African Crop Science Journal, Vol. 13. No. 2, pp. 143-152, 2005
Printed in Uganda. All rights reserved

ISSN 1021-9730/2005 $ 4.00

HETEROSIS AND COMBINING ABILITY FOR GRAIN YIELD AND ITS COMPONENTS IN INDUCED SORGHUM MUTANTS

R. KENGA, S.O. ALABI[1] and S.C.GUPTA[2]
Institute of Agricultural Research for Development (IRAD) Box 33 Maroua, Cameroon
[1]Ahamadu Bello University, Department of Plant Science/ IAR, Zaria, Nigeria
[2]ICRISAT, NASC Complex, pusa, New Delhi 110 012, India

(Received 27 January, 2004; accepted 16 March, 2005)

ABSTRACT

Heterosis, general combining ability (GCA) and specific combining ability (SCA), and their effects were studied for five major traits in a design II mating system in pure sorghum lines obtained by induced mutation. Significant genotype effect was detected for all traits. GCA effects were highly significant for all traits studied. Effects due to SCA were of less magnitude except on plant height. Some parents were identified having high GCA for grain yield and low or negative GCA for days to anthesis, which were considered as good combiners. The ratio of general combining ability to specific combining ability indicated that additive gene effect was the predominant type of gene action for most yield contributing traits. High positive heterosis for grain yield and its components, including days to anthesis and plant height, was found for more than half of the hybrids studied. Some pure lines evaluated may be used directly as male parents of hybrids and as breeding lines for incorporation into selection programs. The results demonstrate for this set of genotypes the considerable potential that exists for improving the yield performance of sorghum in Western Africa. Importance of genotype x environment interaction underlines the necessity of evaluating breeding materials under a broad range of dry land conditions. This research would assist decisions on parental selection for more extensive study of heterozygosity involving large numbers of genotypes.

Keys Words: Combining ability, heterosis, hybrid breeding, *Sorghum bicolor*, West Africa

RÉSUMÉ

Hétérosis, l'aptitude générale combinée (GCA) et l'aptitude spécifique combinée (SCA), et leurs conséquences étaient étudiés pour cinq traits majeurs dans un système « Mating » design II dans des lignées de sorgho pures obtenus par la mutation provoquée. L'effet significatif de génotype était détecté pour tous les traits. Les effets GCA étaient hautement significatifs pour les traits étudiés. Les effets causés aux SCA étaient d'une magnitude inférieure exceptée sur la taille de plante. Quelques parents étaient identifiés ayant une GCA supérieure pur la production de grain et une GCA inférieur ou négative pour les jours jusqu'au anthèses, qui étaient considérés comme bon combinant. La proportion qui va de l'aptitude générale combinée à l'aptitude spécifique combinée, indique que l'effet de gène additif était le type prédominant de l'action de gène pour la plupart des traits contribuant la production. Une hétérosis positive supérieure pour la production de grain et ses composantes, incluant les jours des « anthèses » et la taille des plantes, était retrouvée pour plus de la moite des hybrides étudies. Quelques lignées pures évaluées pouvaient être utilisées directement comme parents males des hybrides et comme lignées de reproduction dans les programmes des sélections. Les résultats démontrent pour cette série de génotypes le potentiel considérable qui existe pour l'amélioration de la performance de production de sorgho en Afrique de l'ouest. L'importance de génotype, multiplier par l'interaction environnementale souligne la nécessité de l'évaluation du matériel de reproduction sous une large portée des conditions des terrains séchés. Cette recherche guiderait les décisions sur la sélection parentale pour une étude extensive de l'heterozigosité impliquant un grand nombre de génotypes.

Mots Clés: Aptitude combinée, hétérosis, hybride de reproduction, *Sorgho bicolore*, Afrique de l'ouest

INTRODUCTION

Sorghum (*Sorghum bicolor* (L.) Moench) is essential in the diets of people in the semi-arid tropics where droughts cause frequent failure of other crops. It is second in importance to maize in Africa, south of Sahara. However, it is probably more important than maize *(Zea mays)* in Africa as a subsistence crop rather than as a commercial crop (Maunder, 1990; Dendy, 1995). In the western hemisphere, sorghum is primarily grown as a livestock feed. Presently, it is the third largest cereal grown in the United States (Shantharam, 1995).

In the semi-arid tropics of Africa, traditional sorghum cultivars have been farmer-selected over long periods of time, greatly narrowing the genetic base and leading to cultivars that are low yielding but reliable. The increase in population and the subsequent rise in the demand for agricultural products (mainly cereal) are expected to be greater in those regions where production is already insufficient (Pinstrup-Anderson *et al.*, 1999). The necessary increase in agricultural production, therefore, represents a challenge to local farming systems and must come mainly from increased yield per unit area (Evans, 1998). With reducing land resources, it becomes even more important to use plant varieties, which can sustain production under the varied agro-climatic conditions.

Improvement of sorghum by selection within traditional cultivars or by selecting progeny from crosses between similar traditional cultivars has generally not been promising in enhancing yields (House, 1995). Today, plant breeding methods have become increasingly versatile. To increase efficiency, plant breeders combine several methods, which enable them to use technique such as molecular methods to select specific genotypes or mutagenesis to enhance variation. The prime strategy in mutation-based plant breeding has been to upgrade the adapted varieties by altering one or two majors traits. These include characters such as plant height, time to maturity and better grain/straw ratio, which contribute to increase yield and quality traits (Ahloowalia and Maluszynski, 2001).

Many induced mutants have been released as cultivars, while several others have been used as parents in the pedigree of some of the leading cultivars (Ahloowalia and Maluszynski, 2001). Sorghum breeders in the tropics have relied heavily on the genetic diversity within local germplasm and have rarely attempted to enhance variation and exploited it to increase food production. Parra-Negreete *et al.* (1984) evaluated induced mutation and hybridisation methods for producing genetic variability in 15 quantitative characters of sorghum. Their results showed large variability in grain yield, plant maturity, plant height and panicles length. Selected mutants with favorable properties can be directly combined in varietal hybrids. Their heterosis with adapted females could be exploited for obtaining improved hybrid performance. Hybrids not only have yield superiority over open-pollinated varieties, but are more stable across different environments (Haussmann *et al.*, 2000).

Where traditional agriculture predominates, average sorghum yields have ranged between 850 to 1500 kg ha^{-1}, depending largely on moisture availability. This average has remained relatively constant over long periods of time. By contrast, in the USA, yields ranged from 900 to 1260 kg ha^{-1} prior hybridisations, rose to 3775 – 4400 kg ha^{-1} by the 1980's (Maunder, 1990). Heterosis for grain yield in sorghum has been explored in numerous studies. Some studies under variable drought stress conditions have indicated that hybrids out-yielded local varieties by 12% (Haussmann *et al.*, 1998). House (1995) indicated that hybrid sorghum almost universally out-yields non-hybrid varieties; and as growing conditions become stressed, hybrids out-yield varieties by an even greater margin. Besides increasing grain productivity, the improved cultivars with enhanced resistance to yield constraints have not only stabilised yield levels, but also led to cultivar diversity, and thus contributed to sustainable productions systems (Belum *et al.*, 2004).

Therefore one approach to enhance production and maintain grain quality in the dry land agriculture of Africa is to use induced mutants as parents in hybrid production. Breeding hybrid parents is essentially a balance of selection for performance per *se* and for combining ability. The general combining ability is the mean performance of a line when crossed with other lines (Falconer, 1989). The performance of a particular cross can deviate from the average general combining ability of two parental lines. This deviation is defined as the specific combining ability. The differences in GCA are mainly due to additive genetic effects and higher order additive interaction. In contrast, the differences in SCA are attributed to non-additive dominance and other types of epistasis (Falconer, 1989). This analysis, therefore, allows broad inferences on the nature of the gene effects for a trait under selection. The breeder can use this information to formulate an effective programme to breed or develop induced mutant and their hybrids. Knowledge of the combining ability of the materials being developed is essential. Information on heterosis and combining ability of sorghum germplasm is limited and incomplete; much less information is available on heterosis and combining ability on pure sorghum lines obtained by induced mutations. The objectives of this study were to evaluate heterosis and combining ability of some induced sorghum mutants, and identify crosses with high levels of heterosis that could be used to develop improved varieties or F1 hybrids.

MATERIALS AND METHODS

Development of pure lines through induced mutations. The parents were four medium duration cultivars of Fara-Fara groups, at present widely used in West Africa. They were chosen for having above average yield in local trials, and in some case for their relevance to the breeding of other elite lines. Dry seeds of the four sorghum cultivars, NR 71176, NR 71182, NR71168, and KSV4 with uniform size and moisture content regulated to 8% in a desiccators were treated with acute doses of gamma rays (200, 300, 400 Gy). Viable seeds were obtained only from treatment with 300 Gy. The viable seeds were sown in an isolated field free from other sorghum pollen sources at the Institute of Agronomic Research (IAR), Samaru, Zaria in Nigeria. About 100 untreated seeds were sown as controls, for evaluation of the selected variants. The seeds were collected from each M_1 plants on an individual plant basis and were sown in the field in single rows to raise M_2 plants. M_2 individual plants were selfed to produce M_3 plants. The mutants isolated from M_2 were carried to M_3 and M_4 to study their stability and performance. Desirable mutants were selected for the following attributes: early and synchronous maturity, reduced in plant height, higher yield and large grain size. Plants were carefully scrutinized for conformity to the defined characteristics. Any progeny row(s) that showed variation were discarded. Individual plant selection was carried out on M_4 and 50 uniform selfed plants were selected to produce M_5 plants. This also served for the investigation of true breeding of these attributes. Only superior mutants were advanced up to M_7 selfed progenies, generally growing two crops (off-season and rainy season) every year from 1995 to 1999. Thus, 8 promising mutants (there after referred to as pure lines) were developed. These were called NR 71176-1; NR 71176-2; NR 71182-2; NR 71182-3; NR 71168-1; NR 71168-3; KSV4-1, and KSV4-2.

Parental lines, hybrids and cultural conditions. Three types of parental lines are used for hybrid seed production in sorghum. The R line (pollen parent, homozygous for nuclear restorer genes with normal or male fertile cytoplasm), the A line (female or seed parent, homozygous for nuclear non-restorer genes with male – sterile cytoplasm) and the B line (maintainer of A line, homozygous for nuclear non-restorer genes with normal cytoplasm).

Five cytoplasmic genetic male sterile lines (ATX 623, ICSA 38, ICSA 39, ICSA 41 and ICSA 902 NG) used as females, were crossed to each of the eight pure lines to produce 40 F1 hybrids. In addition, 10 other F1 hybrids made by crossing two elite open-pollinated varieties (S 35 and CS 54) to each of the A lines were produced. S 35 and

CS 54 are lines released from the sorghum breeding programme at the Institute of Agricultural Research for Development (Dangi *et al.,* 1998). These elite lines are caudatum types and nonphotosensitive cultivars.

A trial consisting of 64 sorghum entries including 50 F1 hybrids, 8 pure lines used as restorer lines, 5 B lines and one check, was conducted in the field in two years (1999 and 2000 raining seasons) and in two locations. The first location was at the Institute of Agricultural Research for Development (IRAD), research farm (Lat 11^0 30' N, Long 15^0 30' E, alt 300 m) at Maroua in Cameroon. The vegetation in the area around Maroua is typical of the Sudan Sahelien Zone (Windmeiger & Andriesse, 1993). Mean total annual rainfall is approximately 750 mm and the length of the growing period is 120 to 140 days, with frequent drought. The second location was at ICRISAT research station (Lat $11^0$53' N, long 8^0 14'E, alt 440 m) at Bagauda in Nigeria. Mean annual total rainfall is 900 mm and the length of the growing period is 140 – 160 days. The landscape is flat and dissected by low to medium density of inland valleys, typical of the Sudan Savanna zone on plintic luvisol with average depth of 90 cm (Windmeijer and Andriesse, 1993).

Field experiments. The 64 entries were arranged in an 8 x 8 triple lattice design, with three replications at each location. Each plot consisted of four rows, each of 5 m long with spacing of 80 cm between rows, resulting in plot size of 16 m^2. Plots were over-planted by hand and later thinned to a distance of 20 cm between plants at two plants per hill, resulting in about 125,000 plants per hectare. All experiments were rainfed. Standard cultural practices for optimum sorghum production were carried out. The same dose of fertiliser (60 kg N, 40 kg P_2O_5, and 30 kg K_2O) ha^{-1} was applied as a basal dose in each experiment. Fourty six kilogramme of N per ha in the form of urea (100 kg ha^{-1}) was top-dressed five weeks after planting and then incorporated into the soil. Weeding was done manually.

The number of days to anthesis, inflorescence length, plant height, grain yield and seed mass were recorded according to the International Board for Plant Genetic Resources (IBPGR) and ICRISAT descriptor list for sorghum (IBPGR/ICRISAT, 1993). The number of days to anthesis was assessed on a whole plot basis. Plant height and inflorescence length were taken from the two central rows of each plot on five randomly selected plants. At maturity, panicles in the two central rows were cut, sun-dried and threshed to determine the grain yield per plot. Seed mass was obtained in each plot by weighing 1000 seeds counted using a numeral electrical seed counter.

Statistical procedure. All statistical analyses were performed using the general linear model (GLM) procedures (SAS Institute, 1989). Each location x year combination was considered as an environment. The data were analysed in two ways. First lattice designs were analysed separately for each environment (data not shown) and then a combined analysis over environments was computed after a Bartlett's test for homogeneity of error variances indicated that error variances from the individual experiments were homogeneous for all traits. Data used for statistical analyses consisted of individual plot value (not adjusted for lattice block effects) at each environment. Environments were considered as random and genotype (hybrids and parental lines) as fixed effects in the linear model. The statistical model used was as fellows:

$$Y_{ijkr} = \mu + G_i + E_j + (GE)_{ij} + R_{jk} + Bl_{jr} + e_{ijkr}$$

Where Y_{ijkr} is the observation of any variable in the r^{th} replication in the k^{th} block in the j^{th} environment (Env) of the i^{th} genotype; μ is the general mean. G_i and E_j represent the effects of the i^{th} genotype and j^{th} environment, while $(GE)_{ij}$ stands for the genotype x environment interactions, R_{jk} for the replication effect of the k^{th} block at the j^{th} environment, Bl_{jr} for the block effect of the r^{th} replication at the j^{th} environment, while e_{ijkr} designates the random errors associated with the r^{th} replication of I^{th} genotypes at the j^{th} environment in the k^{th} block. (i= 1,2...64; j= 1,2,3,4; k = 1, 2....8; r= 1,2,3;)

Entry main effect and their interactions were partitioned into various components: parent, hybrids, parent vs hybrids, env x parent, env x hybrids, env x hybrids vs parent.

The analysis of variance of the combining ability was carried out according to the Design II of

Comstok and Robinson (1948). The sum of squares for hybrids was further partitioned into variations due to female, male, and female x male interaction. Throughout the text, variation due to males, females, and males x females will be referred to interchangeably as GCA males, GCA females, and SCA variation, respectively (Hallauer and Miranda, 1988). Mean squares for GCA was tested against the mean square for GCA x environments and that for SCA against SCA x environment. For each trait, GCA effect for each parental component was calculated as suggested by Singh and Chaudry (1977).

Standard errors for GCA effects of females and males lines were calculated using the method described by Cox and Frey (1984). Two- tailed t-tests were used to test the significance of the GCA, where $t = GCA/SE_{GCA}$. Ratios of mean square components associated with variance of GCA and SCA effects were computed as suggested by Baker (1978) to estimate the relative importance of GCA in explaining performance. The closer the ratio is to unity, the greater the predictability of progeny performance based on GCA effects alone. High parent heterosis (%) for yield and other trait was calculated for each hybrid across all environments.

RESULTS

The combined analyses of variance across the four environments indicated that mean squares due to entries and entry x environments interaction were highly significant ($P < 0.01$) for all traits (Table 1). The mean squares for hybrids and hybrids x environments was significant for all traits. Differences among parents were not significant for grain yield and parents showed no interaction with environments in all but one trait. The parents vs hybrids source of variation was highly significant ($P < 0.01$) for all but one traits.

Mean squares from the combining ability analyses of crosses in four environments are presented in Table 2. The variances due to GCA (males) were highly significant ($P<0.01$) for all traits. Similarly, the GCA (males) x environments mean squares were highly significant for all traits. Significant differences ($P < 0.05$ or $P < 0.01$) in GCA (females) mean squares were indicated for all traits. But the GCA (females) x environment interaction was significant only for grain yield. The mean squares for GCA (females) were appreciably smaller than those for GCA (males)

The variance due to SCA was highly significant ($P < 0.01$) for plant height. Likewise, the SCA x

TABLE 1. Mean squares from combined analysis of variance for five sorghum traits measured across the four environments of West Africa

Source of variation	Df	Grain yield (kg ha^{-1})	Days to anthesis	Plant height (cm)	Inflorescence length(cm)	1000 seed mass (g)
Environment (ENV)	3	148397669 **	2706**	130947**	721**	5643**
Replication/ ENV	8	9237265**	66**	3382**	73**	61**
Block(REP/ENV)	84	774592	16	3160	34	13
Entries	63	2908982**	65**	26184**	169**	50**
Parents	12	667370	28**	1505**	162**	40**
Hybrids	49	1267459**	64**	19513**	74**	29**
Parents vs Hybrids	1	113151956**	588**	675415**	5117**	1263
ENV x Entries	189	1296135**	20**	1289**	19**	13**
ENV x Parents	36	464549	12	328	21	10*
ENV x Hybrids	147	1298915**	19**	1373**	17*	3*
ENV x Parents vs Hybrids	3	37305270**	524**	30122**	287**	193*
Pooled error	420	733219	9	468	13	8

*, ** Significant at 0,0 5 and 0,1 probability levels, respectively

environments mean squares were highly significant for plant height only.

The estimates of variance due to GCA (GCA males plus GCA females) were higher than those of SCA for all traits. The ratio of GCA to SCA variance was equal or greater than unity for all traits (Table 2).

Estimates of GCA effects of parent for different traits are presented in Table 3. The GCA effects for females indicate that ICSA 902 NG was the best combiner for grain yield. The GCA effects of male parents revealed that line NR 71176-2, KSV4-2 were a good combiner for grain yield.

The effects for SCA are not tabulated here but they were obtained as the deviation of individual cross from the average performance of their parents. There were significant differences in SCA effects among hybrids only for plant height (Table 2).

The performance of some parental lines seemed particularly good across environments. Varying levels of heterosis in relation to high parent heterotic value among hybrids for the different traits are presented in Table 4. The high parent heterosis for grain yield ranged from – 1.9 to 92.2 percent. Twenty four hybrids showed significantly positive and high parent heterosis, while the hybrid ATX 623 x NR 71176-1 recorded the highest value. This was followed by ATX 623 x NR 71168-1 (82.2%), and ICSA 902 x NR 71176-1 (79.7%). In the case of days to anthesis, the highest high parent heterosis value was recorded by the cross ICSA 38 x CS 54.

Generally, many hybrids exhibited high heterosis value (Table 4) for grain yield and its component including days to anthesis and plant height. The direction and magnitudes of heterotic responses varied from one cross to another.

DISCUSSION

Combining analysis of variance over the four environments further confirmed the diversity of the pure lines and their differences in environmental responses. Analysis of the performance of hybrids in the experiments indicated that most genetic variation for each trait measured was associated with significant general combining ability effects. The mean square for GCA (males) was larger than the GCA (females), indicating greater diversity among the male parents. Significant interactions between the environment and GCA (male) for all traits indicate the differences of genotypes in environment responses for these traits. The GCA (females) x environments mean square was significant for

TABLE 2. Means squares from combining ability analysis of variance for five traits of sorghum measured across the four environments of West Africa

Source of variation	Df	Grain yield (kg ha^{-1})	Days to anthesis	Plant height (cm)	Inflorescence length(cm)	1000 Seed mass (g)
Environment (ENV)	3	148397669**	2706**	130947**	721**	5643**
Hybrids	49	1267459**	64**	19513**	74**	29**
GCA (males)	9	2652832**	158**	85370**	337**	55**
GCA (females)	4	2339547*	122**	8642**	103**	213**
SCA (m x f)	36	915830	24	2053**	16	16
Hybrids x ENV	147	1298915**	19**	1337**	17*	13*
GCA (females) X ENV	12	2094800**	15	869	7	21
GCA (males) X ENV	27	2871506**	55**	1472**	51**	30**
SCA X ENV	108	828040	20	1624**	11	11
Pooled error	307	869765	18	671	14	13
GCA/SCA		1.0	2.20	10.8	6.08	2.38

*, ** Significant at 0,05 and 0,1 probability levels, respectively

only one trait, indicating that GCA (females) effects were more consistent in expression over environments.

The mean squares for GCA were larger than the mean squares for SCA for each of the components of yield evaluated, even where SCA was statistically significant. The ratio for GCA to SCA ranged from unity upward to a high of 10; indicating the preponderance of additive gene effects in the variance expressed for those traits. These results are consistent with those reported by Can *et al.* (1997) and Andrews *et al.* (1997). Crossing two parents showing the highest general combining ability for a desired trait may produce the best performing cross due to an increase in frequency of favorable gene. Based on the estimates of GCA effects, it was observed that parents ICSA 902 NG, NR 71176-2 and KSV4-2 were the best combiners for grain yield. The superior combining ability of these lines could be exploited either by involving them in hybridization programmes or by recurrent crossing in the segregation generation followed by selection.

For days to anthesis, a relatively higher number of parents showed non-significant negative GCA. The parent NR 71176-1 and CS 54, which showed significant positive GCA, may be useful for incorporation of delayed maturity.

Significant positive GCA is preferred for most of the traits; but positive effects for days to anthesis, plant height may not be desirable in all sorghum growing areas; thus, the combining ability effects of those traits must be assessed in the context of agro-ecological zones or cropping seasons.

However, significant SCA mean square was indicated for plant height suggesting that non-additive gene effects also contributed to variation expressed for this trait. Lack of significance of SCA means shows that the genes which condition such characters as grain yield, days to anthesis, inflorescence length and seed mass are additive.

Quantitative genetic theory states that heterosis is a function of increasing genetic diversity among the parents (Falconer, 1989). Crosses among the

TABLE 3. Estimates of General Combining Ability effects of parent for different sorghum traits across four environments in West Africa

Parents	Grain yield (kg ha^{-1})	Days to anthesis	Plant height (cm)	Inflorescence length(cm)	1000 seed mass (g)
Female lines					
ATX 623	3.3	-0.03	1.31	-0.11	0.39
ICSA 38	23.0	0.20	0.51	-0.16	-0.17
ICSA 39	-53.4	0.37	-3.42	-0.06	-0.32
ICSA 41	-14.25	-0.33	0.16	-0.11	0.24
ICSA 902	41.35**	-0.21	1.44**	0.44	-0.14
SE ±	135.39	0.47	3.42	0.57	0.46
Male lines					
NR 71176-1	-31.23	0.10*	-9.04	0.32	-0.32
NR 71176-2	95.93*	-0.26	-5.69	0.67	-0.12
NR 71182-2	-60.53	-0.01	-8.14	0.07	-0.17
NR 71182-3	27.03	-0.31	-8.09	0.47	-0.02
NR 71168-1	-31.03	-0.01	-8.89	0.77	-0.12
NR 71168-3	-66.33	-0.11	-8.74	0.37	-0.12
KSV4-1	-7.78	-0.51	5.26	-0.69	0.14
KSV4-2	52.58*	-0.71	7.66	-0.74	0.09
S 35	-50.93	0.10	17.86*	-0.79	0.04
CS 54	72.28	0.80*	17.81*	-0.44	0.59
SE ±	191.47	0.66	4.84	0.80	0.64

* ** Significant at 0,05 and 0,1 probability levels, respectively

TABLE 4. Heterosis expressed as percentage of better – parent for five traits across four environments in West Africa

Crosses	Grain yield	Days to anthesis	Plant height (cm)	Inflorescence length	1000 seed mass (g)
ATX 623 x					
71176-1	92.2**	-1.4	40.8**	2.9	9.5
71176-2	72.2**	-4.0*	44.5**	5.7	4.6
71182-2	21.6	-	31.8**	-	4.2
71182-3	28.9*	-	31.1**	-	8.7
71168-1	82.4**	-4.1	39.0**	2.9	18.2**
71168-3	11.2	1.4	24.5**	2.9	-
KSV4-1	20.6	-4.2*	41.2*	-11.4**	13.0**
KSV4-2	33.7**	-2.8	38.5**	-17.1**	8.3
S 35	7.1	7.0*	29.8**	-11.4**	-14.3**
CS 54	12.1	4.2*	33.9**	-11.4**	-11.1
ICSA 38 x					
71176-1	54.1**	-2.7	25.2**	-	4.8
71176-2	72.0**	-4.1	30.9**	8.6*	4.6
71182-2	31.7*	-	26.5**	-	12.5*
71182-3	51.0**	-2.8	28.5**	5.7	8.7
71168-1	44.7*	-1.4	28.8**	5.7	4.5
71168-3	44.6*	-	15.5**	2.9	-8.3
KSV4-1	15.7	-4.2*	35.8**	-14.3**	4.4
KSV4-2	40.9**	-2.8	39.6**	-11.4**	-4.2
S 35	-1.9	6.9**	46.4**	-11.4**	-21.4**
CS 54	10.2	6.9**	46.4**	-11.4**	-7.4
ICSA 39 x					
71176-1	34.5	-1.4	20.4**	2.9	4.8
71176-2	52.9**	-1.4	21.3**	8.8*	-
71182-2	18.1	1.4	15.9**	-2.9	-12.5*
71182-3	17.9	1.4	19.9**	5.9	-8.6
71168-1	45.9*	-1.4	22.6**	8.8*	-4.5
71168-3	38.0*	1.4	27.1**	2.9	-8.3
KSV4-1	11.4	4.2*	13.9**	-5.9	-8.7
KSV4-2	7.9	1.4	11.2*	-	-8.3
S 35	8.9	5.6**	45.1**	-11.8**	-10.7*
CS 54	2.7	5.6**	42.1**	-2.9	-11.1**
ICSA 41 x					
71176-1	59.4**	-4.1*	31.5**	-2.7	14.3*
71176-2	60.7**	-6.7**	26.5**	-2.7	9.1
71182-2	25.4	-2.7	29.9**	-5.4	4.2
71182-3	16.9	-5.4**	31.8**	-8.1*	4.4
71168-1	43.1*	-4.1*	28.1**	2.7	9.1
71168-3	50.7**	-2.7	24.5**	-8.1*	-
KSV4-1	3.1	-6.8**	13.9**	-16.2**	17.4**
KSV4-2	19.3	-9.5**	42.8**	-10.8**	-
S 35	22.7	-2.7	40.9**	-16.2**	-7.2
CS 54	3.3	-1.4	40.7**	-10.8**	-3.7

*, ** Significant at 0,05 and 0,1 probability levels, respectively

male and female lines were characterised by heterosis in all traits studied, though the amount of heterosis varied from cross to cross. The heterotic responses were high for grain yield and plant height. The mean relative superiority of hybrids over high-parent value for grain yield (92.2%) lies above the average estimate reported for sorghum in the literature. Africa's hybrids breeding programmes with sorghum have used female parents descended from exotic lines in combination with African restorer genotypes (House, 1996). Lack of adaptation of some female lines can result in a lower mid-parent performance but may be overcome in hybrids by 50% "adapted" genome from the male parent, leading indirectly to above average heterosis estimates (Haussmann *et al.*, 1998). In fact, the females parents used in the present study generally had a lower mean grain yield than the restorer lines; however, three appeared to be well adapted and exhibited very high heterosis. The expression of such value of heterosis clearly indicates the agronomic potential of these lines for breeding to increase grain yield.

Since additive gene effects were more important than their non-additive counterparts in controlling all characters but one, preliminary screening of the relative potential of these pure lines for use in hybrid combination could be accomplished by crossing to few adapted female lines and evaluate the performance of resulting hybrids in several environments. From the present study it appears that increasing the variability of the region's germplasm would facilitate the selection of adapted parent suitable for producing high yielding hybrids. In addition, some pure lines evaluated should prove useful directly as male parents of hybrids and as breeding lines for incorporation into the selection programmes. The male NR 71176-2 and KSV4-2 were capable of transmitting high yielding potential to offspring. The female ICSA 902 NG would transmit three positive characters (high yielding, earliness, and medium to tall plant status). These seed parents have good potential for developing hybrids and, thus, stabilise yields gain. On the other hand, the parents S 35 and CS 54 were poor general combiners with respect to important traits such as yield and earliness. CS 54 would only contribute to tall plant status and delay flowering, while S 35 would contribute to tall plant status and medium to low yield.

Since the effects of parents were considered to be fixed, these inferences cannot be extended to the whole sorghum population. However, the information generated from this experiment would assist decisions on parental selection for additional studies with advanced generations and large number of genotypes to verify the extent of these findings.

The development of parental lines that are high yielding, yet derived from genetically diverse population should be the ultimate goal of sorghum breeding programs.

REFERENCES

Ahloowalia, B .S. and Maluszynski, M. 2001. Induced mutations – a new paradigm in plant breeding. *Euphytica* 118:167-173.

Andrews, D.J., Ejeta, G., Gilbert, M., Goswani, P., Anand Kumar, K., Mauder, A. B., Porter, K., Rai, K. N., Rajewski, J. F., Belum, V.R., reddy, P. S., Stegmeier, W. and Talukdar. B. S. 1997. Breeding hybrid parents. In: D. Rosenow *et al.*, (Eds.), pp. 173-187. *Proceedings of the Int. Conf. On Genetic Improvement of Sorghum and Pearl Millet.* INTSORMIL /UNL., Publication 97-5. Lubbock,Texas, USA.

Baker, R.J. 1978. Issues in diallel analysis. *Crop Science* 18:533-536.

Belum, V.R., Ramesh, S. and Reddy, P.S. 2004. Sorghum Breeding Research at ICRISAT. Goals, Strategies, Methods and Accomplishments. *International Sorghum and Millets Newsletter* 45:5-12.

Can, N.D., Nakamura, S. and Yoshida, T. 1997. Combining ability and genotype x environmental interaction in early maturing grain sorghum for summer seeding. *Japanese Journal of Crop Science* 66:698-705.

Comstock, R.E. and Robinson, H. F. 1948. The components of genetic variance in population of biparental progenies and their use in estimating the average degree of dominance. *Biometrics* 4: 254 - 266.

Cox, D.J. and Frey, K. J. 1984. Combining ability and the selection of parents for interspecific oat mating. *Crop Science* 24:963-967.

Dangi, O. P., Kenga, R., Rao, N.G. and Murty, D.S. 1998. Registration of "S 35" Sorghum cultivar. *Crop Science* 38:1718.

Dendy, D.A.V. 1995. Sorghum and Millet: Chemistry and technology. *Am Assoc. of Cereal Chem.*, St. Paul, MN.

Evans, L.T. 1988. Feeding the ten billion: Plants and population growth. New York, Cambridge Univ. Press.

Falconer, D.S. 1989. Introduction to quantitative genetic. 3rd ed. Longman Scientific and Technical CO., Essex, England. pp. 275 - 276.

Hallauer, A.R. and Miranda, J. B. 1988. Quantitative genetics in maize breeding. 2nd. Ed. IOWA State University Press, Ames, USA. pp. 1 - 373.

Haussmann, B.I.G., Obilina, A. B., Blum, A., Ayiecho, P. O., Schipprack, W. and Geiger, H. H. 1998. Hybrid performance of sorghum and its relationship to morphological and physiological traits under variable drought stress in Kenya.*Plant Breeding* 117:223-229.

Haussmann, B.I.G., Obilina, A. B., Ayiecho, P. O., Blum, A., Schipprack, W. and Geiger, H. H. 2000. Yield and yield stability of four population types of grain sorghum in a semi-arid area of Kenya. *Crop Science* 40:319-329.

House, L. R. 1995. Sorghum: One of the world's great cereals. *African Crop Science Journal* 3: 135-142.

House, L. R., Verma, B. N., Ejeta, G., Rana, B. S., Kapram, I., Obilana, A.B. and Reddy, B. V. S. 1997. Developing Countries breeding and potential of hybrid sorghum. In: Rosenow, D. *et al.*, (Eds.), pp. 84-96. Proceedings of the *International Conference on Genetic Improvement of Sorghum and Pearl Millet.* INTSORMIL /UNL., Publication 97- 5. Lubbock, Texas, USA.

IBPGR/ICRISAT. 1993. Description for sorghum. IBPGR Secretariat, FAO, Rome, Italy. pp. 1-26

Maunder, A. B. 1990. Importance of sorghum on a global scale. In: Ejeta, G. *et al.*, (Eds.), pp. 6-16. *Proceedings of the International Conference on sorghum nutritional quality.* Purdue University, West Lafayette. IN, USA.

Parra-Negrette, L. E., Mendoza, O. and Orficereceres, J. 1984. Comparison of mutant lines. Parental collections and elite lines. *North American Sorghum Newsletter* 29:14-15.

Pinstrup-Anderson, P., Pandya-Lorch R. and Rosegrant M. W. 1999. World food prospects: Critical issues for the twenty-first century. Washington, IFPRI, USA.

SAS Institute. 1989. SAS Users' guide: Statistics. Version 5 ed. SAS. Inst. Cary, NC, USA.

Shantharam, S. 1995. The importance of biosafety in the deployment of private transgenic sorghums in the environment. *African Crop Science Journal* 3:131-133.

Singh, R.K. and Chaudhary, B. D. 1977. Biometrical Methods in quantitativegenetic analysis. Kalyani Publishers, Ludhiana New Delhi, India. pp. 318.

Windmeijer, P.N. and Andriesse, W. 1993. Inland valleys in West Africa: An agro- ecological characterization of rice-growing environments. Publication 52, International Institute for Land Reclamation and Improvement: Wageningen, Nertherlands.