Australian Journal of Crop Science AJCS
AJCS 9(1):9-13 (2015) ISSN:1835-2707

Heterosis for yield and its components in sorghum (*Sorghum bicolor* L. Moench) hybrids in dry lands and sub-humid environments of East Africa

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Abstract

A study was conducted in 2011 and 2012 growing seasons to determine levels of heterosis and identify parents for use in sorghum hybrid production in East Africa. A total of 36 pairs of male sterile lines and 42 restorers were obtained from ICRISAT-Nairobi and used for generating 121 experimental hybrids in a line × tester mating design. The hybrids were then evaluated at Kiboko, Ukiriguru and Miwaleni locations in an alpha lattice design with three replications. Each genotype was grown in a 4 m long row at spacing of 60 cm ×50 cm. Phenotypic data were collected as per IPGRI, (1993) descriptors for sorghum on five randomly selected plants. There were significant differences among locations, crosses and male parents for all the characters studied. Female lines were highly significant for all traits except days to 50% flowering (DAF). Desired heterobeltiosis for DAF varied from -5.23 to -14% indicating of early maturing material that can escape terminal drought in rainfed agriculture, characteristic of East African cultivation system. Lowest (desired) heterobeltiosis for plant height was -53.61% with crosses ICSA15×Tegemeo and ATX623×KARI-MTAMA1most promising for this trait. Grain yield showed average heterosis and heterobeltiosis of up to 81.90% and 77.18% respectively both expressed in ICSA11×S35. The parents KARI MTAMA1, IESV91104DL, S35, BTX623, ICSB12 and ICSB11 produced hybrids that yielded high with medium height and maturity therefore could be included to develop hybrid sorghum for East Africa region.

Keywords: Average heterosis, heterobeltiosis, sorghum.
Abbreviations: ICRISAT-International Crops Research Institute for the Semi Arid Tropics; IPGRI – International Plant Genetic Resource Institute.

Introduction

Sorghum (*Sorghum bicolor* L. Moench) is a cereal crop native to Africa and staple food crop in many parts of Africa and Asia, especially in sub-humid and semi-arid agro ecologies (Simpson and Conner, 2001). It is among the world's nutritious coarse cereals and traditionally used in unfermented and fermented breads, porridges, snacks, and malted alcoholic and non-alcoholic beverages (Chandrasekara et al., 2011). Despite the fact that Africa contributes >60% of the total land area under sorghum (FAOSTAT, 2012), the yields have remained low (<1t ha^{-1}) due to continuous use of low yielding cultivars. Utilization of hybrid sorghum can significantly increase yields in sorghum growing areas (House et al., 1997) because they out-yield local cultivars and improved varieties by 20 - 60% (Bantilan et al., 2004). In recent years, there has been high demand for sorghum in East Africa due to its drought tolerance and its use in brewing industries. Report by MAFSC (2012) indicates that annual demand for sorghum in Tanzania during 2012 was 3,360 metric tons but production was only 1,084 metric tons implying significant shortage. In Ethiopia, grain yield of up to 6.2t ha^{-1} of hybrid sorghum has been reported (Patil, 2007). Sorghum hybrid NAD-1 in Niger and ICSH 89002NG in Nigeria have been commercially produced with significantly high yield over non-hybrid sorghum (House et al., 1997). Furthermore, in Sudan the popular sorghum hybrid Hageen Dura-1 out-yielded local varieties by 50-85% on farmers' fields and 300-400% under irrigated conditions (Ejeta, 1986). Potential of sorghum hybrids is estimated from the percentage increase or decrease of their performance over the mid parent (average heterosis) and better parent (heterobeltiosis) (Hochholdinger and Hoecker, 2007). According to Lamkey and Edwards, (1999), heterobeltiosis is more realistic and practicable because it shows the performance of the hybrid in comparison with the best parent unlike mid-parent heterosis that compares the hybrid with the mean of the two parents. For the case of this study, average heterosis and heterobeltiosis were worked out in order to have broad picture of performance for materials across dry lands and sub-humid environments. Positive average heterosis and heterobeltiosis in a desired trend is preferred in selection for yield and its components (Lamkey and Edwards, 1999). Furthermore, selection of superior parents for outstanding hybrids depend much on effects of heterosis and heterobeltiosis as also reported by Reif et al.

Table 1. Analysis of variance for some traits evaluated in sorghum across dry low lands and sub-humid environments

Source of Variation	Df	Mean squares						
		Days to 50% flowering	Productive tillers	Plant height (cm)	Panicle length (cm)	Panicle width (cm)	Panicle Exsertion (cm)	Grain yield/ panicle (g)
Environment	2	2382.24**	468.86**	179447.68**	2839.16**	962.58**	3861.24**	111459.71**
Hybrids	88	56.54**	3.24**	5316.32**	49.54**	9.62**	90.26**	1700.66**
A-lines	35	157.02	5.67	6714.09**	106.09**	18.37**	211.61**	1933.95**
R- lines	41	18.73**	2.00*	7540.45**	35.16**	6.99**	45.29**	1587.17**
Error	420	5.65	0.94	221.92	4.69	1.47	11.65	580.59

*, ** significant at 5% and 1% level respectively

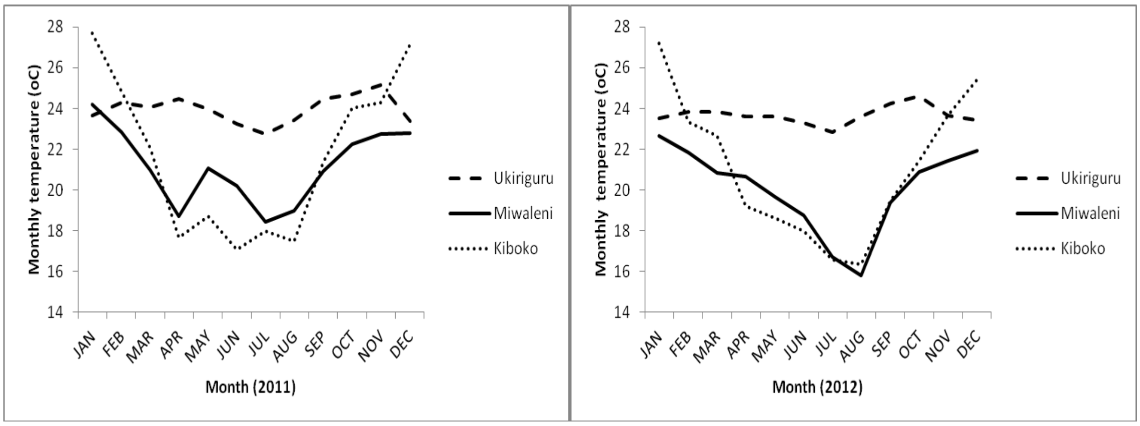

Fig 1. Monthly temperature at Ukiriguru, Miwaleni and Kiboko during 2011 and 2012 seasons.

(2007). Identification, hence utilization of highly productive hybrids can significantly raise production and improve food security in the East African countries as supported by the success stories from Ethiopia (Patil, 2007), Sudan (Ejeta, 1986) and Niger and Nigeria (House et al., 1997). With appropriate selection of parental lines, it is possible to develop superior hybrids sorghum adapted to East African conditions. Objective of this study was to determine the levels of heterosis and heterobeltiosis for yield and yield components by identifying suitable heterotic parents for hybrid sorghum breeding program in East Africa.

Results and Discussions

Data on mean monthly temperature, rainfall and relative humidity from three locations are presented in figures 1, 2 and 3 respectively. In general, Ukiriguru experienced high relative humidity (77 - 79%) and temperatures (18.4 – 29.3^{o}C) especially during flowering (February). The mean monthly rainfall was lower (102mm average) during the same period. Miwaleni location was characterised by relatively higher monthly rainfall (average of 156.2mm), low temperatures (17.3 – 24.4^{o}C) and low relative humidity (54-66.3%) during flowering (March). Kiboko experienced similar conditions to Miwaleni except that rainfall was relatively lower (114mm) in March. There were significant differences among environments, hybrids and inbred lines for all the characters under study (Table 1). The female (A- lines) were highly significant for all traits except days to 50% flowering and productive tillers. Average heterosis and heterobeltiosis in hybrids varied significantly and could be due to genetic diversity of parents used to generate the hybrids and environmental influences. Similar findings are reported by Murty et al., (1994). Variations recorded imply existing potential for exploiting vigor and develop new hybrids. Average heterosis and heterobeltiosis is presented in Supplementary Table 1. Negative (preferred) average heterosis for days to 50% flowering, varied from -4.5 to -17.53% whereas heterobeltiosis ranged between -5.23 to -14%. The most negative average heterosis and heterobeltiosis was expressed in ICSA88001×MACIA indicative of early maturing hybrid. Relatively low heterosis (-3.55 to -22.45) on days to flowering in sorghum was reported by Hemlata and Vithal (2006). A total of 45 and 27 hybrids expressed significant negative average heterosis and heterobeltiosis respectively in days to 50% flowering. It was earlier on reported by Bantilan et al. (2004) that early maturing hybrid sorghum escape terminal drought particularly in rain-fed agriculture typical of east Africa cropping system. Parental lines involved in hybrids that showed negative (desirable) heterosis and heterobeltiosis for DAF can be advanced and commercially released as an open pollinated varieties (OPVs) and developing early maturity hybrids for drought prone areas. Average heterosis for plant height varied from -17.2% to -55.67% whereas heterobeltiosis for the same traits ranged between -11.44 to -53.61%. Hybrids that exhibited negative significant average heterosis and heterobeltiosis were 6 and 4, respectively. ICSA15×Tegemeo and ATX623×KARI-MTAMA1 were the most promising as they were short in stature indicative of dwarfness, thus preferred in dry lowlands. Short sorghums require relatively shorter period to maturity compared to taller ones and withstands lodging as well as easiness during harvesting as also reported by Madhusudhara and Patil, (2013) and Sing et al, (1997). Tall plants can easily lodge but are beneficial in areas where more priority is for fodder, biomass fuel and thatching. Average heterosis for productive tillers ranged from 23.08 to 75.76% whereas heterobeltiosis varied from 25.77 to 56.52%.

Table 2. Superior crosses based on heterobeltiosis for Days to 50% flowering, Plant height, Panicle length, Grain yield per panicle within locations.

TRAIT	KIBOKO	MIWALENI	UKIRIGURU
Days to 50% flowering	IESA2×ICSR24007 MA6×MAKUENI LOCAL	ICSA366×MACIA IESA2×ICSR24010	ICSA11×SP74279 ICSA88001×MACIA
Plant height	ATX623×KARI MTAMA1 ICSA12×KARI MTAMA1	ICSA276×IESV91104DL ICSA6×ICSR93034	ICSA11×S35 ICSA6×ICSR93034
Panicle length	ICSA44×MAKUENI LOCAL ICSA88001×ICSR108	ICSA12×IESV91104DL ICSA687×ICSR172	CK60A×R8602 ICSA44×MAKUENI LOCAL
Grain yield per panicle	ICSA15×TEGEMEO ICSA89003×ICSR89058	ATX623×ICSR23019 ATX623×IESV91104DL	ICSA366×MACIA ICSA88006×KARI MTAMA1

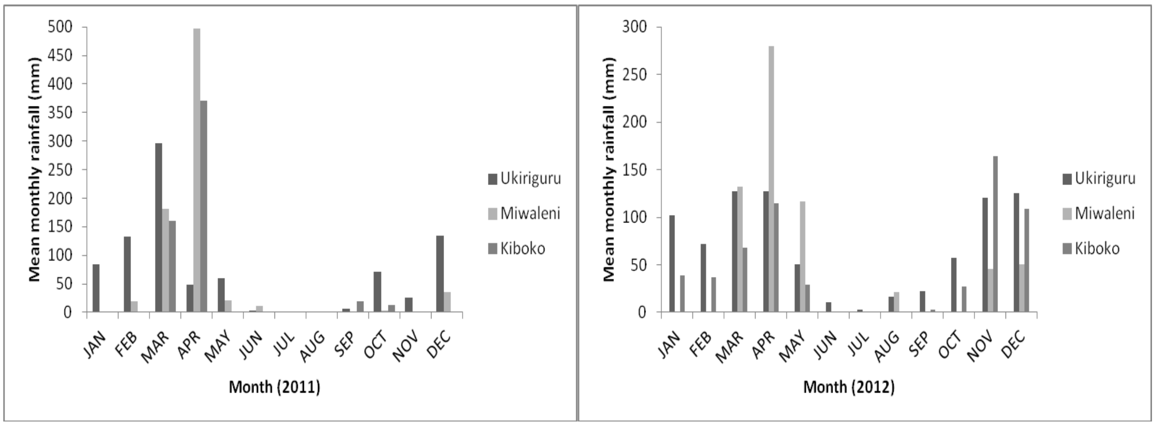

Fig 2. Monthly rainfall at Ukiriguru, Miwaleni and Kiboko during 2011 and 2012 seasons.

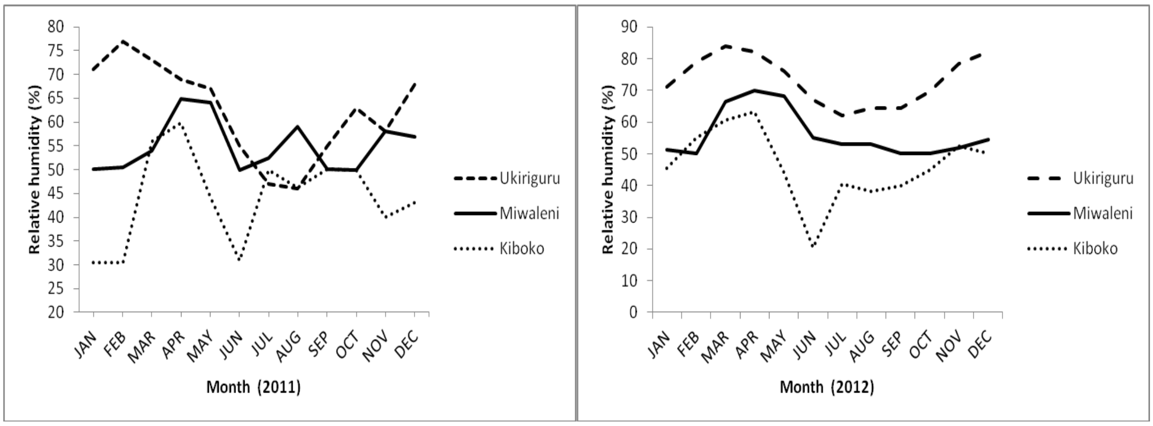

Fig 3. Monthly relative humidity at Ukiriguru, Miwaleni and Kiboko during 2011 and 2012 seasons.

The highest positive significant average heterosis and heterobeltiosis for productive tillers was expressed in the cross ICSA687×IESV23011DL. In sorghum, productive tillers contribute to overall grain yield when water supply is not limiting but profuse tillering is undesirable in dry or sub-humid agroecologies because would reduce water use efficiency as also reported by Madhusudhara and Patil, (2013). In view of heterobeltiosis, the range for panicle length was 10.6 to 17.1% while that of panicle width was 21.0 to 41.4%. However, Hemlata and Vithal (2006) reported relatively higher heterobeltiosis ranging from 39.6 to 48.4% for panicle length and low, 13.1 to 17.9% for panicle width respectively. Positive and significant average heterosis for panicle width ranged between 18.9 expressed in ICSA 12 × IESV 23019) to 54.7 in ICSA 88001 × KARI MTAMA 1. Heterobeltiosis for the same trait varied from 20.9 (CK60A × KARI MTAMA 1) to 40.8 (ICSA 293 × ICSR 24009). Panicle exsertion (length of peduncle from ligule flag leaf to base of inflorescence) is an important attribute that often determine the quality of the grains. Poor panicle exsertion is disadvantageous because the leaf sheath provides favorable conditions for fungi and insects to develop at the base of the panicle hence extend to the whole panicle as also reported by Dogget, (1988). Overall heterosis and heterobeltiosis ranged from 11.64 to 91.10% and 19.38 to 86.86% respectively. Well exserted crosses are more preferred and they were 39 and 26 for average heterosis and heterobeltiosis respectively. The average heterosis and heterobeltiosis for grain yield varied significantly from cross to cross indicating existence of potential heterosis in parental lines. The highest heterobeltiosis was 77.18% and was expressed in hybrid ICSA11×S35. The same hybrids had high average heterosis (81.90%). The grain yield heterosis of 88% has been reported

Fig 4. Some selected sorghum hybrids for semi-arid and sub-humid agroecologies.

by Haussmann et al. (2000) and heterobeltiosis of up to 69.52% for yield per panicle was reported by Hemlata and Vithal (2006). This calls for exploitation of the heterosis from the germplasm used in the present study to develop hybrid sorghum. Hybrid ATX623×KARI-MTAMA1 expressed high heterosis over mid and better parent for yield and majority of phenotypic traits. Variations in heterosis over mid parent and better parent for grain yield in sorghum lines has also been reported by Chapman et al. (2000). Most hybrids that showed positive and significant heterosis for yield also showed it for most of other yield traits as also reported by Jain and Patel (2013). The positive significant heterobeltiosis for grain yield per plant in the hybrids ICSA11×S35 and ATX623×KARI-MTAMA1 could be contributed by high and significant heterosis for productive number of tillers and panicle length. Hemlata and Vithal (2006) reported superiority of hybrids over mid and better parents for grain yield as associated with manifestations of heterotic effects in yield components including panicle length and panicle width. There was no hybrid expressed significant and desired heterobeltiosis for all traits evaluated in all agroecologies (Supplementary table 2). Only two hybrids, CK60A×R8602 and ICSA 687×ICSR162 exhibited significant desired heterobeltiosis for both days to flowering and panicle length indicating high potential of these hybrids for early maturity and grain yield. It was earlier on reported by Bantilan et al. (2004) that, early maturing sorghum can escape terminal drought in rain-fed agriculture, a predominant faming system in east Africa. The lowest (preferred) heterobeltiosis for DAF was -22.8 expressed in the hybrid ICSA11×SP 74279 at Ukiriguru. The lowest (preferred) heterobeltiosis for plant height was -50.6% at Kiboko expressed in ICSA 12 × KARI MTAMA1. The highest desired heterobeltiosis for panicle length was 46.3% in ICSA 90001 × ICSA24008 and for the grain yield was 204.4% in ATX623 × ICSR 23019 at Miwaleni. Several outstanding crosses were identified (Table 2) appropriate for specific agroecologies. It was worthwhile to note that majority of crosses selected for individual location were also good under combined analysis of heterosis. Some of the parents involved in the cross combinations of the selected crosses are superior for more than one trait. For instance, the ATX623 produced crosses that were early maturing and high yielding while ICSA11 produced crosses that were early maturing and short in stature. The line ICSA12 was short in stature and produced long panicles. Additionally, IESV91104DL produced high yielding crosses, long panicles and short statured plants; KARI MTAMA1 produced high yielding crosses and short statured plants. This study revealed that heterotic response for yield and its components in a preferred way was expressed in some cross combinations demonstrating the predominant role of non-fixable interactions. The identified crosses are potential sources of hybrids and could be included in national breeding program in East Africa. Figure 4 shows some of the best selected hybrids at Kiboko, Miwaleni and Ukiruguru.

Materials and Methods

Description of experimental sites

Experiments were conducted in Tanzania (Ukiriguru and Miwaleni) and Kenya (Kiboko) locations respectively. Ukiriguru is found in sub-humid climate (ILCA, 1987) and is located at 2° 43' 0" S and 33° 1' 0" E on 1198m ASL. Temperatures vary from 18.3°C to 29.6°C and annual rainfall of about 861mm. Soil is mainly sandy loam. Miwaleni is located at 3° 25' 30" S and 37° 26' 45" E at 720 m ASL. The soil types are reddish brown and the area experience tropical semi-arid climate. Temperatures range between 10°C to 39°C and the annual rainfall ranging from 500–700 mm (John, 2010). Kiboko lies between 37°45'E and 2°15'S at 960 m ASL and experiences a semi-arid tropical climate with a bimodal rainfall pattern. The annual rainfall is 655mm (www.kari.org). The temperature varies from 13.7^{o}C to 24.7^{o}C. The soil type at this location is sandy clay group.

Plant materials and design

A total of 36 pairs of male sterile lines and 27 restorers (Appendix 1) were obtained from ICRISAT-Nairobi and used to generate 121 experimental hybrids in a line × tester mating design. The hybrids were then evaluated at Kiboko, Ukiriguru and Miwaleni locations in an alpha lattice design with three replications during 2011 and 2012 growing seasons. Each genotype was grown in a 4 m long row at spacing of 60 cm ×50 cm. Data was collected from five randomly selected plants on days to 50% flowering (DAF), plant height (HT) in cm, panicle length (PL) in cm, panicle width (PW) in cm, panicle exertion (PE) in cm, panicle shape (PS), number of tillers per plant (TL) and grain yield (Y) in g/panicle. All data were collected as per standard sorghum descriptors (IPGRI, 1993). The DAF was used as an estimate to maturity status of sorghum materials used in this study.

Statistical analyses

The data collected was analyzed using SAS General Linear Model (GLM) procedure, (SAS, 2008 V9.2). Environments were considered as random effects in the linear model. Analysis of variance was done for each environment according to Gomez and Gomez (1984). Differences were accepted as significant at $p \leq 0.05$. The mid parent heterosis (H_{mp}) and Heterobeltiosis, (H_{bp}) were computed according to Alam et al. (2004) as follows:-

$$H_{mp} = \frac{X_x - X_{mp}}{Xmp} \times 100$$

and

$$H_{bp} = \frac{X_x - X_{bp}}{Xbp} \times 100$$

where:- H_{mp} and H_{bp} = mid parent and better parent heterosis respectively

X_x = observed mean value of the cross

X_{mp} = mean of the mid parent

X_{bp} = mean of the better parent.

Conclusion

This study identified significant and valuable heterobeltiosis and average heterosis for yield and yield components in sorghum that could be harnessed for improving productivity. Parents KARI-MTAMA1, IESV91104DL, S35, ATX623, ICSA12 and ICSA11 produced high yielding hybrids that matured early and short statured including ICSA11×S35 and ATX623×KARI-MTAMA1among others. These materials proposed to be included in breeding hybrid sorghum for sub-humid and dry lands of East Africa region.

Acknowledgements

The authors acknowledge ICRISAT through harnessing opportunities for product enhancement (HOPE) project for providing sorghum materials and financial help for this research.

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