developing sorghum hybrids for the low altitude and moisture stress ecological zones. Series of A and B lines were introduced along with suitable restorers for hybrid development from abroad. Best looking and agronomicaly suitable A and B lines were identified (Brhane 1980). He also mentioned that introduction of fertility restorer line (R-line) has been effected since 1977 and the best combiners have been identified. Hybrid parents need to be genetically complementary for vigor and yield associated traits, but not for other often recessive traits that would adversely affect height, maturity, grain qualities or resistance. The task of hybrid development has gaining moment with the strong collaborative research with INTSORMIL and other national and international research programs. In the recent efforts research aiming at studying the digestibility, drought and striga tolerance of the introduced hybrids are undertaking. Meanwhile, hybrid development activities using male sterile female lines found to have better adaptation and locally adapted and high yielding male parents are being conducting. So far four hybrids found to be better performing in the drier areas were identified and included in the verification trial.

2.3. Heterosis

Heterosis is known as “hybrid vigor” which is usually maximized when we cross individuals that are not genetically related. The term heterosis in sorghum was first reported by Conner and Karper (1927). Sorghum is the first ever self-pollinated cereal staple crop in which heterosis has been commercially exploited using cytoplasmic-nuclear male-sterility (CMS) mechanism to improve productivity. This system was first described in sorghum by Stephens and Holland (1954). Since then several researchers have reported significant increases in yield due to heterosis in sorghum (Pedersen *et al*., 1998). Even though heterosis is seen in plant species, its level of expression is usually variable, depending on the crop and its natural mode of reproduction as well as its natural level of heterozygosity. Heterosis can be expressed as mid parent heterosis (MPH) and standard heterosis (SCH). MPH is the performance of the offspring compared with the average performance of the parents. SCH is the performance of the offspring compared with the best standard check. Out of the two methods of measuring heterosis, the SCH is the most important to breeders. A better performance of hybrids, such as yield increase or number of seeds, is only meaningful if it has increased value over the best standard check.

In sorghum, Quinby (1963) reported that heterosis in sorghum is expressed in the form of increased grain and biomass yields, earlier flowering and maturity, increased plant height and larger stems and panicles. This implies that heterosis was particularly effective in increasing cell number during floral initiation and spikelets formation leads to more seeds per head of sorghum.

Increased numbers of kernels per panicle and seed weight have been reported as major factors contributing to heterosis in grain yield (Blum, 1970; Kambal and Abu-El-Gasim, 1976). This, in turn, results from the fact that panicle development in the hybrid initiated earlier and develops faster than the parents. Blum (1970) reported that heterosis was manifested for plant height but not for tillering and leaf area index. Similarly, Blum *et al.* (1990) also observed a significant heterosis for biomass, grain yield per plant, and grain number per panicle. However, no heterosis was observed for harvest index, signifying that heterosis in grain yield was due to heterosis in biomass. From the above results, it was concluded that the hybrid do not show heterosis for leaf area index and have shorter durations than the parents. This indicates that heterosis in biomass may be due to greater net photosynthesis rate per unit leaf area and time. These observations are in agreement with those by Sinha and Khanna (1975) and suggest that the greater sink size (large panicle) in the hybrid may explain some of the observed increase in photosynthesis in hybrids over their parents. Bhatt *et al.* (1980) observed heterosis for chlorophyll and ascorbic acid turnover, suggesting that a well coordinated system incorporating photosynthetic efficiency and nitrate assimilation may be associated with the manifestation of hybrid vigour in sorghum.

Blum *et al*. (1990) also observed greater carbon exchange rate (CER) in hybrids than their respective parents especially under conditions favoring high CER. Blum (1989) also reported that hybrids fixed more carbon dioxide per unit leaf area over a wider temperature range than their parental lines. This suggests that the stable carbon exchange rate over wide range of temperature in hybrids was associated with greater stomatal conductance and transpiration. However, under extreme stress conditions, the hybrid performance depends on its genetic background more than on heterosis (Blum *et al*., 1990).

Maturity, height and stay green exhibited heterosis with estimates of mid-parent heterosis varying from -1 to -6% for maturity and 5 to 19% for height (Wenzel, 1998). Heterosis was also observed for absolute green leaf area duration and this trait is found to be highly correlated with stay green (Van Oosterom *et al*., 1996). Rana and Murty (1978) reported a significant negative heterosis for protein percentage and positive heterosis for lysine in grain sorghum. This suggested that crosses with high protein were low in lysine, while high lysine crosses were generally low in protein content.

Although heterosis is observed in plant species, its level of expression is usually variable, depending on the crop and its natural mode of reproduction as well as its natural level of heterozygosity (Duvick, 1999). The extent of heterosis was affected by the specific parental combination and their genetic divergence (Li *et al*., 1998; Moll *et al*., 1965). However, Joshi and Vashi (1992) reported that genetic divergent was not found to be correlated with geographic diversity.

Sorghum is naturally a self-pollinating crop, and hence, it apparently has low deleterious recessive genes load. This might lead to the assumption that sorghum hybrids exhibit less heterosis for yield than maize hybrids. A significant positive correlation has been reported between whole genome heterozygosity, yield, and plant height in sorghum. However, maturity is noted to be negatively correlated with whole genome heterozygosity and seems not to be associated with stay green (Jordan *et al*., 2003). Similarly, these authors reported significant correlation between heterozygosity, yield, and height only for five of the ten linkage groups.

Yield of inbred line per se is poor indicator of hybrid performance in sorghum. According to the study by Duvick (1999), variation in average heterozygosity explained only 18% of the variation for grain yield, suggesting that average heterozygosity is of limited use in the prediction of hybrid performance. However, 51% of the variation in grain yield was explained when heterozygosity across linkage groups was considered as a predictor (Jordan *et al*., 2003). These author further report that variation in genetic distance between parental lines for yield and plant height across linkage groups explained 38% of the variation in hybrid yield, signifying the promising potential of parental diversity across linkage groups.

In inbred lines, heterosis is defined the sum of the dominance deviations of those loci that have different alleles in the two lines (Falconer, 1989). When the association of genetic divergence and heterosis is found to be significant, it is advisable to use genetic divergence as a solid criterion for parental selection and, consequently, for the development of heterotic hybrids (Dias and Resende, 2001 cited by Dias *et al*., 2004).

Conditions that affect the use of genetic divergence as a criterion for parental selection includes strong selection pressure that increases genetic similarity in a gene pool (Barbosa *et al*., 2003), gene pool with a narrow genetic base (Maroof *et al*., 1997), lack of linkage disequilibrium (Charcosset *et al*., 1991), epistasis (Boppenmaier *et al*., 1992), genotype-environmental interaction (Dias *et al*., 2003) and lack of linkage between genes controlling the trait and the markers used (Bernardo, 1992).

Doggett (1961) reported the consistent performance of sorghum hybrids over a range of environments. Yield advantage of 50 to 100% of sorghum grain has been reported in hybrids as compared to farmers' local variety over a range of environments in India (Rao, 1962). This kind of superiority of in performance of hybrids over their parents is attributable mainly to the increased number of grains per panicle and large root system (Quinby, 1974). A good example for this superior performance comes from the first hybrids in India which showed a yield advantage of 40% over the local varieties. The advantage was more pronounced under severe moisture stress conditions.

2.4. Combining Ability

Combining ability studies gives information about general combining ability of parents and specific combining ability of hybrids. Information about general and specific combining ability with respect to yield and other component traits is thus useful in production of superior hybrids by means of selecting hybrid parents having better *per se* performance. Combining ability analysis also reveals the relative magnitude of the variances that means general combining ability variance and specific combining ability variance, which in turn provide information on the gene action, for the character being studied. This knowledge helps for further improvement of parental lines and guides the breeder either to follow heterosis breeding or population improvement program.

Combining ability of inbred lines is the ultimate factor determining future usefulness of the lines for hybrids (Hallauer and Miranda, 1988). The concept was refined by Sprague and Tatum (1942) to produce two expressions, general combining ability and specific combining ability. They called the additive portion of genotypic variance general combining ability (GCA), determined by mean hybrid performance of a determined line. The non-additive portion was the specific combining ability (SCA), a measure for cases where some hybrid combinations are better, or worse, than expected based on mean performance of the lines evaluated. They defined SCA as those instances in which certain hybrid combinations are either better or poorer than would be expected on the average performance of the parent inbred lines included in the crosses. Specific combining ability is associated with deviations from additive effects caused by dominance and epistasis.

General combining ability was also defined as the average performance of a line in a hybrid combination, when expressed as a deviation from the overall mean of all its crosses (Falconer, 1989). These deviations can be positive or negative. A positive deviation can be favorable or unfavorable, depending on the trait under consideration. Positive deviation for yield is desirable as this indicates high yielding potential. On the contrary, positive high values on ear rots and foliar disease ratings would not be desirable. Negative GCA values on anthesis date are more desirable for selection of early maturing combinations.

General combining ability tests are used for preliminary screening of lines from a large number of lines in a breeding program. Lines with poor GCA are discarded. GCA estimates can also be used in genetic studies to identify the type of gene action governing traits of interest. A high GCA estimate is indicative of additive gene action (Hallauer and Miranda, 1988).

Any particular cross has an expected value, which is the sum of the general combining abilities of its two parental lines. The cross may deviate from the expected value to a greater or lesser extent and this deviation is called the specific combining ability (SCA) of the two lines in combination (Falconer, 1989). SCA is used to indicate the value of superior genotype combinations. The SCA measurement represents the final stage in the selection of inbred lines as it identifies specific inbred combinations to use in hybrid formation (Hallauer and Miranda, 1988).

Specific combining ability estimates are also used in genetic studies to identify the type of gene action governing the traits of interest. A high SCA measure indicates non-additive gene action. In addition, SCA estimates can be used to determine heterotic relationships among different genotypes. As an example, if a line, A, gives a large positive SCA estimate for yield, when crossed to line B, but a large negative SCA estimate, when crossed to line C, line A is in the same heterotic group with line C but different group with line B. Lines from different heterotic groups which give high positive SCA estimates are said to be complementary to each other (Hallauer and Miranda, 1988). General combining ability and specific combining ability estimates are dependent on the particular set of materials (inbred lines, populations or varieties) included in the test, and therefore any new germplasm introduced in a breeding programme have to be tested for GCA and SCA (Hallauer and Miranda, 1988).

According to Jensen *et al.* (1983), test crossing is the best method for the identification of the best combining elite inbred lines. Earlier studies have also indicated that GCA is relatively more important for days to anthesis, plant height and percentage dry matter while SCA is most important for protein (Ross *et al*., 1979). This implies that additive gene action is more important for days to anthesis, plant height, percentage dry matter and biomass. Similarly, analyses of combining ability for protein and lysine content indicated that both additive and non-additive variation have been proved to be important for protein, while non-additive variation is predominantly important for lysine (Rana and Murty, 1978).

3. MATERIAL AND METHODS

3.1. Description of the Study Site

The experiment was conducted during 2010/11 cropping season at Sirinka Agricultural Research Center Kobo trial site. Kobo is situated in the dry land areas of Ethiopia characterized by low amounts of rainfall with erratic distribution. It is located at latitude of 12^0 08' 21''N and longitude 39^0 38' 21''E with an altitude of 1500 m.a.s.l. The ten years mean annual rainfall of the trial site is 668mm with a mean maximum and mean minimum temperature of 31^0C and 15^0C, respectively. The dominant soil type of the area is clay loam with a pH of 6.5 (SARC, 2009).

3.2. Experimental Materials

The experimental material comprised of eight cytoplasmic male sterile lines (female parents) of sorghum [*Sorghum bicolor* (L.) Moench] namely P-9529A, P-9534A, P-9532A, BON34A, P-851015A, P-851063A, P-850341A and M90950A, obtained from Perdue University, and four testers/restorers (male parents) namely WSV387, 98MW 6002, PDL 984928 and ICSR 161 as well as two standard checks i.e. P9501xICSR-14 and ICSA21xICSR-50 , obtained from MARC, each of which were selected based on performance and adaptation to moisture stress environments. These materials were planted under rain fed condition (Table 1). The cytoplasmic male sterile lines (line-A), their maintainer line (line-B) were used to eliminate the effect of male sterility for seed yield. The parent of the developed CMS lines and restorers were selected for their desirable characters including head size, plant height, early maturity, high yield and drought tolerance (Taye, personal communication). The eight CMS lines were crossed with the four restorers/testers in field experiment at Worer Agricultural Research Center in a line x tester fashion during spring 2009 cropping season to generate F_1s. Female lines, testers and F_1s were maintained at Melkassa Agricultural Research Center.

Table 1. Pedigree of the male and female parents and their crosses used in combining ability studies at Kobo , Ethiopia in 2010/11

Entry #	Pedigree	Seed source	Entry #	Pedigree	Seed source
1	P-9529A x WSV387	2010MW ISH Purdue 11x1#34	24	P-851063A x ICSR 161	2010MW ISH Purdue 16x4#57
2	P-9529A x 98MW 6002	2010MW ISH Purdue 11x2#35	25	P-850341A x WSV387	2010MW ISH Purdue 17x1#58
3	P-9529A x PDL 984928	2010MW ISH Purdue 11x3#36	26	P-850341A x 98MW 6002	2010MW ISH Purdue 17x2#59
4	P-9529A x ICSR 161	2010MW ISH Purdue 11x4#37	27	P-850341A x PDL 984928	2010MW ISH Purdue 17x3#60
5	P-9534A x WSV387	2010MW ISH Purdue 12x1#38	28	P-850341A x ICSR 161	2010MW ISH Purdue 17x4#61
6	P-9534A x 98MW 6002	2010MW ISH Purdue 12x2#39	29	M90950A x WSV387	2010MW ISH Purdue 18x1#62
7	P-9534A x PDL 984928	2010MW ISH Purdue 12x3#40	30	M90950A x 98MW 6002	2010MW ISH Purdue 18x2#63
8	P-9534A x ICSR 161	2010MW ISH Purdue 12x4#41	31	M90950A x PDL 984928	2010MW ISH Purdue 18x3#64
9	P-9532A x WSV387	2010MW ISH Purdue 13x1#42	32	M90950A x ICSR 161	2010MW ISH Purdue 18x4#65
10	P-9532A x 98MW 6002	2010MW ISH Purdue 13x2#43	33	WSV 387	**2010MW R lines 1#**
11	P-9532A x PDL 984928	2010MW ISH Purdue 13x3#44	34	98MW 6002	**2010MW R lines 2#**
12	P-9532A x ICSR 161	2010MW ISH Purdue 13x4#45	35	PDL 984928	**2010MW R lines 3#**
13	BON34A x WSV387	2010MW ISH Purdue 14x1#46	36	ICSR 161	**2010MW R lines 4#**
14	BON34A x 98MW 6002	2010MW ISH Purdue 14x2#47	37	P-9529B	**2010MW A & B Lines #9B**
15	BON34A x PDL 984928	2010MW ISH Purdue 14x3#48	38	P-9534B	**2010MW A & B Lines #7B**
16	BON34A x ICSR 161	2010MW ISH Purdue 14x4#49	39	P-9532B	**2010MW A & B Lines #18B**
17	P-851015A x WSV387	2010MW ISH Purdue 15x1#50	40	BON34B	**2010MW A & B Lines #19B**
18	P-851015A x 98MW 6002	2010MW ISH Purdue 15x2#51	41	P-851015B	**2010MW A & B Lines #20B**
19	P-851015A x PDL 984928	2010MW ISH Purdue 15x3#52	42	P-851063B	**2010MW A & B Lines #21B**
20	P-851015A x ICSR 161	2010MW ISH Purdue 15x4#53	43	P-850341B	**2010MW A & B Lines #22B**
21	P-851063A x WSV387	2010MW ISH Purdue 16x1#54	44	M90950B	**2010MW A & B Lines #23B**
22	P-851063A x 98MW 6002	2010MW ISH Purdue 16x2#55	45	P9501 x ICSR-14	08 Seed inc. (standard check)
23	P-851063A x PDL 984928	2010MW ISH Purdue 16x3#56	46	ICSA 21 x ICSR-50	08 Seed inc. (standard check)

3.3. Experimental Design and Trial Management

The experimental materilas were planted in randomized complete block design (RCBD) with three replications. During sowing, the seeds were manually drilled into 1- row plots of 5 m length, spaced 0.75 m apart. At approximately 20 days after sowing the seedlings were thinned to 0.15 m between plants. The data were collected from the whole plot area for grain yield (kg ha^{-1}), above ground dry matter (kg ha^{-1}), harvest index (%) seedling vigor (scored on a 1–5 scale, where 1 = highly vigorous and 5 = very low vigor), time to 50% emergence (days), time to flowering (days), time to maturity (days) and number of productive tillers per plant; and randomly selected five plants were used for panicle length (cm), panicle yield (gm), panicle weight (gm), 1000-seed weight (gm), plant height (cm), panicle exertion (cm), number of green leaves 95 days after planting (Haussmann *et al.,* 1999). Phosphorus and nitrogen fertilizers were applied at the recommended rates of 46 kg P_2O_5 ha^{-1} and 54 kg nitrogen ha^{-1} in the form of diammonium phosphate and urea, respectively. The plots were weeded as frequently as needed. Other management practices were applied uniformly to all plots.

3.4. Data Collected

The data were recorded on the following growth and phenological traits and yield and yield components:

3.4.1. Growth and phenological traits

The major phenological and growth traits thought to be associated with drought tolerance were recorded using standard procedures (Taye, 2006). These include:

1. **Days to 50% emergence** – this is the time between planting and fifty percent emergence in a plot.
2. **Seedling vigor** – this is a subjective measurement of plant vigor scored using a 1-5 scale with score "1" means highly vigorous and "5" means very low vigor.
3. **Days to 50% flowering** – the time between days to emergence until 50% of the plants in a plot reached half-bloom stage.
4. **Days to 50% maturity** – the time from emergence until the grains from the main shoot reached to the black layer stage.
5. **Plant height (cm)** – the length from the base of the plant to the tip of the panicle.
6. **Panicle exertion (cm) –** the length between the final (the most top) node up to the base of the panicle.
7. **NGL (95 days)** - Number of green leaf per plant counted at 95 days after planting as a measure of stay green trait (Haussmann *et al.,* 1999).

3.4.2. Yield and yield components

These are plant attributes directly related to crop yield (Taye, 2006). Depending on the time of onset of drought, some yield components may be seriously affected while others remain normal. The important yield related traits considered in this study were:

1. **Number of productive tillers** – the average number of tillers that bear grain per plant.
2. **Panicle length (cm)** - the average length of five randomly selected plants from the base of the panicle to the tip.
3. **Panicle weight (gm)** – the average weight of individual panicle as measured using five representative samples in a plot.
4. **1000 kernel weight (gm)** – the average weight of one thousand counted kernels obtained from a composite grain sample harvested from five representative panicles.
5. **Panicle yield (gm)** – the yield obtained by threshing five representative panicles from a plot.
6. **Stand count after anthesis**– the number of head bearing shoots from 3.75 m^2 area of the plot.
7. **Grain yield (kg)** – this is the total grain weight harvested from 3.75 m^2 area of the plot.
8. **Above ground dry matter (Kg)** – this is a sun dry weight of the above ground total plant biomass per 5 meter.
9. **Harvest index (%)**- this is a ratio of total grain yield to the biomass yield.

3.5. Statistical Analysis

AGROBASE 20 (Agronomix Software Inc. 1999) and Statistical Analysis Systems (SAS) version 9.1 were used for analysis of variance (ANOVA) as well as for GCA and SCA analysis. In the analysis the total genotypic variance were partitioned into variation due to lines, due to testers, and that due to the interaction between line and testers (Table 3 and 4).

3.5.1. Analysis of variance

The data recorded on the aforementioned traits were analyzed based on RCBD using the following linear additive model as outlined by Snedecor and Cochran (1980).

$$Y_{ijk} = \mu + L_i + T_j + s_{ij} + \varepsilon_{ijk}$$

Where Y_{ijk} = the observed phenotype value from each experimental units

μ = the population mean

L_i = the effect of the i^{th} parental line

T_j = the effect of the j^{th} tester line

LxT_{ij} = is the interaction effect of the cross between the i^{th} line and j^{th} tester

ε_{ijk} = is the error term associated with each observation

Thereafter, estimates of combining ability were computed using "Line x Tester Analysis" as given by Kempthorn (1957). The estimate of general combining ability (GCA) effects of parents, and specific combining ability (SCA) effects of hybrids as well as their corresponding standard error were obtained as under. The GCA and SCA were used for the estimation of additive (σ_A^2) and dominance (σ_D^2) genetic variance.

3.5.2. Estimation of general combining ability effects

a) Lines: $GCA_i = \left(\frac{y_{i.}}{rt}\right) - \left(\frac{Y}{rlt}\right)$

b) Testers: $GCA_J = \left(\frac{y_{.j}}{rl}\right) - \left(\frac{Y}{rlt}\right)$

Where, GCA_i and GCA_j = the general combining ability of the i^{th} line and j^{th} tester, respectively.

$y_{i.}$ and $y_{.j}$ = the grand total of the i^{th} line mated with all testers and the j^{th} tester mated with all lines, respectively

Y = the grand total of all crosses

r = the number of replication

l = the number of lines

t = the number of testers

3.5.3. Estimation of specific combining ability effects

$$SCA_{ij} = \left(\frac{y_{ij}}{r}\right) - \left(\frac{y_{i.}}{rt}\right) - \left(\frac{y_{.j}}{rl}\right) + \left(\frac{Y}{rlt}\right)$$

Where SCA_{ij} = the specific combining ability effect of ij^{th} cross

y_{ij} = the grand total for cross i^{th} line and the j^{th} tester

$y_{i.}$ = the grand total of lines for the ij^{th} cross

$y_{.j}$ = the grand total of testers for the ij^{th} cross

Y = the grand total of all crosses

r = the number of replication

l = the number of lines

t = the number of testers

The GCA and SCA were used for the estimation of additive (σ_A^2) and dominance (σ_D^2) genetic variance as follows.

σ_{GCA}^2 was calculated as:

$$\sigma_{GCA}^2 = Cov\,(HS)$$

$$Cov\,(HS) = \tfrac{1}{4}\sigma_A^2 + \tfrac{1}{16}\sigma_{AA}^2 + \tfrac{1}{64}\sigma_{AAA}^2 + \cdots + etc,\ when\ F = 0$$

$$Cov\,(HS) = \tfrac{1}{2}\sigma_A^2 + \tfrac{1}{4}\sigma_{AA}^2 + \tfrac{1}{8}\sigma_{AAA}^2 + \cdots + etc,\ when\ F = 1$$

Where F is coefficient of inbreeding

Similarly, σ_{SCA}^2 was calculated as:

$$\sigma_{SCA}^2 = Cov\,(FS) - 2Cov\,(HS)$$

$$Cov\,(FS) = \tfrac{1}{2}\sigma_A^2 + \tfrac{1}{4}\sigma_D^2 + \tfrac{1}{8}\sigma_{AA}^2 + \tfrac{1}{8}\sigma_{AD}^2 + \tfrac{1}{16}\sigma_{DD}^2 + \cdots etc,\ when\ F = 0$$

$$Cov\,(PHS) = \sigma_l^2 = \tfrac{1}{4}\sigma_A^2 \quad and \quad Cov\,(MHS) = \sigma_t^2 = \tfrac{1}{4}\sigma_A^2$$

where PHS = parental half sib and MSH = maternal half sib

$$Cov(FS) = \sigma_D^2 + \tfrac{1}{2}\sigma_{AA}^2 + \tfrac{1}{2}\sigma_{AD}^2 + \tfrac{1}{4}\sigma_{DD}^2 + \cdots etc, \; when\, F = 1$$

$$Cov(FS) = \tfrac{1}{2}\sigma_A^2 + \tfrac{1}{4}\sigma_D^2$$

$$\sigma_{SCA}^2 = \left(\tfrac{1}{2}\sigma_A^2 + \tfrac{1}{4}\sigma_D^2\right) - 2\left(\tfrac{1}{4}\sigma_A^2\right) = \tfrac{1}{4}\sigma_D^2$$

3.5.4. Estimation of standard errors for combining ability effects

$$S.E. \quad (gca \;\; for\, line) = \sqrt{Me/r * t}$$

$$S.E. \quad (gca \;\; for\, tester) = \sqrt{Me/r * l}$$

$$S.E. \quad (sca \;\; for\, hybrid) = \sqrt{Me/r}$$

$$S.E. \quad (gi - gj)\, line = \sqrt{2Me/r * t}$$

$$S.E. \quad (gi - gj)\, tester = \sqrt{2Me/r * l}$$

$$S.E. \quad (Sij - Skl) = \sqrt{2Me/r}$$

Where Me = error mean square of the respective trait

r = replication

t = number of tester

l = number of line

Critical difference estimate is obtained by multiplying the respective standard error with table ‘‘t’’ value at error degrees of freedom. Respective critical difference values helps for testing the significance of combining ability effects and also to test the significance of differences between the effects. Combining ability variances and combining ability effects with respective standard errors were estimated for 16 traits for F_1 hybrids and parents.

3.5.5. Contribution of lines, testers and their interaction to the total variance

The contribution of lines, testers and their interaction out of hundred were determined by the following formula.

$$Contribution\ of\ line = \frac{SS(l)x100}{SS(Crosses)}$$

$$Contribution\ of\ tester = \frac{SS(t)x100}{SS(Crosses)}$$

$$Contribution\ of\ (lxt) = \frac{SS(lxt)x100}{SS(Crosses)}$$

Where $SS(l)$ = sum square of lines

$SS(t)$ = sum square of testers

$SS(lxt)$ =sum square of line x tester interaction

$SS(Crosses)$ = sum square of crosses

Table 2. Skeleton of ANOVA of combining ability

Sources of Variation	df	MS	Expectations
Replication	r-1		
Genotypes (G)	g-1		
Parents (P)	p-1		
Crosses (LxT)	h-1		
Checks	c-1		
Checks Vs Parents Vs Crosses	2		
Parent Vs Crosses	1		
Lines /Females(L)	l-1	MS l	$\sigma^2 + rCov(FS) - 2Cov(HS) + rlCov(HS)$
Testers /Males (T)	t-1	MS t	$\sigma^2 + rCov(FS) - 2Cov(HS) + rtCov(HS)$
Line x Testers (L x T)	(l-1) (t-1)	MS lxt	$\sigma^2 + rCov(FS) - 2Cov(HS)$
Error	(r-1)(g-1)	MS e	σ^2

3.5.6. Estimation of Heterosis

Mid- parent heterosis for yield or other characters were used to estimate the hybrid advantage compared to the mean of the parents. This provides an estimate of the mean directional dominance of allele for a given character. Similarly, standard heterosis was used to estimate genetic gain or superiority of the hybrids to standard varieties in a given area. The mid-parent heterosis (MPH) and standard heterosis (SCH) in percent were calculated for the trait that showed significant differences between genotypes (crosses and parents) following the method suggested by Falconer and Mackay (1996).

3.5.6.1. Mid-parent heterosis (%)

Mid- parent heterosis computed as:

$$MPH(\%) = \left(\frac{F_1 - MP}{MP}\right) x\,100\,, where\ MP = \left(\frac{P_1 + P_2}{2}\right), in\ which\ P_1\ and\ P_2\ are\ mean\ of\ parent\ 1\ and\ 2,\ respectively$$

F_1 = the mean of F_1 hybrid performance

3.5.6.2. Standard heterosis (%)

Standard heterosis computed as:

$$SCH(\%) = \left(\frac{F_1 - SC}{SC}\right) x\,100$$

Where SC = mean of the standard check (Ethiopian Sorghum Hybrid I)

F_1 = the mean of F_1 hybrid performance

The standard error of the difference for heterosis was calculated as follows:

$$\text{SE (m) for mid parent} = \pm\sqrt{\frac{3Me}{2r}}$$

$$\text{SE (m) for standard check} = \pm\sqrt{\frac{2Me}{r}}$$

SE (d) for mid parent = SE(m) for mid parent x t value at error degree of freedom. SE (d) for standard check = SC(m) for standard parent x t at error degree of freedom. Test of significance for heterosis was done by comparing (F_1-Mid Parent) with SE(d) for mid parent and (F_1- Standard check) with SE (d) for standard /economic heterosis.

Where, SE(m) is standard error of the mean, SE(d) is standard error of the difference, Me is error mean square and r is the number of replications. The minimum value were considered as better parent in the case of days to 50% emergency, flowering, maturity and seedling vigor.

4. RESULTS AND DISCUSSION

Mean square values of seven growth and phenological traits and nine yield and yield components of sorghum from analysis of variance (ANOVA) are presented in Appendix Table 3 and Table 4, respectively. Highly significant differences ($P \leq 0.01$) existed among sorghum genotypes for all growth and phenological traits as well as yield and yield components, indicating wide genetic diversity among genotypes. The sum of squares of genotypes for these traits were further partitioned in to sum of squares pertaining to parents, crosses, checks, parents vs. crosses and checks vs. parents vs. crosses. There were highly significant ($P \leq 0.01$) differences among parents, crosses, checks, parents vs. crosses and checks vs. parents vs. crosses for all phenological and growth traits except parents vs. crosses which was non-significant for days to emergency. For stand count after anthesis there was non-significant difference in the checks vs. parents vs.crosses component. Non-significant results were also existed for above ground dry matter in the checks and parents vs. crosses as well as for harvest index in the checks and checks vs. parents vs. crosses component. The significance of parents vs crosses mean squares for all traits except days to emergence and above ground dry matter, reflecting the average heterotic effect for these traits, their magnitudes were large compared with those for all sources of variation. Similarly the sums of squares for crosses were further partitioned into sum of squares for lines, testers and line x tester components. Mean square due to testers was higher than the female lines for days to emergence, seedling vigor, days to maturity, plant height, panicle exertion, number of green leaf per plant, panicle weight, thousand kernel weight, panicle yield, grain yield, above ground dry matter and harvest index. This larger tester mean square for the respective trait indicates that the great differences among the testers for these traits. While the mean square among female lines were larger than among testers for the rest of the traits, indicating wide differences among female lines for these traits. Similar results were obtained by Amir (1999), Ali (2000) and Kenga *et al.* (2004)

Highly significant differences existed among the lines for all growth and phenological traits and yield and yield components except days to 50% emergency in the growth and phenological traits as well as stand count after anthesis and above ground dry matter in the yield and yield components. Highly significant differences were found among testers except days to 50% flowering in the growth and phenological traits and panicle length and stand count after anthesis in the yield and yield components. However, line x tester interaction was highly significant ($P \leq 0.01$) for all the growth and phenological traits as well as yield and yield components. These results are in agreement with Hovny *et al.* (2005), Hovny and El-Dsouky (2007) and Abd-El-Mottaleb (2009) in their respective studies.

Highly significant differences among sorghum genotypes, parents, crosses, checks, lines and testers for days to 50% emergence, seedling vigor, days to 50% flowering, days to 50% maturity, plant height (cm), panicle exertion (cm) and number of green leaf per plant in the growth and phenological traits and number of productive tillers, panicle length, panicle weight, 1000 kernel weight(gm), panicle yield(gm), stand count after anthesis, grain yield (t ha^{-1}), above ground dry matter (t ha^{-1}) and harvest index (%) were observed.

4.1. Performance of Lines and Testers

The cytoplasmic male sterile (CMS) lines and testers used in the present study provided a wide range of expression for various characters as evident from Table 3 and 5 in the case of growth and phenological traits and Table 4 and 6 in the case of yield and yield components. In the growth and phonological traits of female lines days to emergency ranged from 6.00 (P-851063) to 8.00 (P-850341, P-9534) and averaged 7.04 where as days to emergency in the testers ranged from 6.00 (PDL 984928) to 8.00 (98MW 6002) and averaged 6.92. Not all seed that germinate will emerge from the seedbed. A host of biotic and abiotic seed and soil-related factors could drastically reduce emergence of germinating seed. Martin *et al.* (1935) demonstrated that both seedbed temperature and sowing depth affect the rate and time of emergence, independently of germination. Sorghum emergence was decreased appreciably as temperature was reduced from 20 to 15 ^{0}C, especially at a sowing depth of 3cm or more.

Minimum number of seedling vigor in the female lines was taken by P-851063B (5.00) and maximum number of seedling vigor was taken by M9095 (1.00). In the case of testers, minimum number of seedling vigor was taken by PDL 984928 (5.00) and maximum number of seedling vigor was taken by WSV 387 (2.33). Seedling vigor averaged 3.00 in the female linens where as 4.00 in the testers. Days to 50% flowering in the female lines ranged from 68.33 (P-9534, P-851015 and P-851063) to 70.00 (M90950) and averaged 68.79. In the case of testers days to 50% flowering ranged from 68.33 (98MW6002) to 76.00 (WSV 387) and averaged 71.08. Days to 50% maturity in the female lines ranged from 104.33 to 112.33 for BON 34 and P-9534 respectively where as days to 50% maturity in the testers ranged from 104.33 to 111.33 for WSV 387 and PDL 984928 respectively. From their averaged performance numerically fewer days to maturity were taken by female lines (107.13) than testers (108.33). Plant height ranged from 101.67 to 131.67 cm for P-851063 and P-9529 respectively in the female lines where as in the testers ranged from 121.67 to 154.33 cm for 98MW 6002 and WSV 387 respectively. Female lines P-9529 and P-850341 produced minimum and maximum panicle exertion of (1.33 cm) and (17.00 cm) respectively. Similarly testers 98MW6002 and ICSR 161 produced minimum and maximum panicle exertion of (0.67 cm) and (6.00 cm) respectively. Number of green leaf per plant at 95 days among female lines gave highest and lowest values of 8.67 (M90950) and 5.00 (BON34). Similarly testers gave highest and lowest values of 10.33 (PDL 984928) and 6.33 (WSV 387). Female lines P-851063 had the maximum number of productive tillers per plant (10.00) where as P-9529 had the minimum number of productive tillers per plant (1.67). In the case of testers the maximum and minimum number of productive tillers per plant was observed by PDL 984928 (1.33) and ICSR 161 (5.67) respectively. Panicle length (cm) in the female lines ranged from 23.67 (P-851063) to 29.33 (P-9529 and M90950) where as in the testers it ranged from 23.33 (98MW6002) and 29.00 (PDL 984928). Among female lines panicle weight ranged from 67.43 gm (P-851015) to 115.87gm (P-9529). Similarly in the case of testers it ranged from 93.61 gm (98MW6002) to 141.27 gm (PDL 984928). Thousand kernel weights among female lines gave highest and lowest values of 32.80 gm (P-9534) and 19.47 gm (P-851063) and testers gave highest and lowest values of 35.60 gm (PDL 984928) and 22.63 gm (ICSR161).

The sorghum female line M90950 on average possessed higher panicle yield with values of 89.90 gm and female parental line P-9532 on average possessed lowest panicle yield (60.00 gm) where as in the case of testers PDL 984928 possessed higher panicle yield with values of 114.93 gm and 98MW6002 on the other hand possessed lower panicle yield with values of 74.30 gm. Numerically higher values of panicle yield recorded by testers than female lines. Among female lines minimum stand count after anthesis recorded by P-851015 with values 28.67 and the maximum stand count after anthesis was taken by P-850341 with values 35.33 where as in the case of testers both WSV 387 and 98MW6002 were taken the lowest stand count after anthesis (29.33) and PDL 984928 was taken the maximum stand count after anthesis with values 38.00. From female lines maximum grain yield was given by M90950 with values of 3.52 t ha^{-1}. However, the minimum grain yield of 1.82 t ha^{-1} was exhibited by female parental lines P-9532. Among testers, the maximum grain yield was given by PDL 984928 with values 4.38 t ha^{-1} and the minimum grain yield of 2.57 t ha^{-1} was given by tester 98MW6002. In the experiment conducted female line M90950 and P-9534 gave the maximum (30.71 t ha^{-1})

and minimum 21.67 t ha^{-1}) above ground dry matter yield. Among testers maximum above ground dry matter yield was observed by PDL984928 (41.07 t ha^{-1}). However, tester WSV 387 and 98MW6002 gave the minimum above ground dry matter yield of 24.89 t ha^{-1}. Harvest index in female lines ranged from 6.95 to 16.18% for P-9532 and P-9534, respectively. In the case of testers it ranged from 10.66 to 13.54% for 98MW6002 and WSV 387, respectively. Harvest index in sorghum may vary from about 6% in tall and late maturing African landraces (Blum *et al.,*1991) to about 50% in modern temperate hybrids (Prihar andStewart,1991)

Table 3. Mean values of phenological and growth traits of eight sorghum lines (female parents) tested at Kobo in 2010/11

Female parents (Lines)	Days to 50% emergence	Seedling vigor (1-5)	Days to 50% flowering	Days to 50% maturity	Plant height (cm)	Panicle exertion (cm)	Number of green leaf per plant
P-9529B	7.00	2.33	69.00	105.67	131.67	1.33	6.00
P-9534B	8.00	4.67	68.33	112.33	120.33	5.00	5.67
P-9532B	6.67	1.33	69.67	105.00	110.00	9.00	6.67
BON34B	7.33	3.67	68.00	104.33	104.33	2.33	5.00
P-851015B	6.33	4.67	68.33	107.67	126.00	10.00	6.33
P-851063B	6.00	5.00	68.33	106.67	101.67	11.00	7.67
P-850341B	8.00	1.33	68.67	105.67	130.33	17.00	7.33
M90950B	7.00	1.00	70.00	109.67	114.67	8.00	8.67
Mean	7.04	3.00	68.79	107.13	117.38	7.96	6.67
CV (%)	5.25	17.25	0.70	0.92	1.90	11.99	9.33
LSD 5%	0.648	0.906	0.844	1.730	3.909	1.671	1.089
LSD 1%	0.899	1.258	1.171	2.402	5.425	2.320	1.512

Table 4. Mean values of yield and yield components of eight sorghum lines (female parents) tested at Kobo in 2010/11

Female parents (Lines)	Number of productive tillers /plant	Panicle length(cm)	Panicle weight (gm)	1000 kernel weight (gm)	Panicle yield (gm)	Stand count after anthesis	Grain yield (t ha^{-1})	Above ground dry matter (t ha^{-1})	Harvest index (%)
P-9529B	1.67	29.33	115.87	26.13	86.50	32.67	3.09	26.67	11.65
P-9534B	4.33	29.00	74.75	32.80	64.27	32.00	3.51	21.67	16.18
P-9532B	2.33	26.33	72.33	20.67	60.00	29.00	1.82	26.11	6.95
BON34B	3.33	26.00	94.69	26.67	71.70	30.33	2.64	28.45	9.24
P-851015B	6.67	28.67	67.43	21.53	60.50	28.67	2.27	22.73	10.00
P-851063B	10.00	23.67	89.70	19.47	72.60	32.00	2.22	22.49	9.85
P-850341B	6.67	26.33	81.61	21.00	71.67	35.33	2.90	25.65	11.33
M90950B	7.67	29.33	101.13	26.87	87.90	31.67	3.52	30.71	11.79
Mean	5.33	27.33	87.19	24.39	71.89	31.46	2.75	25.56	10.87
CV	13.80	3.08	2.18	9.57	6.54	11.11	15.61	10.92	18.47
LSD 5%	1.289	1.474	3.335	4.087	8.229	6.120	0.751	4.888	3.516
LSD 1%	1.789	2.046	4.629	5.672	11.42	8.495	1.042	6.784	4.880

Table 5. Mean values of phenological and growth traits of four sorghum testers (male parents) tested at Kobo in 2010/11

Male parents (Testers)	Days to 50% emergence	Seedling vigor (1-5)	Days to 50% flowering	Days to 50% maturity	Plant height (cm)	Panicle exertion (cm)	Number of green leaf per plant
WSV 387	7.00	2.33	76.00	104.33	154.33	1.00	6.33
98MW 6002	8.00	4.67	68.33	110.33	121.67	0.67	7.67
PDL 984928	6.00	5.00	69.33	111.33	124.33	5.67	10.33
ICSR 161	6.67	4.00	70.67	107.33	150.33	6.00	7.00
Mean	6.92	4.00	71.08	108.33	137.67	3.33	7.83
CV	4.17	11.79	2.14	0.88	2.31	10.00	7.06
LSD 5%	0.577	0.942	3.034	1.913	6.344	0.667	1.104
LSD 1%	0.874	1.427	4.596	2.898	9.612	1.009	1.673

Table 6. Mean values of yield and yield components of four sorghum testers (male parents) tested at Kobo in 2010/11

Male parents (Testers)	Number of productive tillers /plant	Panicle length(cm)	Panicle weight (gm)	1000 kernel weight (gm)	Panicle yield (gm)	Stand count after anthesis	Grain yield (t ha^{-1})	Above ground dry matter (t ha^{-1})	Harvest index (%)
WSV 387	4.00	27.33	108.76	33.57	85.73	29.33	3.36	24.89	13.54
98MW 6002	4.67	23.33	93.61	29.03	74.30	29.33	2.57	24.89	10.66
PDL 984928	1.33	29.00	141.27	35.60	114.93	38.00	4.38	41.07	10.71
ICSR 161	5.67	25.33	103.00	22.63	80.50	30.00	3.16	26.13	12.08
Mean	3.92	26.25	111.66	30.21	88.87	31.67	3.37	29.24	11.75
CV	14.11	3.11	2.57	1.87	10.44	11.54	10.86	13.46	10.05
LSD 5%	1.104	1.631	5.730	1.127	18.529	7.303	0.730	7.862	2.359
LSD 1%	1.673	2.472	8.681	1.707	28.074	11.065	1.106	11.911	3.574

4.2. Performance of Hybrids

Mean performance of 34 hybrids including 2 hybrid checks investigated for their 16 plant traits in the line x tester analysis is given in Table 7 for growth and phenological traits as well as Table 8 for yield and yield components. The number of days to 50% emergency varied from 6.00 (for P-9529xICSR161, BON34xPDL984928, P-851015XWSV387, M90950xICSR161, P-850341xICSR161 and ICSA21xICSR-50) to 8.00 (for P-9532x98MW6002, P-851063xM90950xPDL984928 and P-9501xICSR-14) with an over all grand mean of 6.89 days. Eighteen hybrids emerged earlier and took less than 6.89 days to emerge. The range for seedling vigor was from 1.00 (for P-9529 x WSV387, P-9534 x WSV387, P-9532 x PDL 984928, BON34 x ICSR 161, P-851015 x WSV387, P-851063 x WSV387, P-850341 x WSV387 and P-850341 x ICSR 161) to 5.00 (for BON34 x WSV387, P-851063 x ICSR 161 and ICSA 21 x ICSR-50). Out of 34 hybrids seventeen hybrids were below the grand mean seedling vigor score. Days to 50% flowering was varied from 66.00 (P-850341 x ICSR 161) to 73.67 (ICSA 21 x ICSR-50). Twenty hybrids were below the grand mean number of days to flowering (68.83 days). The number of days to maturity ranged from 101.33 (P-9534 x WSV387) to 119.33 (ICSA 21 x ICSR-50). Plant height ranged from 114.87 cm (P-851063 x PDL 984928) to 204.00 cm (P-850341 x ICSR 161) with a grand mean of 161.00 cm. Sixteen hybrids were found less than the grand mean hybrid plant height. Variation for panicle exertion was recorded from 4.60 cm (P-9529 x WSV387) to 23.00 cm (P-851015 x WSV387) with a mean of 13.13 cm. Variation in number of green leaf per plant ranged from 3.33 (ICSA 21 x ICSR-50) to 7.60 (P-9534 x WSV387) with a grand mean of 5.62 green leaves per plant at 95 days after planting. The minimum number of productive tillers was 0.33 (P9501 x ICSR-14) and the maximum 6.00 (P-850341 x WSV387) with overall grand mean values of 1.98 productive tillers. Panicle length ranged from 25.00 cm (ICSA 21 x ICSR-50) to 32.00 cm (P9501 x ICSR-14) with grand mean values of 29.24 cm. Variation for panicle weight was recorded from 30.33 gm (P-851015 x 98MW 6002) to 152.13 gm (P-9532 x PDL 984928) with grand mean values of 109.00 gm. Out of 34 hybrids 20 were below the grand mean panicle weight.

Thousand kernel weight varied from 16.03 gm (P-851063 x PDL 984928) to 39.77 gm (P-851015 x WSV387) with grand mean values of 28.19 gm. Fourteen out of 34 crosses produced higher thousand kernel weight (Table 10). Panicle yield ranged from 71.17 gm (P-850341 x WSV387) to 134.26 gm (P-9534 x WSV387) with grand mean values of 92.71 gm. Maximum stand count after anthesis obtained in P-851015 x WSV387 (39.00) and minimum in P-850341 x PDL 984928 (29.33) with mean values of 34.24. Lowest (2.73 t ha^{-1}) and highest (5.51 t ha^{-1}) grain yield was observed in crosses (P-850341 x PDL 984928) and (P-851015 x WSV387) respectively with grand mean values of 3.63 t ha^{-1}. Only twelve hybrids gave more than 3.63 t ha^{-1} grain yield. The highest above ground dry matter yield of 33.60 t ha^{-1} was observed in the cross (P-9532 x PDL 984928) where as the lowest above ground dry matter yield 18.67 t ha^{-1} in the cross (P-851063 x PDL 984928) with mean values of 25.85 t ha^{-1}. Maximum harvest index was given by P-851015 x ICSR 161 with values of 23.42%. However, the minimum harvest index of 9.56% was exhibited by the cross P-851015 x 98MW 6002.

Table 7. Mean values of phenological and growth traits of thirty four sorghum crosses tested at Kobo in 2010/11

Crosses	Days to 50% emergence	Seedling vigor (1-5)	Days to 50% flowering	Days to 50% maturity	Plant height (cm)	Panicle exertion (cm)	Number of green leaf per plant
P-9529A x WSV387	7.67	1.00	69.33	107.00	151.20	4.60	5.63
P-9529A x 98MW 6002	6.33	3.00	68.33	106.33	142.73	6.00	4.03
P-9529A x PDL 984928	7.00	2.00	69.33	107.33	149.07	10.13	4.83
P-9529A x ICSR 161	6.00	2.33	68.67	106.33	172.93	17.07	5.10
P-9534A x WSV387	6.67	1.00	67.67	101.33	190.00	18.33	7.60
P-9534A x 98MW 6002	7.00	4.00	69.33	106.33	145.07	4.73	4.90
P-9534A x PDL 984928	7.33	4.67	69.33	106.67	116.00	13.87	5.83
P-9534A x ICSR 161	7.67	4.67	68.67	106.67	160.87	13.27	4.23
P-9532A x WSV387	6.67	1.67	69.67	107.33	168.27	7.13	5.97
P-9532A x 98MW 6002	8.00	4.67	69.00	107.33	143.53	8.93	5.37
P-9532A x PDL 984928	6.33	1.00	67.00	102.67	178.60	18.67	6.63
P-9532A x ICSR 161	6.67	4.33	68.33	106.00	178.93	13.67	4.83
BON34A x WSV387	6.67	5.00	71.33	107.33	147.00	6.53	4.63
BON34A x 98MW 6002	7.67	4.67	68.67	105.67	137.80	5.80	5.63
BON34A x PDL 984928	6.00	2.33	69.67	106.00	119.73	10.87	4.90
BON34A x ICSR 161	6.33	1.00	68.67	106.33	164.27	10.67	4.57
P-851015A x WSV387	6.00	1.00	68.33	103.00	202.67	23.00	6.93
P-851015A x 98MW 6002	7.00	3.00	68.67	106.33	161.20	12.87	4.70

Table 7. (Continued)

Crosses	Days to 50% emergence	Seedling vigor(1-5)	Days to 50% flowering	Days to 50% maturity	Plant height (cm)	Panicle exertion (cm)	Number of green leaf per plant
P-851015A x PDL 984928	7.33	4.67	68.33	105.67	125.47	10.93	5.23
P-851015A x ICSR 161	6.33	1.33	68.00	101.67	195.67	22.00	7.00
P-851063A x WSV387	6.33	1.00	67.67	103.00	162.53	11.00	6.33
P-851063A x 98MW 6002	7.67	4.67	68.00	106.00	166.87	12.33	5.83
P-851063A x PDL 984928	8.00	4.67	68.67	105.67	114.87	13.07	4.77
P-851063A x ICSR 161	6.67	5.00	70.00	106.67	179.67	12.93	5.23
P-850341A x WSV387	7.33	1.00	68.33	105.67	164.93	15.07	5.17
P-850341A x 98MW 6002	6.67	1.33	68.00	107.67	178.53	17.87	6.10
P-850341A x PDL 984928	6.67	2.00	69.00	107.67	154.73	11.93	5.77
P-850341A x ICSR 161	6.00	1.00	66.00	102.67	204.00	21.87	6.50
M90950A x WSV387	7.33	3.67	69.33	106.00	175.00	14.00	6.10
M90950A x 98MW 6002	7.00	2.33	68.67	106.67	145.33	9.87	4.50
M90950A x PDL 984928	8.00	3.33	70.00	106.67	155.93	11.60	6.50
M90950A x ICSR 161	6.00	1.33	67.67	102.00	200.67	21.00	6.33
P9501 x ICSR-14	8.00	4.00	69.00	107.33	173.33	20.67	6.67
ICSA 21 x ICSR-50	6.00	5.00	73.67	119.33	146.33	13.67	3.33
Mean	6.89	2.87	68.83	106.07	161.00	13.13	5.62
CV (%)	9.62	15.61	1.53	1.50	5.63	13.60	16.37
LSD 5%	1.081	0.699	1.722	2.596	14.778	2.911	1.499
LSD 1%	1.436	0.928	2.287	3.448	19.632	3.866	1.992

Table 8. Mean values of yield and yield components of thirty four sorghum crosses tested at Kobo in 2010/11

Crosses	Number of productive tillers	Panicle length(cm)	Panicle weight(gm)	1000 kernel weight(gm)	Panicle yield(gm)	Stand count after anthesis	Grain yield (t ha^{-1})	Above ground dry matter(t ha^{-1})	Harvest index(%)
P-9529A x WSV387	1.33	28.80	115.37	25.47	97.29	33.00	3.09	31.11	10.77
P-9529A x 98MW 6002	2.00	27.80	89.17	26.70	72.44	33.00	2.90	24.27	11.90
P-9529A x PDL 984928	1.00	31.00	110.89	29.17	86.15	34.83	3.48	25.51	13.56
P-9529A x ICSR 161	2.00	29.13	93.46	27.33	85.03	33.00	3.15	23.64	14.00
P-9534A x WSV387	1.00	31.33	149.90	36.50	134.26	37.00	4.69	33.60	14.36
P-9534A x 98MW 6002	1.33	30.60	111.93	26.67	95.03	31.67	3.26	29.24	11.30
P-9534A x PDL 984928	1.00	28.13	95.77	19.37	78.83	34.33	3.00	19.91	15.06
P-9534A x ICSR 161	2.00	30.07	95.63	27.80	83.41	32.33	3.15	22.40	14.19
P-9532A x WSV387	1.00	28.73	115.21	28.87	98.46	31.67	3.67	28.62	13.00
P-9532A x 98MW 6002	2.00	29.40	91.66	31.17	74.37	38.50	3.14	28.00	11.77
P-9532A x PDL 984928	1.00	31.00	152.13	33.17	131.30	37.50	5.34	33.60	16.01
P-9532A x ICSR 161	3.33	30.93	113.58	31.17	101.23	35.67	3.96	28.62	14.02
BON34A x WSV387	3.33	27.20	97.45	27.73	88.35	29.67	3.03	23.64	12.83
BON34A x 98MW 6002	3.00	30.13	115.88	30.00	99.35	32.67	3.42	29.87	12.20
BON34A x PDL 984928	4.67	28.60	98.97	20.50	76.97	34.50	2.97	20.53	14.65
BON34A x ICSR 161	4.67	28.93	91.33	26.83	79.17	36.50	3.45	23.64	14.63
P-851015A x WSV387	1.00	31.80	31.80	39.77	133.56	39.00	5.51	31.73	18.01
P-851015A x 98MW 6002	2.17	30.33	30.33	25.87	77.93	32.00	2.81	31.11	9.56

Table 8. (Continued)

Crosses	Number of productive tillers	Panicle length(cm)	Panicle weight(gm)	1000 kernel weight(gm)	Panicle yield(gm)	Stand count after anthesis	Grain yield (t ha^{-1})	Above ground dry matter(t ha^{-1})	Harvest index (%)
P-851015A x PDL 984928	1.00	28.87	103.68	21.47	90.35	33.50	3.43	22.40	15.30
P-851015A x ICSR 161	1.00	31.07	148.12	34.90	131.74	37.00	4.91	21.16	23.42
P-851063A x WSV387	1.00	28.47	116.68	30.43	84.57	34.00	4.64	23.64	19.71
P-851063A x 98MW 6002	1.67	28.80	90.72	26.83	75.92	34.17	3.16	28.00	11.72
P-851063A x PDL 984928	3.67	27.80	89.61	16.03	73.80	32.33	2.82	18.67	15.11
P-851063A x ICSR 161	1.00	29.20	98.88	27.57	85.35	31.67	3.24	26.13	13.50
P-850341A x WSV387	6.00	27.53	81.14	24.97	71.17	35.50	3.04	23.02	13.22
P-850341A x 98MW 6002	1.00	28.00	90.65	27.57	78.37	34.00	3.07	28.00	11.18
P-850341A x PDL 984928	3.67	28.47	90.59	24.47	79.11	29.33	2.73	27.38	10.21
P-850341A x ICSR 161	1.00	30.07	137.27	33.23	108.51	38.33	4.80	23.64	20.73
M90950A x WSV387	2.00	29.87	96.21	30.40	90.55	35.17	3.81	24.89	15.33
M90950A x 98MW 6002	1.00	28.20	99.59	27.70	87.65	34.67	3.63	23.64	16.15
M90950A x PDL 984928	1.17	27.60	113.86	27.10	98.75	34.50	3.88	26.13	14.84
M90950A x ICSR 161	1.00	28.73	98.93	30.83	93.33	36.33	4.55	22.40	20.75
P9501 x ICSR-14	0.33	32.00	148.31	33.73	121.83	35.00	4.55	28.59	15.96
ICSA 21 x ICSR-50	2.67	25.00	115.41	27.20	87.43	30.00	3.11	22.18	14.09
Mean	1.98	29.24	109.00	28.19	92.71	34.24	3.63	25.85	14.50
CV	17.52	4.31	11.77	10.22	13.80	7.44	11.64	20.45	19.98
LSD 5%	0.566	2.054	20.922	4.695	20.857	4.154	0.689	8.619	4.723
LSD 1%	0.751	2.728	27.794	6.238	27.708	5.519	0.915	11.451	6.274

4.3. Combining Ability Analysis

Sorghum improvement program can be enhanced considerably if some basic information is made available to the plant breeders. The current study results of general combining ability (GCA) and specific combining ability (SCA) in relation to the respective trait investigated were presented explicitly.

4.3.1. General combining ability effects

Variation in general combining ability effect was estimated among lines and testers for 16 plant traits to identify the best parent for subsequent hybrid development program. The results of general combining ability effects of female lines are presented in Table 9 for phenological and growth traits as well as Table 10 for yield and yield components. Based on the present study there is no significant GCA effect among female lines for days to emergency. Maximum score of seedling vigor and minimum number of days to 50% flowering are preferred to reduce the crop growth period. Therefore, P-850341 showing highly significant GCA effect in the desired negative direction is the potential parent for the development of vigor and early flowering progeny. In addition to this, in case of seedling vigor female line P-9529 and P-851015 having highly significant and significant GCA effect in the desired negative direction respectively are also the potential parents. Seedling vigor associated with drought tolerance was revealed the existence of statistically significant variability among female lines. Early season plant vigor may be considered as pre-flowering drought tolerance (Ludlow and Muchaw, 1990; Ciss and Ejeta, 2003).

Farmers need short duration sorghum hybrids because these reduce the effect of drought due to early maturity. Among female lines P-851015 and P-9529 showed highly significant GCA effect for days to 50% maturity but female line P-851015 showing highly significant negative GCA effects can be considered for selection due to shorter number of days to maturity. Female line P-850341, P-851015, M90950 and P-9532 showed highly significant GCA value to the desired positive direction for plant height and they are the best candidate material to induce tallness. In contrary, female lines

BON34, P-9534 and P-9529 have highly significant GCA value to the negative direction and they are the best materials to develop dwarf types. In case of panicle exertion, female lines P-851015, P-850341 and M90950 showed highly significant GCA effects in the positive direction. Negative, significant and highly significant GCA effects for number of green leaves per plant were observed in lines BON34 and P-9529 respectively. All female lines except lines P-9532 and P-851063 showed highly significant GCA effects for number of productive tillers per plant but female line BON34 and P-850341 showed highly significant GCA effects in the desired positive direction. Female lines P-851015 showed highly significant GCA effect in the desired positive direction for panicle length. In addition to these female lines P-9534 and P-9532 showed significant GCA effects in the desired positive direction. Positive and highly significant GCA effects for panicle weight, thousand kernel weight, panicle yield and grain yield were observed in lines P-9532 and P-851015. Line M90950 also showed significant and positive GCA effect for grain yield. Among female lines P-851015, P-9532 and M90950 with their respective order were the best general combiner for grain yield and some other yield related components. Lines with high positive GCA estimates for grain yield (are good candidates to be used as parents for the development of drought tolerant hybrids with high grain yield. In general high combiners for grain yield in these materials also seemed to show high combining ability effects for one or more traits, such as seedling vigor, days to 50% flowering, days to 50% maturity, plant height, panicle exertion, number of green leaves per plant, number of productive tillers per plant, panicle length, panicle weight, thousand seed weight and panicle yield. Early maturity can also be useful as a drought escape. Sorghum varieties that maintain green leaves and stems until harvest are associated with both pre and post anthesis drought tolerance. Stay green trait delays the premature death of leaves and plants, prolongs grain filling when moisture is limiting and reduces the incidence of lodging (Borrell *et. al.,*2000). Line P-9532 showed highly significant GCA effects for above ground dry matter. Drought susceptible cultivars produce low biomass under drought stress conditions primarily due to the serious effect of drought on plant height (Blum *et al.,*1989) and remobilization of the stored product in the stem during grain filling stage (Hammar and Broad, 2003). Positive and highly significant GCA effects for harvest index in the positive direction were observed in lines M90950 and P-851015.

Estimate of general combining ability effects for sixteen plant traits in four sorghum testers (male parents) are presented in Table 11&112 for their phonological and growth traits and yield and yield components respectively. Among the testers ICSR 161 exhibited the negative and highly significant GCA effects for days to 50% emergency, flowering and maturity. All testers except tester ICSR 161 showed significant GCA effects for seedling vigor. Highly significant and positive GCA effects for plant height were given by ICSR 161 and WSV 387. For panicle exertion highly significant and positive GCA effect was exhibited by ICSR 161. Among the testers only tester WSV 387 gave positive and significant GCA effect for number of green leaves per plant. Significant and positive GCA effect for panicle length, thousand kernel weigh, grain yield and harvest index were given by ICSR 161. Among restorers, positive GCA effects are important for panicle weight, thousand kernel weight, panicle yield and grain yield. Therefore, restorer WSV 387 having the positive and significant GCA effect is the potential parent wherein selection will be effective for its efficient use in subsequent hybrid development with desirable panicle weight, thousand kernel weight, panicle yield and grain yield. Most of these results are in harmony with Kenga *et al.* (2004) and Hovny *al.*(2005). Similarly, Hovny et al. (2000) observed that the female line ICSA40 and the restorer lines CSR138, ICSR93002 had highly significant general combining ability effects, while five crosses out of thirty had positive significant specific combining ability effects.

Table 9. Estimate of general combining ability effects of phenological and growth traits of eight sorghum lines (female parents) tested at Kobo in 2010/11

Female parents (Lines)	Days to 50% emergence	Seedling vigor	Days to 50% flowering	Days to 50% maturity	Plant height (cm)	Panicle exertion (cm)	Number of green leaf per plant
P-9529B	-0.1354	-0.6875**	0.2396	1.1354*	-7.0833**	-3.3750**	-0.5729*
P-9534B	0.2813	0.8125**	0.0729	-0.3646	-8.1667**	-0.2917	0.1771
P-9532B	0.0313	0.1458	-0.1771	0.2188	6.3333**	-0.7917	0.0938
BON34B	-0.2188	0.4792**	0.9063**	0.7188	-18.8333**	-4.3750**	-0.7396**
P-851015B	-0.2188	-0.2708*	-0.3438	-1.4479*	10.1667**	4.4583**	0.3438
P-851063B	0.2813	1.0625**	-0.0938	-0.2813	-5.0000*	-0.5417	0.0104
P-850341B	-0.2188	-1.4375**	-0.8438**	0.3021	14.5000**	3.7083**	0.3438
M90950B	0.1979	-0.1042	0.2396	-0.2813	8.0833**	1.2083**	0.3438
SE(GCA for lines)	0.1754	0.1267	0.3012	0.4154	2.3435	0.4392	0.2454
SE($gi - gj$) *for lines*	0.2481	0.1791	0.4260	0.5874	3.3142	0.6211	0.3470

*and ** = significant, highly significant respectively.

Table 10. Estimate of general combining ability effects of yield and yield components of eight sorghum lines (female parents) tested at Kobo in 2010/11

Female parents (Lines)	Number of productive tillers	Panicle length(cm)	Panicle weight(gm)	1000 kernel weight(gm)	Panicle yield(gm)	Stand count after anthesis	Grain yield (t ha^{-1})	Above ground dry matter(t ha^{-1})	Harvest index (%)
P-9529B	-0.4271**	-0.0313	-5.3496	-0.8823	-6.7104	-0.8438	-0.4633**	0.2527	-1.9125**
P-9534B	-0.6771**	0.8854*	5.7271	-0.4656	5.9229	-0.5104	-0.0908	0.4085	-0.7417
P-9532B	-0.1771	0.7188*	10.5871**	3.0427**	9.3979**	1.5729	0.4117**	3.8294**	-0.7675
BON34B	1.9063**	-0.5313	-6.6646*	-1.7823*	-5.9854	-0.9271	-0.4000**	-1.4581	-0.8925
P-851015B	-0.6771**	1.2188**	17.3971**	2.4510**	16.4396**	1.0729	0.5492**	0.7194	2.1075**
P-851063B	-0.1771	-0.6146	-8.6079**	-2.8323**	-12.035**	-1.2604	-0.1508	-1.7690	0.5392
P-850341B	0.9063**	-0.8646*	-7.6563*	-0.4906	-7.6438*	-0.0104	-0.2058	-0.3690	-0.6325
M90950B	-0.6771**	-0.7813*	-5.4329	0.9594	0.6146	0.9063	0.3500**	-1.6140	2.3000**
SE(GCA for lines)	0.1325	0.3403	3.2542	0.7770	3.4510	0.8222	0.1213	1.4273	0.7814
SE($gi - gj$) *for lines*	0.1874	0.4813	4.6021	1.0988	4.8804	1.1627	0.1715	2.0184	1.1050

*and ** = significant, highly significant respectively.

Table 11. Estimate of general combining ability effects of phenological and growth traits of four sorghum testers (male parents) tested at Kobo in 2010/11

Male parents (Testers)	Days to 50% emergence	Seedling vigor	Days to 50% flowering	Days to 50% maturity	Plant height (cm)	Panicle exertion (cm)	Number of green leaf per plant
WSV 387	-0.0521*	-0.8542**	0.2813	-0.5313	9.1667**	-0.4167	0.4271**
98MW 6002	0.2813	0.6875**	-0.0938	0.9271**	-8.5000**	-3.0417**	-0.3229
PDL 984928	0.1979	0.3125**	0.2396	0.4271	-21.7500**	-0.2083	0.0104
ICSR 161	-0.4271**	0.1458	-0.4271*	-0.8229**	21.0833**	3.6667**	-0.1146
SE(GCA for testers)	0.1240	0.0896	0.2130	0.2937	1.6571	0.3105	0.1735
E($gi - gj$) *for testers*	0.1754	0.1267	0.3012	0.4154	2.3435	0.4392	0.2454

*and ** = significant, highly significant respectively.

Table 12. Estimate of general combining ability effects of yield and yield components of four sorghum testers (male parents) tested at Kobo in 2010/11

Male parents (Testers)	Number of productive tillers	Panicle length(cm)	Panicle weight(gm)	1000 kernel weight(gm)	Panicle yield(gm)	Stand count after anthesis	Grain yield (t ha^{-1})	Above ground dry matter (t ha^{-1})	Harvest index (%)
WSV 387	0.0729	-0.0729	8.5388**	2.4677**	7.8313**	0.0729	0.3183**	1.6523	0.1854
98MW 6002	-0.2188**	-0.1146	-9.9821**	-0.2365	-9.3188**	-0.4688	-0.4417**	1.8865	-2.4967**
PDL 984928	0.1563	-0.3229	-0.6313	-4.1406**	-2.5354	-0.3854	-0.1613	-1.6135	-0.1263
ICSR 161	-0.0104	0.5104*	2.0746	1.9094**	4.0229	0.7813	0.2846**	-1.9252	2.4375**
SE(GCA for testers)	0.0937	0.2406	2.3010	0.5494	2.4402	0.5814	0.0858	1.0092	0.5525
$SE(gi-gj)\ for\ testers$	0.1325	0.3403	3.2542	0.7770	3.4510	0.8222	0.1213	1.4273	0.7814

*and ** = significant, highly significant respectively.

4.3.2. Specific combining ability effects

The estimate of specific combining ability (SCA) effects of thirty two sorghum hybrids is presented in Table 13 for growth and phenological traits as well as in Table 14 for yield and yield components. Minimum number of days to 50% emergency, seedling vigor, days to 50% flowering and maturity are desirable for drought tolerant sorghum crop. Of the thirty two, four crosses showed negative and significant SCA effects for days to 50% emergency. Similarly for seedling vigor and days to 50% flowering ten and four crosses exhibited significant SCA effects in the desired (negative) direction respectively. These are the potential hybrids needed for earliness in seedling vigor and flowering. Similar findings were registered by Kanawade *et al.,* 2001 and Gaikwad *et al.,* 2002 in their respective work. The hybrids having negative and significant SCA effects for days to 50% maturity show their ability to contribute genes for earliness in terms of number of days to maturity. The hybrids P-9534 x WSV387, P-9532 x PDL 984928, P-851015 x ICSR 161, P-851063 x WSV387, P-850341 x ICSR 161 and M90950 x ICSR 161 were found higher among the hybrids that exhibited negative and significant SCA effect for days to 50% maturity. Importance of both additive and dominance components of genetic variance for maturity was highlighted by Giriraj (1983) and Dabholkar *et al*., (1984). In specific combining ability effect for plant height, cross combinations P-9529 x PDL 984928, P-9534 x WSV387, P-9532 x PDL 984928, P-851015 x WSV387 and P-851063 x 98MW 6002 were showed highly significant positive SCA effect. Positive and significant SCA effect also observed by cross combinations P-850341 x 98MW 600 and M90950 x ICSR 161 for plant height, where as cross P-851015 x PDL 984928 (-23.8333) gave maximum negative and highly significant SCA effect followed by P-850341 x WSV387 (-20.0833), P-851063 x PDL 984928 (-19.3333), P-9534 x 98MW 6002 (-15.2500) and P-9534 x PDL 984928 (-15.1667) for plant height. Crosses elucidating highly significant SCA effects in the negative direction are good for the development of dwarf sorghum cultivars. Importance of non-additive gene action with pronounced *sca* variance for plant height was highlighted by Subba Rao *et al*. (1975), Patil *et al*. (1985) and Berenji (1988) in their related work.

Eight crosses demonstrated positive and highly significant SCA effects for panicle exertion. Number of green leaves per plant is a desirable trait as it contributes to the production of maximum photosynthesis. Only three crosses expressed positive and significant SCA effects for number of green leaves per plant. Of the thirty two crosses, 10 of them exhibited positive and significant SCA effects for number of productive tillers per plant. Cross combinations P-9529 x PDL 984928 and P-9532 x ICSR 161 showed highly significant and significant SCA effects respectively for panicle length in the desired positive direction. Out of the six crosses showing highest positive SCA effects for panicle weight, thousand kernel weight and panicle yield only five of them were common in showing positive and significant SCA effects for the respective trait. Cross combination P-851015 x WSV387 revealed highest positive and significant SCA effects of 3.5104 for stand count after anthesis. Positive and significant SCA effects for grain yield t ha^{-1} were recorded in seven crosses. Grain yield is an ultimate objective of sorghum breeding and hybrid development programs. Cross combination P-9532A x PDL 984928 depicted highly positive and significant SCA effects (1.4338) for grain yield t ha^{-1} closely followed by P-850341 x ICSR 161 (1.0988) and P-851015 x WSV387 (1.0300). Cross combination P-851015 x ICSR 161, P-851063 x WSV387 and P-850341 x ICSR 161 expressed maximum positive and highly significant SCA effects for harvest index.

The crosses that recorded high SCA effects, coupled with high per se performance for yield and its components involved either one or both of the parents with good GCA for the trait being considered. The parents that were the best general combiners did not always produce the best hybrid combinations. This may have been expected because of lack of higher order interactions. This difficulty in predicting the productivity level of the hybrid, on the basis of GCA alone should necessitate testing of specific male-female combination. However, in all high yielding hybrids at least a good general combiner was involved. According to Marilia *et al.* (2001), the SCA effect alone has limited value for parental choice in breeding programs. The SCA effect should be used in combination with other traits, such as hybrid means and the GCA of the respective parents. Thus, hybrid combination with high mean, with favorable SCA estimate and involving at least one of the parents with high GCA, would tend to increase concentration of favorable alleles; an appreciable situation to any breeder. These results are in agreement with those obtained by Kenga *et al.* (2004) and Essa (2009)

Table 13. Estimate of specific combining ability effects of phenological and growth traits of thirty two sorghum crosses tested at Kobo in 2010/11

Crosses	Days to 50% emergence	Seedling vigor	Days to 50% flowering	Days to 50% maturity	Plant height (cm)	Panicle exertion (cm)	Number of green leaf per plant
P-9529A x WSV387	0.9688**	-0.2292	0.1354	0.7813	-12.1667**	-4.4167**	0.1563
P-9529A x 98MW 6002	-0.6979*	0.2292	-0.4896	-1.3438	-2.5000	-0.4583	-0.4271
P-9529A x PDL 984928	0.0521	-0.3958	0.1771	0.1563	16.7500**	1.0417	-0.0938
P-9529A x ICSR 161	-0.3229	0.3958	0.1771	0.4063	-2.0833	3.8333**	0.3646
P-9534A x WSV387	-0.4479	-1.7292**	-1.3646*	-3.3854**	27.9167**	6.1667**	1.4063**
P-9534A x 98MW 6002	-0.4479	-0.2708	0.6771	0.1563	0.5833	-4.8750**	-0.1771
P-9534A x PDL 984928	-0.0313	0.7708**	0.3438	0.9896	-15.1667**	1.6250	0.1563
P-9534A x ICSR 161	0.9271**	1.2292**	0.3438	2.2396**	-13.3333**	-2.9167**	-1.3854**
P-9532A x WSV387	-0.1979	-0.3958	0.8854	2.0313*	-8.2500	-4.6667**	-0.1771
P-9532A x 98MW 6002	0.8021*	1.0625**	0.5938	0.5729	-15.2500**	-0.0417	0.2396
P-9532A x PDL 984928	-0.7813*	-2.2292**	-1.7396**	-3.5938**	33.0000**	6.7917**	0.9063
P-9532A x ICSR 161	0.1771	1.5625**	0.2604	0.9896	-9.5000*	-2.0833*	-0.9688
BON34A x WSV387	0.0521	2.6042**	1.4688**	1.5313	-4.0833	-1.4167	-0.6771
BON34A x 98MW 6002	0.7188*	0.7293**	-0.8229	-1.5938	3.9167	0.2083	1.0729*
BON34A x PDL 984928	-0.8646*	-1.2292**	-0.1563	-0.7604	-0.8333	2.7083**	-0.2604
BON34A x ICSR 161	0.0938	-2.1042**	-0.4896	0.8229	1.0000	-1.5000	-0.1354

Table 13. (Continued)

Crosses	Days to 50% emergence	Seedling vigor	Days to 50% flowering	Days to 50% maturity	Plant height (cm)	Panicle exertion (cm)	Number of green leaf per plant
P-851015A x WSV387	-0.6146	-0.6458*	-0.2813	-0.6354	22.2500**	6.0833**	0.5729
P-851015A x 98MW 6002	0.0521	-0.1875	0.4271	1.2396	-1.7500	-1.2917	-1.0104*
P-851015A x PDL 984928	0.4688	1.8542**	-0.2396	1.0729	-23.8333**	-5.7917**	-0.6771
P-851015A x ICSR 161	0.0938	-1.0208**	0.0938	-1.6771*	3.3333	1.0000	1.1146*
P-851063A x WSV387	-0.7813*	-1.9792**	-1.1979*	-1.8021*	-2.5833	-0.9167	0.2396
P-851063A x 98MW 6002	0.2188	0.1458	-0.4896	-0.2604	19.0833**	3.0417**	0.6563
P-851063A x PDL 984928	0.6354	0.5208*	-0.1562	-0.0938	-19.3333**	0.8750	-0.6771
P-851063A x ICSR 161	-0.0729	1.3125**	1.8438**	2.1562*	2.8333	-3.0000**	-0.2188
P-850341A x WSV387	0.7188*	0.5208*	0.2188	0.2813	-20.0833**	-1.1667	-1.4271**
P-850341A x 98MW 6002	-0.2813	-0.6875**	0.2604	0.8229	11.5833*	4.4583**	0.6563
P-850341A x PDL 984928	-0.1979	0.3542	0.9271	1.3229	1.1667	-4.7083**	-0.0104
P-850341A x ICSR 161	-0.2396	-0.1875	-1.4063*	-2.4271**	7.3333	1.4167	0.7813
M90950A x WSV387	0.3021	1.8542**	0.1354	1.1979	-3.0000	0.3333	-0.0938
M90950A x 98MW 6002	-0.3646	-1.0208**	-0.1563	0.4063	-15.6667**	-1.0417	-1.0104**
M90950A x PDL 984928	0.7188*	0.3542	0.8438	0.9063	8.2500	-2.5417**	0.6563
M90950A x ICSR 161	-0.6563	-1.1875**	-0.8229	-2.5104**	10.4167*	3.2500**	0.4479
SE (SCA effect)	0.3508	0.2534	0.6025	0.8308	4.6870	0.8783	0.4908
SE (Sij-Skr)	0.4962	0.3583	0.8520	1.1749	6.6284	1.2421	0.6940

*and ** = significant, highly significant respectively.

Table 14. Estimate of specific combining ability effects of yield and yield components of thirty two sorghum crosses tested at Kobo in 2010/11

Crosses	Number of productive tillers	Panicle length(cm)	Panicle weight(gm)	1000 kernel weight(gm)	Panicle yield(gm)	Stand count after anthesis	Grain yield (t ha^{-1})	Above ground dry matter (t ha^{-1})	Harvest index (%)
P-9529A x WSV387	-0.3229	-0.1771	4.6196	-4.1677**	4.2188	-0.5729	-0.3808	3.3244	-1.9688
P-9529A x 98MW 6002	0.6354*	-1.1354	-3.0729	-0.2302	-3.4646	-0.0313	0.1858	-3.7531	1.8367
P-9529A x PDL 984928	-0.7396**	2.0729**	9.3029	6.1406**	3.4521	1.8854	0.4854*	0.9902	1.1229
P-9529A x ICSR 161	0.4271	-0.7604	-10.8496	-1.7427	-4.2063	-1.2813	-0.2904	-0.5615	-0.9908
P-9534A x WSV387	-0.4063	1.2396	28.0563**	6.4490**	28.5521**	3.0938	0.8433**	5.6585	0.4438
P-9534A x 98MW 6002	0.2188	0.6146	8.6238	-0.6802	6.4688	-1.6979	0.1733	1.0677	0.0692
P-9534A x PDL 984928	-0.4896	-1.5104*	-16.9138*	-4.0760*	-16.5146*	0.8854	-0.3571	-4.7623	1.4621
P-9534A x ICSR 161	0.6771*	-0.3438	-19.7663**	-1.6927	-18.5063**	-2.2813	-0.6596**	-1.9640	-1.9750
P-9532A x WSV387	-0.9063**	-1.2604	-11.4704	-4.6927**	-10.7230	-4.3229*	-0.6825**	-2.7423	-0.8871
P-9532A x 98MW 6002	0.3854	-0.5521	-16.5229*	0.3115	-17.6396*	3.2188	-0.4425	-3.5965	0.5650
P-9532A x PDL 984928	-0.9896**	1.3229	34.6329**	6.2156**	32.5104**	2.1354	1.4738**	5.5035	2.4379
P-9532A x ICSR 161	1.5104**	0.4896	-6.6396	-1.8344	-4.1479	-1.0313	-0.3488	0.8352	-2.1158
BON34A x WSV387	-0.6563*	-1.3438	-11.9921	-1.0010	-5.4396	-3.8229*	-0.5075*	-2.4315	-0.9321
BON34A x 98MW 6002	-0.6979**	1.3646*	24.9488**	3.9698*	22.6771**	-0.2813	0.6492**	3.5610	1.1200
BON34A x PDL 984928	0.5938*	0.2396	-1.3021	-1.6260	-6.4396	1.6354	-0.0913	-2.2756	1.1996
BON34A x ICSR 161	0.7604**	-0.2604	-11.6546	-1.3427	-10.7979	2.4688	-0.0504	1.1460	-1.3875

Table 14. (Continued)

Crosses	Number of productive tillers	Panicle length(cm)	Panicle weight(gm)	1000 kernel weight(gm)	Panicle yield(gm)	Stand count after anthesis	Grain yield (t ha^{-1})	Above ground dry matter (t ha^{-1})	Harvest index (%)
P-851015A x WSV387	-0.4063	1.2396	23.4196**	6.7990**	17.3354**	3.5104*	1.0300**	3.4810	1.2546
P-851015A x 98MW 6002	1.2188**	0.2813	-23.8396**	-4.3969**	-21.1479**	-2.9479	-0.9133**	2.6235	-4.5167**
P-851015A x PDL 984928	-0.4896	-1.5104*	-20.6638**	-4.8927**	-15.4979**	-1.3646	-0.5771*	-2.5865	-1.1504
P-851015A x ICSR 161	-0.3229	-0.0104	21.0838**	2.4906	19.3104**	0.8021	0.4604	-3.5181	4.4125**
P-851063A x WSV387	-0.9063**	0.0729	9.1579	2.7490	-3.1563	0.8438	0.8533**	-2.1206	4.5096**
P-851063A x 98MW 6002	0.0521	0.1146	1.7321	1.8531	5.3271	1.7188	0.1333	2.0019	-0.7917
P-851063A x PDL 984928	1.6771**	-0.3438	-8.7121	-5.0427**	-3.5896	-0.3646	-0.4838*	-3.8281	0.2279
P-851063A x ICSR 161	-0.8229**	0.1563	-2.1779	0.4406	1.4188	-2.1979	-0.5029*	3.9469	-3.9458*
P-850341A x WSV387	3.0104**	-1.0104	-27.3204**	-5.0594**	-20.9479**	1.2604	-0.6817**	-4.1406	-0.7988
P-850341A x 98MW 6002	-1.6979**	-0.3021	0.7138	0.2448	3.4021	0.1354	0.1050	0.6019	-0.1567
P-850341A x PDL 984928	0.5938*	0.2396	-8.6971	1.0490	-2.6479	-4.6146**	-0.5221	3.4819	-3.4971*
P-850341A x ICSR 161	-1.9063**	1.0729	35.3038**	3.7656*	20.1938**	3.2188	1.0988**	0.0569	4.4525**
M90950A x WSV387	0.5938*	1.2396	-14.4704*	-1.0760	-9.8396	0.0104	-0.4742	-1.0290	-1.6213
M90950A x 98MW 6002	-0.1146	-0.3854	7.4171	-1.0719	4.3771	-0.1146	0.1092	-2.5065	1.8742
M90950A x PDL 984928	-0.1563	-0.5104	12.3529	2.2323	8.7271	-0.1979	0.0721	3.4769	-1.8029
M90950A x ICSR 161	-0.3229	-0.3438	-5.2996	-0.0844	-3.2646	0.3021	0.2929	0.0585	1.5500
SE (SCA effect)	0.2650	0.6806	6.5083	1.5539	6.9013	1.6443	0.2426	2.8545	1.5627
SE (Sij-Skr)	0.3748	0.9625	9.2042	2.1975	9.7608	2.3254	0.3430	4.0369	2.2100

*and ** = significant, highly significant respectively.

4.4. Variance due to General and Specific Combining Ability

Variance due to general and specific combining ability (σ^2_{gca} and σ^2_{sca}), ratio of GCA:SCA variances, additive variance (σ^2_A) and dominance variance (σ^2_D) are presented for phenological and growth traits as well as yield and yield components in Table 17 &18 respectively. It is evident from the tables that the hybrids in general were superior to parents for all the sixteen indicated traits studied during the investigation.

Table 15&16 also depicts that variance due to specific combining ability was more important than the variance due to general combining ability as well as the additive variance for all the traits. It is evident from the table that the variance due to SCA wherein dominance variance was more important for most of plant traits. Preponderance of dominance gene action is declared by the degree of dominance greater than 1 for the 16 indicated traits. The preponderance of dominance gene action for these traits is also clear from the gca:sca ratio and lesser than one degree of additive variance. Similar to the present findings, the importance of non-additive gene effects for grain yield and other attributes in sorghum have also been observed by Hovny *et al.* (2000), and Badhe and Patil (1997). Kadam *et al.* (2000) reported SCA variance to be higher than GCA variance for plant height which is in accordance with the present study. Information on preponderance of *sca* variance for panicle length was documented by Iyanar *et al*.(2001), Kanawade *et al*.(2001) and Siddiqui and Baig (2001). Predominance of *sca* variance for panicle length was reported by Aruna (1997) and Iyanar *et al.* (2001). Ravindrababu *et al*. (2003) explained that estimates of components of variance for *sca* were larger in magnitude than *gca* for thousand kernel weight in sorghum. Siddiqui and Baig (2001) reported similar results and advocated heterosis breeding for improvement of the trait. Siddiqui and Baig (2001) obtained the ratio of general combining ability and specific combining ability variances less than unity indicating the presence of non-additive gene action for grain yield. The crosses 90B x 323B, 36642B x 30B were identified as superior crosses exhibiting high *sca* effects for gain yield.

Table 15. Estimate of variance due to GCA(σ^2_{gca}), variance due to SCA (σ^2_{sca}), additive variance (σ^2_{a}), dominance variance (σ^2_{d}) and ratio of SCA to GCA ($\sigma^2_{gca} / \sigma^2{}_{sca}$) of sorghum genotypes tested at Kobo in 2010/11

Genetic Components	Days to 50% emergence	Seedling vigor	Days to 50% flowering	Days to 50% maturity	Plant height (cm)	Panicle exertion (cm)	Number of green leaf per plant
Cov H.S(lines)	-0.055	0.127	0.021	-0.281	59.448	5.363	-0.017
Cov H.S(Testers)	0.048	0.171	-0.010	0.217	322.771	5.560	0.001
Cov H.S(average)	-0.001	0.015	0.001	-0.005	18.075	0.545	-0.001
Cov F.S.	0.358	2.688	0.590	3.124	1165.96	36.736	0.533
$\sigma^2_{gca} = [(1+F)/4]\sigma^2 A$	-0.001	0.015	0.001	-0.005	18.075	0.545	-0.001
(a) With F=0, σ^2_A	-0.003	0.059	0.003	-0.020	72.301	2.182	-0.003
(b) With F=1, σ^2_A	-0.001	0.029	0.001	-0.010	36.150	1.091	-0.002
	0.302	2.094	0.590	2.909	263.45	15.849	0.551
$\sigma^2_{sca} = [(1+F)/2]^2 \sigma^2 D$	1.209	8.376	2.361	11.634	1053.81	63.396	2.204
$(a)\ with\ F=0, \sigma^2_D$	0.302	2.094	0.590	2.909	263.45	15.849	0.551
$(b)\ with\ F=1, \sigma^2_D$							
$\sigma^2_{gca} / \sigma^2{}_{sca}$	-0.002	0.007	0.001	0.002	0.069	0.034	0.001

Table 16. Estimate of variance due to GCA (σ^2_{gca}), variance due to SCA (σ^2_{sca}), additive variance (σ^2_{a}), dominance variance (σ^2_{d}) and ratio of SCA to GCA ($\sigma^2_{gca}/\sigma^2_{sca}$) of sorghum genotypes tested at Kobo in 2010/11

Genetic Components	Number of productive tillers	Panicle length(cm)	Panicle weight(gm)	1000 kernel weight(gm)	Panicle yield(gm)	Stand count after anthesis	Grain yield (t ha^{-1})	Above ground dry matter (t ha^{-1})	Harvest index (%)
Cov H.S(lines)	0.499	0.369	-9.540	-0.502	22.883	-0.634	0.013	-0.091	0.424
Cov H.S(Testers)	-0.158	-0.031	5.543	6.684	19.927	-0.551	0.067	2.482	3.143
Cov H.S(average)	0.020	0.018	-0.258	0.281	2.152	-0.060	0.004	0.110	0.168
Cov F.S.	1.608	1.178	388.554	32.537	327.705	2.132	0.672	11.870	13.625
$\sigma^2_{gca} = [(1+F)/4]\sigma^2 A$	0.020	0.018	-0.258	0.281	2.152	-0.060	0.004	0.110	0.168
(c) With F=0, σ^2_A	0.078	0.074	-1.031	1.126	8.607	-0.238	0.015	0.439	0.671
(d) With F=1, σ^2_A	0.039	0.037	-0.516	0.563	4.304	-0.119	0.008	0.219	0.336
	1.404	0.805	385.977	15.946	248.359	4.327	0.484	5.591	5.015
$\sigma^2_{sca} = [(1+F)/2]^2\sigma^2 D$	5.617	3.219	1543.907	63.784	993.437	17.310	1.937	22.365	20.062
$(a)\ with\ F = 0, \sigma^2_D$	1.404	0.805	385.977	15.946	248.359	4.327	0.484	5.591	5.015
$(b)\ with\ F = 1, \sigma^2_D$									
$\sigma^2_{gca}/\sigma^2_{sca}$	0.014	0.023	-0.001	0.018	0.009	-0.014	0.008	0.020	0.033

4.5. Proportional Contribution of Lines, Testers and their Interaction to the Total Variance

A line x tester analysis of sorghum with eight cytoplasmic male sterile lines and four restorer lines as testers was adopted to obtain the proportional contribution of lines, testers and lines x testers to the total variance for the 16 different plant traits presented in Table 17 & 18. The contribution of maternal and paternal interaction (line x tester) was very high for all traits. It revealed preponderance of paternal and maternal interaction (line x tester) influence for all these traits except plant height. This results again showed that genotypes which give minimum amount for example grain yield when they planted and evaluated individually as a tester or female line, the can show a better performance when they existed in cross combination. This is due to the genetic bases of heterosis i.e. over dominance, dominance and epistatics because according to tha assumption that the deleterious effect of the recessive gene masked by the dominant gene of each trait except plant height.

Table 17. Proportional contribution of lines, testers and their interaction to the total variance for indicated phenological and growth traits of sorghum genotypes tested at Kobo in 2010/11

Contribution Lines,Testers and Line x Testers (%)	Days to 50% emergence	Seedling vigor	Days to 50% flowering	Days to 50% maturity	Plant height (cm)	Panicle exertion (cm)	Number of green leaf per plant
Lines	11.26	25.02	24.25	15.91	20.07	33.36	21.07
Testers	18.96	14.18	8.77	14.70	47.08	22.95	9.95
Line x Tester	69.79	60.80	66.98	69.39	32.85	43.69	68.98

Table 18. Proportional contribution of lines, testers and their interaction to the total variance for indicated phonological and growth traits of sorghum genotypes tested at Kobo in 2010/11

Contribution Lines,Testers and Line x Testers (%)	Number of productive tillers	Panicle length(cm)	Panicle weight(gm)	1000 kernel weight(gm)	Panicle yield(gm)	Stand count after anthesis	Grain yield (t ha^{-1})	Above ground dry matter (t ha^{-1})	Harvest index (%)
Lines	43.49	39.29	20.78	16.00	26.35	16.83	22.16	19.39	20.12
Testers	1.11	6.27	10.79	30.12	13.27	4.21	17.17	20.87	30.71
Line x Tester	55.40	54.44	68.43	53.89	60.38	78.96	60.67	59.74	49.18

4.6. Heterosis

Heterosis (hybrid vigour) plays a major role in improving crop productivity and quality in order to feed the ever-increasing human population particularly in developing countries. The development of hybrids in the world major food crops and methods of hybrid seed production are critical for achieving this goal. The results of the mid parent and standard heterosis studies are presented in Table 19 & 20 as well as Table 21 & 22 respectively.

Out of the thirty two crosses, eighteen for days to 50% emergency and twelve for days to 50% flowering gave significant negative heterosis over mid parent in the desired (negative) direction. Maximum negative heterosis over mid parent value was observed in cross combination P-850341 x ICSR 161 (-18.18%) followed by P-850341 x 98MW 6002 (-16.67%) for days to emergency and P-9534 x WSV387 (-6.24%) followed by P-850341 x WSV387 (5.53%) for days to 50% flowering respectively. Early emergency and flowering provide sufficient time for seed formation process and if emergency or flowering is delayed the duration of seed formation (seed filling period) is altered resulting in poor seed formation especially loss of kernel weight. Hence for early flowering with negative heterosis is desirable. Negative heterosis over mid-parent value for days to flowering was observed by Indi and Goud (1981), Kide *et al*. (1985), Shivanna and Patil (1988) and Belavatagi (1997). Of the twenty four crosses, cross combinations BON34 x ICSR 161 (-73.91%), P-851063 x WSV387 (-72.73%), P-851015 x WSV387 (-71.43%), P-851015 x ICSR 161 (-69.23%) and P-9532 x PDL 984928 (-68.42%) gave maximum significant negative heterosis over mid parent value for seedling vigor in the desired direction.

Genotypes with early maturity habit are desirable, therefore, significant negative heterosis for days to maturity is considered functional. Out of the thirty two crosses, fifteen of them exhibited significant negative heterosis over mid parent value for days to 50% maturity. The top five cross combinations which showed maximum negative heterosis over mid parent value for days to 50% maturity were P-9534 x WSV387 (-6.46%), M90950 x ICSR 161 (-5.99%), P-851015 x ICSR 161 (-5.43%), P-9532 x PDL

984928 (-5.08%) and P-9534 x PDL 984928 (-4.62%). Desirable negative heterosis over mid-parent for days to maturity was observed by Patel *et al*.(1990) and Biradar (1995). Exploitable negative heterosis in desirable direction was obtained by Tiwari *et al*.(2003) in the cross KIJ53 x KIJ77 in a diallel analysis involving 10 diverse sorghum.

For plant height, all except five cross combinations showed maximum significant positive heterosis over mid parent value. The highest significant positive heterosis value depicted by cross P-9532 x PDL 984928 (52.43%) followed by M90950 x ICSR 161 (51.64%) and P-851063 x 98MW 6002 (49.57%). Maximum extent of relative heterosis for plant height was reported by Franca *et al*. (1986) and Jebaraj *et al*.(1988). Highly significant positive and maximum heterosis for panicle exertion and number of green leaves per plant were exhibited by cross P-9534 x WSV387 with values 485.11% and 27.02% for panicle exertion and number of green leaves per plant respectively. Giriraj and Goud (1983) reported wide range of heterosis over mid-parent with values ranging from 2.10 per cent to 87.64 per cent. For number of productive tillers per plant, all cross combinations showed highly significant heterosis value over the mid parent but only three out of thirty three crosses showed maximum and highly significant positive heterosis over mid parent value. Highly significant positive heterosis was depicted by BON34 x PDL 984928 (100.00%) followed by P-850341 x WSV387 (12.50%) and BON34 x ICSR 161 (3.70%).

An overview of the Table 20 revealed that most of the cross combinations manifested highly significant positive heterosis over the mid parent value for panicle length. Cross combination P-851063 x 98MW 6002 (22.73%) showed highly significant maximum positive heterosis followed by BON34 x 98MW 6002 (22.33%) and P-9532 x ICSR 161 (19.74). Pronounced hybrid vigour with significant mid-parent heterosis for panicle length was reported by Franca *et al*. (1986), Nimbalkar *et al*. (1988) and Biradar *et al*. (1996). Tiwari *et al*. (2003) documented highest magnitude of heterosis for length of panicle in the cross 880 x FTB24. For panicle weight, all of the cross combinations investigated showed highly significant negative heterosis over mid parent value. Highest range of heterosis over mid-parent (96.34%) was recorded for panicle weight by Gururaj Rao *et al*., (1993). For thousand kernel weight, fourteen crosses out of thirty two showed highly significant positive heterosis over the mid parent value. Highly significant positive heterosis over the mid parent value was depicted by P-851015 x ICSR 161 (58.04%) followed by P-850341 x ICSR 161 (52.33%) and P-851015 x WSV387 (44.34%). Badhe and Patil (1997) noticed heterosis in positive direction over mid-parent for thousand kernel weight. Hetrotic studies for panicle yield showed that nine crosses out of thirty two expressed highly significant positive heterosis in the desired direction (positive). The maximum and highly significant positive heterosis for panicle yield was revealed by P-851015 x ICSR 161 (86.87%) followed by P-851015 x WSV387 (82.68%) and P-9534 x WSV387 (79.01%). Highest average or relative heterisis for the trait was evidenced by Franca *et al*.(1986) and Patel *et al*.(1990) in their respective work. Twenty four crosses out of the thirty two depicted significant heterosis value in the positive and negative direction for stand count after anthesis. Highly significant maximum positive heterosis over mid parent value was recorded in cross combination P-851015 x WSV387 (34.48%) followed by P-9532 x 98MW 6002 (32.00%) and P-851015 x ICSR 161 (26.14%).

Highly significant positive heterosis for grain yield t ha^{-1} is crucial because it is an effective yield component. All cross combinations showed highly significant heterosis result in the positive (desired) and negative (undesired) direction. Only twenty three crosses out of thirty two displayed highly significant positive heterosis over mid parent value. The top six crosses which showed more than 50% highly significant positive hetrosis over mid parent value were P-851015 x WSV387 (95.68%), P-851015 x ICSR 161 (80.77%), P-9532 x PDL 984928 (72.46%), P-851063 x WSV387 (66.24%), P-9532 x ICSR 161(59.27%) and P-850341 x ICSR 161 (58.40%). Similar results was reported by Tiwari *et al*.(2003). For above ground dry matter t ha^{-1}, positive heterosis displayed by twelve crosses out of thirty two cross combinations. The maximum highly significant positive heterosis was expressed by P-9534 x WSV387 (44.34%) followed by P-851015 x WSV387 (33.27%) and P-851015 x 98MW 6002 (30.66%).

Most of the crosses studied in this experiment revealed that positive heterosis over the mid parent value for harvest index. The maximum highly significant positive hetrosis over the mid parent value was recorded by P-851015 x ICSR 161(112.12%) followed by P-9532 x PDL 984928 (81.33%) and P-850341 x ICSR 161 (77.04%). Cross combinations P-851015 x WSV387, P-851015 x ICSR 161 and P-9532 x ICSR 161 showed better performance in relation to the nine traits of yield and yield components. Favorable heterosis has been obtained by several researchers for sorghum traits which varied according to the cross combinations and traits (Axtell *et al.,* 1999; Borgonovi, 1985; Chapman *et al.,*2000; Haussmann *et al.,*2000; Degu *et al.,* 2009.

Table 19. Heterosis expressed as percent of mid parent for phenological and growth traits of thirty two sorghum crosses derived from eight lines and four testers of sorghum genotypes tested at Kobo in 2010/11

Crosses	Days to 50% emergence	Seedling vigor	Days to 50% flowering	Days to 50% maturity	Plant height (cm)	Panicle exertion (cm)	Number of green leaf per plant
P-9529A x WSV387	9.52**	-57.14**	-4.37**	1.90	5.73	283.33**	-7.40**
P-9529A x 98MW 6002	-15.56**	-14.29**	-0.49	-1.54	12.74*	462.50**	-38.89**
P-9529A x PDL 984928	7.69**	-45.45**	0.24	-1.08	16.58**	186.79**	-39.71**
P-9529A x ICSR 161	-12.20**	-26.32**	-1.67	-0.16	22.71**	378.50**	-19.05**
P-9534A x WSV387	-11.11**	-71.43**	-6.24**	-6.46**	38.32**	485.11**	27.02**
P-9534A x 98MW 6002	-12.50**	-14.29**	1.46	-4.49**	19.92**	57.78**	-24.62**
P-9534A x PDL 984928	4.76**	-3.45**	0.73	-4.62**	-5.10	153.66**	-26.32**
P-9534A x ICSR 161	4.55**	7.69**	-1.20	-2.88**	18.90**	141.21**	-31.72**
P-9532A x WSV387	-2.44**	-9.09**	-4.35**	2.55	27.19**	39.87**	-6.04**
P-9532A x 98MW 6002	9.09**	55.56**	0.00	-0.31	23.84**	79.87**	-21.84**
P-9532A x PDL 984928	0.00**	-68.42**	-3.60**	-5.08**	52.43**	151.12**	-19.92**
P-9532A x ICSR 161	0.00**	62.50**	-2.61**	-0.16	37.39**	83.04**	-26.40**
BON34A x WSV387	-6.98**	66.67**	-0.93	2.88**	13.57*	292.00**	-18.48**
BON34A x 98MW 6002	0.00**	12.00**	0.73	-1.55	21.91**	278.26**	-9.14**
BON34A x PDL 984928	-10.00**	-46.15**	1.46	-1.70	4.75	171.67**	-35.67**
BON34A x ICSR 161	-9.52**	-73.91**	-0.96	0.47	28.97**	164.46**	-22.60**

Table 19. (Continued)

Crosses	Days to 50% emergence	Seedling vigor	Days to 50% flowering	Days to 50% maturity	Plant height (cm)	Panicle exertion (cm)	Number of green leaf per plant
P-851015A x WSV387	-10.00**	-71.43**	-5.31**	-2.83**	44.59**	315.66**	13.66**
P-851015A x 98MW 6002	-2.33**	-35.71**	0.49	-2.45*	30.25**	138.27**	-28.97**
P-851015A x PDL 984928	18.92**	-3.45**	-0.73	-3.50**	0.35	38.98**	-34.85**
P-851015A x ICSR 161	-2.56**	-69.23**	-2.16**	-5.43**	41.68**	178.48**	10.82**
P-851063A x WSV387	-2.56**	-72.73**	-6.24**	-2.37	27.01**	78.38**	-9.95**
P-851063A x 98MW 6002	9.52**	-3.45**	-0.49	-2.30	49.57**	104.42**	-22.74**
P-851063A x PDL 984928	33.33**	-6.67**	-0.24	-3.06**	1.80	53.73**	-46.84**
P-851063A x ICSR 161	5.26**	11.11**	0.72	-0.31	42.71**	51.56**	-27.82**
P-850341A x WSV387	-2.22**	-45.45**	-5.53**	0.63	15.80**	66.79**	-24.76**
P-850341A x 98MW 6002	-16.67**	-55.56**	-0.73	-0.31	41.66**	100.75**	-17.38**
P-850341A x PDL 984928	-4.76**	-36.84**	0.00	-0.77	21.55**	4.99**	-34.47**
P-850341A x ICSR 161	-18.18**	-62.50**	-5.26**	-3.60**	45.33**	91.81**	-8.24**
M90950A x WSV387	4.76**	120.00**	-5.02**	-0.93	30.21**	211.11**	-17.01**
M90950A x 98MW 6002	-6.67**	-17.65**	-0.72	-3.03**	23.16**	125.95**	-42.80**
M90950A x PDL 984928	23.08**	11.11**	0.48	-3.47**	30.74**	69.76**	-29.98**
M90950A x ICSR 161	-12.20**	-46.67**	-3.79*	-5.99**	51.64**	205.83**	-16.30**
SE (m) MD	0.4201	0.3138	0.7334	1.0341	5.6386	1.1268	0.5945

*and ** = significant, highly significant respectively.

Table 20. Heterosis expressed as percent of mid parent for yield and yield components of thirty two sorghum crosses derived from eight lines and four testers of sorghum genotypes tested at Kobo in 2010/11

Crosses	Number of productive tillers	Panicle length(cm)	Panicle weight(gm)	1000 kernel weight(gm)	Panicle yield(gm)	Stand count after anthesis	Grain yield (t ha^{-1})	Above ground dry matter (t ha^{-1})	Harvest index (%)
P-9529A x WSV387	-52.94**	1.89*	-47.81**	-14.68**	12.97	6.45**	-4.22**	20.69**	-14.44**
P-9529A x 98MW 6002	-36.84**	5.70**	-55.04**	-3.20	-9.91	6.45**	2.31**	-5.86	6.70**
P-9529A x PDL 984928	-33.33**	6.16**	-58.91**	-5.51**	-14.46	-1.42	-6.90**	-24.67**	21.27**
P-9529A x ICSR 161	-45.45**	6.46**	-56.01**	12.10**	1.82	5.32**	0.78**	-10.44**	17.99**
P-9534A x WSV387	-76.00**	11.51**	-25.24**	9.99**	79.01**	20.65**	36.45**	44.34**	-3.36
P-9534A x 98MW 6002	-70.37**	17.09**	-37.05**	-13.75**	37.16**	3.26	7.08**	25.63**	-15.79**
P-9534A x PDL 984928	-64.71**	-3.10**	-61.58**	-43.37**	-12.02	-1.90	-23.79**	-36.52**	12.06**
P-9534A x ICSR 161	-60.00**	10.54**	-50.16**	0.30	15.22	4.30*	-5.39**	-6.28	0.41
P-9532A x WSV387	-68.42**	7.48**	-42.19**	6.45**	35.13**	8.57**	41.60**	12.24**	26.88**
P-9532A x 98MW 6002	-42.86**	18.71**	-48.09**	25.42**	10.76	32.00**	43.28**	9.80**	33.62**
P-9532A x PDL 984928	-45.45**	12.05**	-38.67**	17.89**	50.13**	11.94**	72.46**	0.03	81.33**
P-9532A x ICSR 161	-16.67**	19.74**	-40.43**	43.96**	44.09**	20.90**	59.27**	9.57**	47.30**
BON34A x WSV387	-9.09**	2.26**	-53.70**	-7.91**	12.25	-0.56	0.97**	-11.34**	12.63**
BON34A x 98MW 6002	-25.00**	22.33**	-38.29**	7.72**	36.10**	9.50**	31.39**	12.00**	22.63**
BON34A x PDL 984928	100.00**	3.87**	-61.82**	-34.15**	-17.50*	0.98	-15.42**	-40.92**	46.90**
BON34A x ICSR 161	3.70**	12.58**	-54.75**	8.86**	4.03	20.99**	19.01**	-13.36**	37.19**

Table 20. (Continued)

Crosses	Number of productive tillers	Panicle length(cm)	Panicle weight(gm)	1000 kernel weight(gm)	Panicle yield(gm)	Stand count after anthesis	Grain yield (t ha^{-1})	Above ground dry matter (t ha^{-1})	Harvest index (%)
P-851015A x WSV387	-81.25**	13.44**	-20.27*	44.34**	82.68**	34.48**	95.68**	33.27**	53.05**
P-851015A x 98MW 6002	-61.76**	16.37**	-47.66**	2.31	15.63	10.34**	16.03**	30.66**	-7.42**
P-851015A x PDL 984928	-75.00**	-0.35	-57.79**	-24.85**	3.02	0.50	3.05**	-29.78**	47.73**
P-851015A x ICSR 161	-83.78**	14.50**	-21.30**	58.04**	86.87**	26.14**	80.77**	-13.41**	112.12**
P-851063A x WSV387	-85.71**	11.93**	-43.90**	14.77**	6.85	10.87**	66.24**	-0.19	68.50**
P-851063A x 98MW 6002	-77.27**	22.73**	-51.03**	10.65**	3.39	11.41**	31.85**	18.20**	14.29**
P-851063A x PDL 984928	-35.29**	5.44**	-65.10**	-41.77**	-21.27*	-7.62**	-14.43**	-41.26**	46.97**
P-851063A x ICSR 161	-87.23**	19.02**	-50.40**	30.96**	11.51	2.15	20.78**	7.49*	23.09**
P-850341A x WSV387	12.50**	2.99**	-60.21**	-8.49**	-9.57	9.79**	-2.72**	-8.89*	6.34**
P-850341A x 98MW 6002	-82.35**	13.06**	-49.98**	10.19**	7.38	5.15*	12.30**	10.82**	1.69
P-850341A x PDL 984928	-8.33**	2.89**	-64.15**	-13.55**	-15.20	-20.00**	-25.02**	-17.92**	-7.32**
P-850341A x ICSR 161	-83.78**	16.39**	-29.72**	52.33**	42.61**	17.35**	58.40**	-8.67*	77.04**
M90950A x WSV387	-65.71**	5.79**	-54.98**	0.61	4.31	15.30**	10.65**	-10.47**	21.04**
M90950A x 98MW 6002	-83.78**	7.36**	-47.85**	-0.89	8.09	13.66**	19.08**	-14.95**	43.82**
M90950A x PDL 984928	-74.07**	-5.37**	-56.62**	-13.23**	-2.62	-0.96	-1.83**	-27.18**	31.89**
M90950A x ICSR 161	-85.00**	5.12**	-51.76**	24.58**	10.85	17.84**	36.05**	-21.19**	73.82**
SE(m) MP	0.3298	0.8288	7.8176	1.8698	8.3294	1.9824	0.2910	3.4353	1.8783

*and ** = significant, highly significant respectively.

Minimum zero heterosis over the standard check value for days to 50% emergency was observed by cross combinations P-9529 x ICSR 161, BON34 x PDL 984928, P-851015 x WSV387, P-850341 x ICSR 161 and M90950 x ICSR 161 with 0.00% heterosis value even though these values are statistically non significant. Cross combinations P-9529 x 98MW 6002, P-9532 x PDL 984928, BON34 x ICSR 161, P-851015 x ICSR 161 and P-851063 x WSV387 with the same highly significant positive heterosis value (5.56%) relative to the other cross combinations was obtained in the study for days to emergency. For seedling vigor, twenty nine crosses showed statistically highly significant heterosis result. Out of twenty nine, eight cross combinations that showed maximum highly significant negative heterosis over the standard check value for seedling vigor were P-851015 x WSV387, P-851063 x WSV387, P-9532 x PDL 984928, BON34 x ICSR 161, P-851015 x WSV387, P-851063 x WSV387, P-850341 x WSV387 and P-850341 x ICSR 161 with the same -25.00% heterosis value. Early emergency and flowering give sufficient time for seed formation process and if emergency or flowering is delayed the length of seed formation (seed filling period) is altered. Genotypes with early emergency, flowering and maturity habit are desirable, therefore, maximum significant negative heterosis over the standard check value for days to 50% emergency, flowering and maturity are considered important. Cross combinations P-9534 x WSV387, P-9532 x PDL 984928, P-850341 x ICSR 161 and M90950 x ICSR 161 gave better heterosis performance over the standard check value to the desired direction for the above mentioned three traits. Similarly, Kulkarni (2002) reported both early and late maturity types in the 33 hybrids involving 3 diverse male sterile lines and 11 testers with values ranging from–10.29 to 19.63 for standard heterosis.

For plant height, only fourteen out of the thirty two cross combinations showed highly significant positive and negative heterosis over the standard check value. The maximum and highly significant positive heterosis depicted by P-850341 x ICSR 161 (17.69%) followed by P-851015 x WSV387 (16.92%) and M90950 x ICSR 161 (15.77%). Similarly, pronounced hybrid vigour with appreciable standard heterosis for plant height was reported by Franca *et al*., 1986 and Ganesh *et al*.,1996.

Cross combination P-851015 x WSV387 and P-851015 x ICSR 161 gave highly significant and positive heterosis over the standard check value in the desired direction for panicle exertion and number of green leaves per plant. Cross combination P-9534 x WSV387 (14.00%) exhibited the maximum highly significant positive heterosis over the standard check for number of green leaves per plant. Similarly, Vasudev Rao and Goud (1977) documented partial dominance for panicle exertion with significant standard heterosis in the hybrids.

Out of thirty two cross combinations, studied in the experiment only seven, three, three, four and ten crosses expressed positive heterosis over the standard check for number of productive tillers per plant, panicle weight, thousand seed weight, panicle yield and stand count after anthesis respectively. Similar results were reported by, Gite *et al*. (1997) identified two hybrids*, viz.* MS101A x GMPR4 and 53A x GMPR4 with highest degree of useful heterosis over commercial check for panicle weight. Franca et al. (1986) made the genetic analysis of some agronomic traits in grain sorghum and reported high positive heterosis for yield per panicle in post rainy season indicating the adoption of the parents to the particular season.

In sorghum breeding the ultimate objective is to obtain maximum grain yield per unit area, therefore, heterosis in the positive direction is desirable. Of the thirty two crosses, only six crosses demonstrated maximum highly significant heterosis result over the standard check value in the desired (positive) direction. The maximum highly significant positive grain yield t ha^{-1} over the standard check was exhibited by P-851015 x WSV387 (21.23%) followed by P-9532 x PDL 984928 (17.38%) and P-851015 x ICSR 161 (7.95%). Similar results was reported by Ghorade *et al*. (1997) after evaluating 32 hybrids. Nine and seven crosses out of thirty two expressed positive heterosis for above ground dry matter t ha^{-1} and harvest index respectively in the desired direction. Cross combination P-9532 x PDL 984928 (17.54 t ha^{-1}) and P-851015 x ICSR 161 (46.82%) gave maximum positive heterosis over the standard check value for above ground dry matter and harvest index respectively.

Table 21. Heterosis expressed as percent of standard check for phenological and growth traits of thirty two sorghum crosses derived from eight lines and four testers of sorghum genotypes tested at Kobo in 2010/11

Crosses	Days to 50% emergence	Seedling vigor	Days to 50% flowering	Days to 50% maturity	Plant height (cm)	Panicle exertion (cm)	Number of green leaf per plant
P-9529A x WSV387	27.78**	-25.00**	0.48	-0.31	-12.77	-77.74**	-15.50**
P-9529A x 98MW 6002	5.56**	125.00**	-0.97	-0.93	-17.65**	-70.97**	-39.50**
P-9529A x PDL 984928	16.67**	50.00**	0.48	0.00	-14.00*	-50.97**	-27.50**
P-9529A x ICSR 161	0.00	75.00**	-0.48	-0.93	-0.23	-17.42**	-23.50**
P-9534A x WSV387	11.11**	-25.00**	-1.93*	-5.59**	9.62	-11.29**	14.00**
P-9534A x 98MW 6002	16.67**	200.00**	0.48	-0.93	-16.31*	-77.10**	-26.50**
P-9534A x PDL 984928	22.22**	250.00**	0.48	-0.62	-33.08**	-32.90**	-12.50**
P-9534A x ICSR 161	27.78**	250.00**	-0.48	-0.62	-7.19	-35.81**	-36.50**
P-9532A x WSV387	11.11**	25.00**	0.97	0.00	-2.92	-65.48**	-10.50**
P-9532A x 98MW 6002	33.33**	250.00**	0.00	0.00	-17.19**	-56.77**	-19.50**
P-9532A x PDL 984928	5.56**	-25.00**	-2.90**	-4.35**	3.04	-9.68**	-0.50**
P-9532A x ICSR 161	11.11**	225.00**	-0.97	-1.24	3.23	-33.87**	-27.50**
BON34A x WSV387	11.11**	275.00**	3.38**	0.00	-15.19*	-68.39**	-30.50**
BON34A x 98MW 6002	27.78**	250.00**	-0.48	-1.55	-20.50**	-71.94**	-15.50**
BON34A x PDL 984928	0.00	75.00**	0.97	-1.24	-30.92**	-47.42**	-26.50**
BON34A x ICSR 161	5.56**	-25.00**	-0.48	-0.93	-5.23	-48.39**	-31.50**

Table 21. (Continued)

Crosses	Days to 50% emergence	Seedling vigor	Days to 50% flowering	Days to 50% maturity	Plant height (cm)	Panicle exertion (cm)	Number of green leaf per plant
P-851015A x WSV387	0.00	-25.00**	-0.97	-4.04**	16.92*	11.29**	4.00**
P-851015A x 98MW 6002	16.67**	125.00**	-0.48	-0.93	-7.00	-37.74**	-29.50**
P-851015A x PDL 984928	22.22**	250.00**	-0.97	-1.55	-27.62**	-47.10**	-21.50**
P-851015A x ICSR 161	5.56**	0.00	-1.45	-5.28**	12.88	6.45**	5.00**
P-851063A x WSV387	5.56**	-25.00**	-1.93*	-4.04**	-6.23	-46.77**	-5.00**
P-851063A x 98MW 6002	27.78**	250.00**	-1.45	-1.24	-3.73	-40.32**	-12.50**
P-851063A x PDL 984928	33.33**	250.00**	-0.48	-1.55	-33.73**	-36.77**	-28.50**
P-851063A x ICSR 161	11.11**	275.00**	1.45	-0.62	3.65	-37.42**	-21.50**
P-850341A x WSV387	22.22**	-25.00**	-0.97	-1.55	-4.85	-27.10**	-22.50**
P-850341A x 98MW 6002	11.11**	0.00	-1.45	0.31	3.00	-13.55**	-8.50**
P-850341A x PDL 984928	11.11**	50.00**	0.00	0.31	-10.73	-42.26**	-13.50**
P-850341A x ICSR 161	0.00**	-25.00**	-4.35**	-4.35**	17.69**	5.81**	-2.50**
M90950A x WSV387	22.22**	175.00**	0.48	-1.24	0.96	-32.26**	-8.50**
M90950A x 98MW 6002	16.67**	75.00**	-0.48	-0.62	-16.15*	-52.26**	-32.50**
M90950A x PDL 984928	33.33**	150.00**	1.45	-0.62	-10.04	-43.87**	-2.50**
M90950A x ICSR 161	0.00	0.00	-1.93*	-4.97**	15.77*	1.61	-5.00**
SE(m) SC	0.4851	0.3623	0.8468	1.1940	6.5110	1.3012	0.6864

*and ** = significant, highly significant respectively.

Table 22. Heterosis expressed as percent of standard check for yield and yield components of thirty two sorghum crosses derived from eight lines and four testers of sorghum genotypes tested at Kobo in 2010/11

Crosses	Number of productive tillers	Panicle length(cm)	Panicle weight(gm)	1000 kernel weight(gm)	Panicle yield(gm)	Stand count after anthesis	Grain yield (t ha^{-1})	Above ground dry matter (t ha^{-1})	Harvest index (%)
P-9529A x WSV387	-50.00**	-10.00**	-22.21*	-24.51**	-20.14*	-5.71*	-32.09**	8.83*	-32.47**
P-9529A x 98MW 6002	-25.00**	-13.13**	-39.88**	-20.85**	-40.54**	-5.71*	-36.32**	-15.11**	-25.42**
P-9529A x PDL 984928	-62.50**	-3.13**	-25.23**	-13.54**	-29.28**	-0.48	-23.60**	-10.76**	-15.04**
P-9529A x ICSR 161	-25.00**	-8.96**	-36.98**	-18.97**	-30.20**	-5.71*	-30.80**	-17.29**	-12.25**
P-9534A x WSV387	-62.50**	-2.08*	1.07	8.20**	10.21	5.71*	3.02**	17.54**	-10.01**
P-9534A x 98MW 6002	-50.00**	-4.38**	-24.53**	-20.95**	-22.00*	-9.52**	-28.43**	2.30	-29.18**
P-9534A x PDL 984928	-62.50**	-12.08**	-35.43**	-42.59**	-35.30**	-1.90	-33.96**	-30.35**	-5.58*
P-9534A x ICSR 161	-25.00**	-6.04**	-35.52**	-17.59**	-31.54**	-7.62**	-30.69**	-21.64**	-11.07**
P-9532A x WSV387	-62.50**	-10.21**	-22.32*	-14.43**	-19.18*	-9.52**	-19.42**	0.12	-18.51**
P-9532A x 98MW 6002	-25.00**	-8.12**	-38.20**	-7.61**	-38.95**	10.00**	-30.87**	-2.05	-26.24**
P-9532A x PDL 984928	-62.50**	-3.13**	2.58	-1.68	7.78	7.14**	17.38**	17.54**	0.38
P-9532A x ICSR 161	25.00**	-3.33**	-23.42*	-7.61**	-16.91	1.90	-12.93**	0.12	-12.11**
BON34A x WSV387	25.00**	-15.00**	-34.30**	-17.79**	-27.48**	-15.24**	-33.42**	-17.29**	-19.60**
BON34A x 98MW 6002	12.50**	-5.83**	-21.87*	-11.07**	-18.45	-6.67**	-24.75**	4.48	-23.52**
BON34A x PDL 984928	75.00**	-10.63**	-33.27**	-39.23**	-36.82**	-1.43	-34.80**	-28.17**	-8.16**
BON34A x ICSR 161	75.00**	-9.58**	-38.42**	-20.45**	-35.02**	4.29	-24.20**	-17.29**	-8.31**

Table 22. (Continued)

Crosses	Number of productive tillers	Panicle length(cm)	Panicle weight(gm)	1000 kernel weight(gm)	Panicle yield(gm)	Stand count after anthesis	Grain yield (t ha^{-1})	Above ground dry matter (t ha^{-1})	Harvest index (%)
P-851015A x WSV387	-62.50**	-0.62	5.83	17.89**	9.63	11.43**	21.23**	11.01**	12.91**
P-851015A x 98MW 6002	-18.75**	-5.21**	-38.55**	-23.32**	-36.03**	-8.57**	-38.17**	8.83*	-40.06**
P-851015A x PDL 984928	-62.50**	-9.79**	-30.09**	-36.36**	-25.83**	-4.29	-24.66**	-21.64**	-4.11
P-851015A x ICSR 161	-62.50**	-2.92**	-0.13	3.46	8.14	5.71*	7.95**	-26.00**	46.82**
P-851063A x WSV387	-62.50**	-11.04**	-21.33*	-9.78**	-30.58**	-2.86	1.91**	-17.29**	23.52**
P-851063A x 98MW 6002	-37.50**	-10.00**	-38.83**	-20.45**	-37.68**	-2.38	-30.59**	-2.05	-26.54**
P-851063A x PDL 984928	37.50**	-13.13**	-39.58**	-52.47**	-39.42**	-7.62**	-38.00**	-34.70**	-5.30*
P-851063A x ICSR 161	-62.50**	-8.75**	-33.33**	-18.28**	-29.94**	-9.52**	-28.67**	-8.58*	-15.38**
P-850341A x WSV387	125.00**	-13.96**	-45.29**	-25.99**	-41.58**	1.43	-33.08**	-19.47**	-17.12**
P-850341A x 98MW 6002	-62.50**	-12.50**	-38.88**	-18.28**	-35.67**	-2.86	-32.47**	-2.05	-29.91**
P-850341A x PDL 984928	37.50**	-11.04**	-38.92**	-27.47**	-35.06**	-16.19**	-40.06**	-4.23	-35.98**
P-850341A x ICSR 161	-62.50**	-6.04**	-7.45	-1.48	-10.93	9.52	5.42**	-17.29**	29.92**
M90950A x WSV387	-25.00**	-6.67**	-35.13**	-9.88**	-25.68**	0.48	-16.24**	-12.94**	-3.90
M90950A x 98MW 6002	-62.50**	-11.88**	-32.85**	-17.89**	-28.06**	-0.95	-20.17**	-17.29**	1.20
M90950A x PDL 984928	-56.25**	-13.75**	-23.23*	-19.66**	-18.94	-1.43	-14.74**	-8.58*	-6.98**
M90950A x ICSR 161	-62.50**	-10.21**	-33.30**	-8.60**	-23.39**	3.81	-0.06	-21.64**	30.08**
SE(m) SC	0.3809	0.9570	9.0270	2.1591	9.6179	2.2891	0.3361	3.9668	2.1689

*and ** = significant, highly significant respectively.

5. SUMMARY AND CONCLUSIONS

Sorghum [*Sorghum bicolor* (L.) Moench] is one of the dominant crops grown in the semi arid tropics with substantial genetic diversity for the most important characters. However, exploiting the enormous genetic potential of this crop prohibited by several production constraints of which drought took the maximum priority.

Thirty two hybrids developed at Melkassa Agricultural Research Center using eight female parental lines (CMS) introduced from Purdue research station selected based on their repose to drought crossed with four male R-lines as per the line x tester mating scheme. A total of 32 F_1 hybrids, 12 parental lines and 2 standard checks were involved in the study and 16 yield and other morphological attributes were considered in order to determine the performance of the hybrids and parental lines in moisture stressed area of the country, estimate the general and specific combining ability of the lines, determine the mode of gene action and estimate percentage of heterosis over the mid parent and standard check value of drought tolerant traits for each CMS female and male R-lines.

Highly significant differences ($P \leq 0.01$) existed among sorghum genotypes for all growth and phonological traits as well as yield and yield components. The sum of squares of genotypes for these traits were further partitioned in to sum of squares pertaining to parents, crosses, checks, parents vs. crosses and checks vs. parents vs. crosses. There were highly significant ($P \leq 0.01$) differences among parents, crosses, checks, parents vs. crosses and checks vs. parents vs. crosses except days to emergency in the growth and phonological traits showed that non significant difference in the parents vs. crosses as well as yield and yield components showed non significant difference for stand count after anthesis in the checks vs. parents vs. crosses, above ground dry matter in the checks, parents vs. crosses and checks vs. parents vs. crosses as well as harvest index in the checks and checks vs. parents vs. crosses components. Similarly the sums of squares for crosses were further partitioned in to sum of squares for lines, testers and line x tester components.

Highly significant differences existed among lines for all growth and phonological traits and yield and yield components except days to 50% emergency in the growth and phonological traits as well as stand count after anthesis and above ground dry matter in the yield and yield components. Highly significant differences were found among testers except days to 50% flowering in the growth and phonological traits and panicle length and stand count after anthesis in the yield and yield components. However, line x tester interaction was highly significant ($P \leq 0.01$) for all the growth and phonological traits as well as yield and yield components.

Highly significant differences among sorghum genotypes, parents, crosses, checks, lines and testers for days to 50% emergence, seedling vigor, days to 50% flowering, days to 50% maturity, plant height (cm), panicle exertion (cm) and number of green leaf per plant in the growth and phonological traits and number of productive tillers, panicle length, panicle weight, 1000 kernel weight, panicle yield, stand count after anthesis, grain yield, above ground dry matter and harvest index were observed.

Among sorghum female lines included P-851063 for early emergency and number of productive tillers per plant, M90950 for seedling vigor, number of green leaves per plant, panicle length, panicle yield, grain yield and above ground dry matter, BON34 for early flowering and maturity were best performed lines.

Among the restores included ICSR161 for panicle exertion and number of productive tillers per plant, restorer WSV 387 for seedling vigor, early maturity, plant height and harvest index and restorer PDL 984928 early emergency, number of green leaves per plant, panicle length, panicle weight, 1000 kernel weight, panicle yield, stand count after anthesis, grain yield and above ground dry matter were best performed restorers.

Female line P-851015 was found the best general combiner for early emergency, maturity, panicle exertion, number of green leaves per plant, panicle length, panicle weight, panicle yield and grain yield, where as P-850341 was the best general combiner for early emergency, seedling vigor, flowering, plant height and number of green leaves per plant. Female line P-9532 was the best general combiner for 1000 kernel weight, stand count after anthesis and above ground dry matter.

Among the superior restore lines included ICSR 161 for early emergency, flowering, maturity, plant height, panicle exertion, panicle length, stand count after anthesis and harvest index and WSV 387 for seedling vigor, number of green leaves per plant, panicle weight, 1000 kernel weight, panicle yield and grain yield were the best general combiner to develop drought tolerant hybrid sorghum.

The estimates of specific combining ability effects revealed that hybrids P-9532 x PDL 984928 for desirable days to 50% emergency, flowering, maturity, seedling vigor, plant height, panicle exertion, number of productive tillers per plant, panicle weight, thousand kernel weight, panicle yield, grain yield t ha^{-1}, P-9534 x WSV387 for seedling vigor, days to flowering, days to maturity, plant height, panicle exertion, number of green leaves per plant, panicle weight, thousand kernel weight, panicle yield, grain yield t ha^{-1}, P-851063A x WSV387 for days to emergency, flowering, maturity, seedling vigor, P-850341 x ICSR161 for days to flowering, days to maturity, number of productive tillers per plant, panicle weight, thousand kernel weight, panicle yield, grain yield t ha^{-1} and P-851015 x WSV387 for seedling vigor, plant height, panicle exertion, panicle weight, thousand kernel weight, panicle yield, stand count after anthesis, grain yield t ha^{-1} were the best specific combiners.

Dominance effects were preeminent for days to 50% emergency, flowering, maturity, seedling vigor, plant height, panicle exertion, number of green leaves per plant, number of productive tillers per plant, panicle length, panicle weight, thousand kernel weight, panicle yield, stand count after anthesis, grain yield t ha^{-1}, above ground dry matter and harvest index.

Proportional contribution of lines x testers was very high, which revealed preponderance of paternal and maternal interaction influence for days to 50% emergency, flowering, maturity, seedling vigor, plant height, panicle exertion, number of green leaves per plant, number of productive tillers per plant, panicle length, panicle weight, thousand kernel weight, panicle yield, stand count after anthesis, grain yield t ha^{-1}, above ground dry matter and harvest index.

Heterotic studies in relation to grain yield cross combinations P-851015 x WSV387, P-851015 x ICSR 161, P-9532 x PDL 984928, P-851063 x WSV387, P-9532 x ICSR 161 and P-850341 x ICSR 161 were the best crosses which depicted more than 50% grain yield t ha^{-} increment over the mid parent value. For standard heterosis cross combinations P-851015 x WSV387, P-9532 x PDL 984928, P-851015 x ICSR 161, P-850341 x ICSR 161, P-9534 x WSV387 and P-851063 x WSV387 were the six more important crosses which gave positive heterosis result over the standard check value (Ethiopian Sorghum Hybrid I).

It could therefore, be concluded that cross combinations P-9532 x PDL 984928, P-850341x ICSR 161 and P-851015 x WSV387 were showed higher specific combining ability, mid-parent and standard heterosis result in relation to grain yield t ha^{-1} and other yield related traits. Hence, female line P-851015 and P-9532 as well as tester line WSV387 and PDL984928 which have high GCA effects for yield and yield components resulted in hybrids with better performance for yield. Moreover, these materials may be selected for population improvement for drought tolerance. However, these should be confirmed further over many locations and season.

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7. APPENDIX

Table 3. Mean square from analysis of variance for phenological and growth traits of eight sorghum lines and four testers tested at Kobo in 2010/11

Sources of Variation	Days to 50% emergence	Seedling vigor	Days to 50% flowering	Days to 50% maturity	Plant height (cm)	Panicle exertion (cm)	Number of green leaf per plant
Replication	0.1159 ^{ns}	0.1377^{ns}	0.2609^{ns}	8.0942*	204.5435*	8.7246*	1.5290^{ns}
Genotypes	1.3805**	7.1240**	7.4134**	26.4329**	2238.419**	101.3424**	4.7628**
Parents	1.5760**	7.3330**	14.3230**	23.0580**	791.967**	71.6440**	6.1720**
Crosses	1.2390**	7.2140**	2.8920**	10.5400**	1765.849**	77.3060**	2.3330**
Checks	6.0000**	6.0000**	32.6667**	216.0000**	1093.50**	73.5000**	16.6667**
Check Vs Parent Vs Cross	3.0201**	4.0019**	33.0922**	256.6326**	770.2718**	141.8889**	11.4245**
Parent Vs Crosses	0.3440^{ns}	8.2840**	20.2050**	95.8340**	35735.35**	1092.0450**	51.2650**
Lines	0.6180 ^{ns}	7.9940**	3.1060**	7.4270**	1569.643**	114.2140**	2.1770**
Testers	2.4270**	10.5690**	2.6220^{ns}	16.0100**	8590.778**	183.3060**	2.3990**
Line x Tester	1.2760**	6.4740**	2.8600**	10.7960**	856.262**	49.8610**	2.3750**
Error	0.3530	0.1969	1.0757	2.1386	63.5879	2.5395	0.7068

*and ** = significant, highly significant at P≤ 0.05 and P≤0.01 probability level respectively and ns-non significant.

Table 4. Mean square from analysis of variance for yield and yield components of eight sorghum lines and four testers tested at Kobo in 2010/11

Sources of Variation	Number of productive tillers	Panicle length(cm)	Panicle weight(gm)	1000 kernel weight (gm)	Panicle yield(gm)	Stand count after anthesis	Grain yield ($t\ h^{-1}$)	Above ground dry matter ($t\ h^{-1}$)	Harvest index (%)
Replication	0.8768*	1.5072ns	27.8051ns	7.7340ns	75.8226ns	7.9638ns	0.1645ns	46.5678ns	11.8285ns
Genotypes	13.7721**	11.3986**	1413.7313**	74.0510**	1051.0425**	23.8011**	1.9601**	53.6185**	31.7838**
Parents	20.1490**	13.9070**	1298.1710**	90.5920**	692.5800**	23.4820**	1.4800**	79.7920**	15.6120**
Crosses	5.4080**	4.7340**	1272.0310**	69.2460**	996.2750**	18.0960**	1.8190**	46.7370**	30.8200**
Checks	8.1667**	73.5000**	1623.6150**	64.0267**	1775.0400**	37.5000*	3.0960**	61.5681ns	5.2267ns
Check Vs Parent Vs Cross	8.8432**	36.8159**	2994.3895**	55.9197**	1678.5465**	22.0704ns	1.9996**	32.3749ns	8.6896ns
Parent Vs Crosses	212.7650**	139.5910**	3917.2470**	77.3130**	5436.9190**	207.6140**	11.5300**	21.5190ns	285.7440**
Lines	10.4150**	8.2370**	1170.5310**	49.0640**	1162.5810**	13.4870ns	1.7860**	40.1290ns	27.4550**
Testers	0.6220*	3.0660ns	1418.0370**	215.4880**	1366.2380**	7.8720ns	3.2270**	100.7900**	97.8010**
Line x Tester	4.4230**	3.8040**	1285.0060**	55.0820**	887.9870**	21.0940**	1.6290**	41.2180*	22.3730**
Error	0.2176	1.3739	122.2312	6.9926	138.7572	7.8601	0.1694	23.6031	7.0559

*and ** = significant, highly significant at P≤ 0.05 and P≤0.01 probability level respectively and ns-non significant.