Journal of Plant Breeding and Crop Science Vol. 1(9). pp. 311-319, November, 2009
Available online http://www.academicjournals.org/jpbcs
ISSN 2006-9758 © 2009 Academic Journals

Full Length Research Paper

Line x tester analysis across locations and years in Sudanese x exotic lines of forage sorghum

Maarouf I. Mohammed

Shambat Research Station, ARC, P.O. Box 30, Khartoum North. Sudan. E-mail: ibrahimarof@yahoo.com.

Accepted 5 October, 2009

Combining ability in forage sorghum [*Sorghum bicolor* (L.) Moench] was not as much investigated as in grain sorghum. In the present study, 4 local stocks (Testers) and 7 exotic stocks in A3 cytoplasm were crossed in line x tester fashion to investigate combining ability in forage sorghum. The hybrids and their parents were evaluated across two years (2002 - 2003) and at two locations in Khartoum State, Sudan. Forage yield, days to flower, plant height, leaf to stem ratio and stem diameter were studied. Significant general (GCA) and specific combining ability (SCA) effects in desirable direction were detected for most traits. The best general combiners for forage yield and earliness in flowering were identified. Both additive and non-additive gene actions were important in the expression of all characters with the preponderance of additive actions for days to flower, forage yield, stem diameter, leaf to stem ratio and non-additive actions for plant height. GCA effects were more stable over years than specific ones. Selection in early generations was suggested for characters predominately controlled by additive genes. Heterosis breeding was recommended for forage yield improvement. For leaf to stem ratio, selection must be based on more genetically diverse materials.

Key words: A3 cytoplasm, additive, ankolib, combining ability, islang, hybrid sorghum, shambat.

INTRODUCTION

Forage sorghum [*Sorghum bicolor* (L). Moench] has recently witnessed an increasing importance in the semi arid tropics and drier parts of the world where livestock constitutes a major component of the production system. Compared to other cereals, especially maize, sorghum is more droughts tolerant, less input demanding and can thrive better under harsh conditions. Most of sorghum improvement programs are grain oriented. Improvement for non-grain attributes has been limited. Kelley et al. (1991) questioned the current strategy of strictly adopting grain-yield criteria in evaluating sorghum genotypes, arguing that fodder's contribution to the total value of sorghum production has increased considerably. They reported that the grain/straw price ratio of sorghum has dropped from 6:1 in 1970 to 3:1 in 1990 and is likely to decline further. In the Sudan, where the second largest animal wealth in Africa exists, forage sorghum constitutes the bulk of the animal feed in the country (Mohammed, 2007). Very little or no attempts have been made to develop improved forage types. The first fully devoted forage improvement program in the country was initiated in 2000 (Mohammed et al., 2008). One of the program objectives was to develop locally adapted forage sorghum hybrids. Knowing general (GCA) and specific (SCA) combing ability effects of genetic materials is of practical value in breeding programs. Both components play an important role in selecting superior parents for hybrid combinations (Duvick, 1999) and represent a powerful method to measure the nature of gene action involved in quantitative traits (Baker, 1978). GCA effects represent the fixable component of genetic variance, and are important to develop superior genotypes. SCA represents the non-fixable component of genetic variation, it is important to provide information on hybrid performance. Most of our present information about combining ability in sorghum was based on studies carried under temperate environments with materials limited to photoperiod conversion program (Maunder, 1992). The objectives of this study were to investigate combining ability for some agronomic traits in introduced and local forage sorghum genetic stocks using line x tester analysis to identify parents with desirable GCA effects and cross combinations with desirable SCA effects and to study the nature of gene action involved in

Table 1. Genetic stock designation, recurrent parent and cytoplasm source of the seven female parents used as lines in the study.

Genetic stock	Recurrent parent	Cytoplasm source	Pericarp color	Mid-rib color
A3N166	Blue Ribbon	A3Tx 398	brown	green
A3N168	Hastings	A3Tx 398	brown	green
A3N169	E-35-1	A3Tx 430	white	green
A3N159	N 100	A3Tx 398	brown	green
A3N173	N 109	A3Tx 398	white	green
A3N154	Sugar Drip	A3Tx 398	brown	green
A3N151	Dale	A3Tx 398	brown	green

yield and related traits in forage sorghum.

MATERIALS AND METHODS

Plant materials

Seven forage sorghum genetic stocks in A3 cytoplasm chosen from the materials received from J. F. Pedersen, USDA-ARS, USA were used as females (Lines) in this study. They include: Blue Ribbon, Hastings, Sugar Drip, Dale, N100, E-35-1, and N109. Table 1 reflects the genetic stock designation, recurrent parent and cytoplasm source of the seven selected females. The males (Testers) comprised four local genetic stocks, two of which, namely: S.70 and S. 186 represent the two major types of the traditional cultivar 'Abu Sab'in', known as Alyab and Rubatab, respectively. The other two were: 'Garawi', a cultivated forage type of Sudan Grass (*Sorghum sudanense* (Piper) Stapf) and 'Ankolib', a local sweet sorghum cultivar. They are heterogeneous land race cultivars with broad genetic base, desirable for providing information about the general combining ability of a line. Abu Sab'in selections, on the other hand, are expected to show good performance in specific hybrid combinations with the selected lines.

The experiment

The seven lines and the four testers were grown together with their 28 hybrids for two years (2002 and 2003) and at two locations in Khartoum State, namely: Shambat (lat.15° 39' N; long. 32° 31' E) and Islang (lat.15° 53' N; long. 32° 32' E). The soil at Shambat site is heavy clay with pH 8.5. The physical properties of Islang soil varies from silty clay to silty loam. The growing season of the year 2002 compared to that of 2003 was characterized by increased maximum temperature, reduced total rain fall and lower relative humidity. In the year 2002, sowing date was on the 12th and 25th of July at Shambat and Islang, respectively, while in the year 2003, sowing date was on the 24th of June and 11th of July at Shambat and Islang, respectively. Apart from that, other methods and materials were similar for different years and locations. The treatments were arranged in a randomized complete block design with three replicates. The plot size was 7.5 x 0.7 m ridge. Three to four seeds were sown in holes spaced at 10 cm along the ridge. The plants were later thinned to one plant per hole. The experiment was watered every 7 - 10 days. Harvesting was carried out 15 days after each entry had completed 50% flowering, which simulates the common farmer practice.

Green matter yield (GMY) was estimated from 6.5 m harvested from each plot leaving 0.5 m from each side. The dry matter yield (DMY) was estimated from a random sample of 0.5 kg taken from the harvested plot after determining GMY and oven-dried at 75°C for 48 h. Yield related traits include: Days to flower, plant height, stem diameter and leaf to stem ratio.

Statistical analysis

Single analysis of variance was performed for all characters prior to combine analysis. Line x tester analysis was performed based on data combined over years and locations. Source of variation due to entry and its interaction with year and location were subdivided into variations due to hybrids and parents. Similarly, the hybrid source of variation was partitioned into variations due to lines, testers and line x testers. Estimates of general (GCA) and specific (SCA) combining ability based on data combined over years and locations were worked out following the procedure of Biel and Atkins (1967) which is comparable to the analysis of a two-way classification model with interaction component being a measure of the SCA effects. Estimate of GCA of a tester (male) was obtained in terms of its performance in F1 hybrid combinations with all possible lines (females). Likewise, GCA of a line was determined in terms of its performance in F1 hybrid combinations with all possible testers. The lines and testers were considered as fixed effects. Years and location were considered as random effects. GCA and SCA effects were determined for each trait as follows:

GCA lines (L) = $\bar{X}_{j} - \bar{Y}$

GCA tester (T) = $\bar{X}_{i} - \bar{Y}$

SCA (L x T) = $\bar{X}_{ij} - \bar{X}_{j} - \bar{X}_{i} - \bar{Y}$,

Where:

$\bar{X}_{j}$: = the mean of hybrid with a given line (female) averaged over all replications, years, locations and testers (males),

$\bar{X}_{i}$: = the mean of hybrid with a given tester (male) averaged over all replications, years, locations and lines (females),

$\bar{X}_{ij}$: = the mean of a given hybrid (L x T) averaged over replications, years and locations,

$\bar{Y}$: = the experimental mean.

Standard errors (SE) for general and specific combining ability were calculated following Groz et al. (1987) as follows:

$SE_{Lines} = (M_{fyl} / rmyl)^{½}$, SETesters = $(M_{myl} / rfyl)^{½}$, and $SE_{Line\ x\ Tester} = (M_{fmyl} / ryl)^{½}$,

Where

M_{fyl} and M_{myl} are the respective mean squares of line x year x location and tester x year x location divided by number of observations (replicates, years, locations, males or females). M_{fmyl}

Table 2. Mean squares from combined ANOVA for green (GMY), dry (DMY) matter yield and yield related-traits of 28 forage sorghum hybrids and their parents tested over 2 years (2002-03) and 2 locations (Shambat, Islang).

		Mean squares					
Source of variation	**d.f.**	**GMY (t/ha)**	**DMY (t/ha)**	**Days to flower**	**Plant height (cm)**	**Stem diameter (cm)**	**Leaf/stem ratio (%)**
Year (Yr)	1	436.70 **	1.668 NS	2239.59 **	1868.29 **	0.799 **	204.719 **
Location (Lo)	1	1135.55 **	16.193 **	208.154 **	19192.88 **	1.801 **	1569.0 **
Yr x Lo	1	9.798 NS	0.708 NS	49.51 **	4598.93 **	0.006 NS	20.459 NS
Rep (Lo x Yr)	8	76.629 *	2.194 **	65.418 **	9975.56 **	0.027 NS	121.118 **
Entry (E)	38	854.685 **	15.247 **	728.104 **	8885.22 **	0.412 **	183.739 **
Parent (P)	10	618.172 **	10.445 **	838.553 **	13064.32 **	0.488 **	384.088 **
Hybrid (H)	27	364.729 **	8.188 **	701.545 **	892.809 **	0.282 **	63.359 **
P vs H	1	16448.65 **	253.87 **	340.69 **	182889.5 **	3.157 **	1430.49 **
Yr x E	38	71.512 **	1.208 **	28.654 **	752.389 **	0.060 **	19.696 *
Yr x H	27	73.063 **	1.313 *	25.930 **	944.406 **	0.057 **	22.027 *
Yr x P	10	56.451 **	0.979 **	36.296 **	255.725 NS	0.027 **	15.291 *
Lo x E	38	2.059 NS	0.047 NS	0.958 NS	57.063 NS	0.002 NS	2.936 NS
Lo x H	27	1.588 NS	0.050 NS	0.477 NS	36.683 NS	0.002 NS	1.824 NS
Lo x P	10	3.034 NS	0.045 NS	2.061 NS	105.924 NS	0.002 NS	3.382 NS
Yr x Lo x E	38	3.320 NS	0.066 NS	1.154 NS	54.654 NS	0.006 NS	4.501 NS
Yr x Lo x H	27	1.997 NS	0.049 NS	0.460 NS	24.475 NS	0.003 NS	0.761 NS
Yr x Lo x P	10	6.842 NS	0.092 NS	2.212 NS	111.420 NS	0.0 12 NS	11.161 NS
Error	304	31.530	0.671	6.486	253.073	0.016	12.122

*, **: Significant at 0.05 and 0.01 probability level respectively. NS: Non-significant at 0.05 probability level.

is the mean square for (line x tester) x year x location divided by number of observations (replicates, years, locations).

The critical difference (C.D.) was calculated as follows: C.D. = SE x t (tabulated). If the absolute effect of GCA or SCA is greater than the C.D., it is considered significantly different from zero. Data analysis was performed using the statistical package of GenStat (2006).

RESULTS

Table 2 reveals that the entries and their sub-sources of variation (parents, hybrids, and parents vs hybrids) differed significantly ($p < 0.01$) for all characters. Their interactions with years, unlike those with locations, were significant for most characters. Table 3 shows that differences among lines, testers and line x tester were significant ($p < 0.01$) for all characters. The interaction of lines with years was significant ($p < 0.01$) for days to flower, plant height and stem diameter and that of testers was significant ($p < 0.05$) for DMY and plant height. The line x tester interaction with years, unlike that with locations, was significant for all characters.

General and specific effects

Tables 4 and 5 show that significant GCA effects were expressed by some lines and testers in nearly all characters. The exceptions being plant height for both lines and testers and leaf to stem ratio for lines (Table 5). More significant cases were displayed by testers compared to lines, with significant cases being more frequent for number of days to flower. Table 4 shows that the highest significant ($p < 0.01$) positive GCA effects for yield was expressed by E-35-1 and S.70 among lines and testers, respectively. Yield ranking indicated that both entries were among the top yielders. Positive, but insignificant, GCA effects were shown by the line Dale and the tester Ankolib. For days to flower, where negative effects are desirable, Blue Ribbon from lines and S.186 from testers showed the highest significant ($p < 0.01$) negative GCA effects, followed by N 109 and Garawi from lines and testers respectively (Table 5). Positive significant ($p < 0.01$) GCA effects were expressed by the line E-35-1 and the tester Ankolib. For leaf to stem ratio, Garawi, among testers, gave the highest significant ($p < 0.01$) positive GCA effect followed by Ankolib. No significant GCA effects were displayed by lines for leaf to stem ratio. For Plant height, no significant GCA effects were displayed by both lines and testers.

Table 6 shows that significant ($p < 0.01$) positive SCA effect for GMY was shown by 6 hybrids, of which Sugar Drip x Ankolib, and Blue Ribbon x Ankolib scored the highest SCA estimates. Yield ranking indicated that hybrids with significant positive SCA effects were also among the best in per se performance. However, the hybrid E-35-1 x S.70, which was the top yielder in the whole material, showed insignificant negative SCA effects.

Table 3. Mean squares from line x tester analysis based on data combined over 2 years and 2 locations for green (GMY), dry (DMY) matter yield and yield-related traits of 28 forage sorghum hybrids.

Source of variation	d.f.	Mean squares					
		GMY (t/ha)	DMY (t/ha)	Days to flower	Plant height (cm)	Stem diameter (cm)	Leaf/stem ratio (%)
Line (L)	6	796.872 **	20.309 **	1401.07 **	1094.33 **	0.584 **	42.740 **
Tester (T)	3	746.501 **	18.101 **	2795.20 **	1150.74 **	0.800 **	288.405 **
L x T	18	157.164 **	2.495 **	112.302 **	783.923 **	0.092 **	32.893 **
Yr x L	6	63.994 NS	0.758 NS	28.563 **	1126.39 **	0.097 **	3.818 NS
Yr x T	3	74.368 NS	2.104 *	14.283 NS	895.652 *	0.040 NS	13.478 NS
Lo x L	6	1.006 NS	0.054 NS	0.323 NS	58.491 NS	0.002 NS	2.246 NS
Lo x T	3	1.208 NS	0.011 NS	0.243 NS	42.494 NS	0.001 NS	1.211 NS
Yr x Lo x L	6	4.669 NS	0.072 NS	0.693 NS	43.438 NS	0.004 NS	1.212 NS
Yr x Lo x T	3	0.903 NS	0.024 NS	2.262 NS	12.644 NS	0.003 NS	0.825 NS
Yr x L x T	18	75.708 **	1.372 *	26.458 **	895.494 **	0.046 **	29.557 **
Lo x L x T	18	1.848 NS	0.054 NS	0.968 NS	27.930 NS	0.002 NS	1.760 NS
Yr x Lo x L x T	18	1.268 NS	0.045 NS	0.684 NS	19.778 NS	0.002 NS	0.599 NS
Error	216	35.207	0.761	7.997	291.41	0.018	14.060

*, **: Significant at 0.05 and 0.01 probability level respectively. NS. : Non-significant at 0.05 probability level.

Table 4. Estimates of general combining ability (GCA) in forage sorghum for green (GMY) and dry (DMY) matter yield based on data combined over years and locations.

Parents	GMY			DMY		
	GCA_{Lines}	(t/ha)	Rank	GCA_{Lines}	(t/ha)	Rank
Lines (Females)						
E-35-1	2.953**	30.89	3	0.474**	4.28	3
Hastings	- 0.234	22.41	6	- 0.116	2.74	8
Blue Ribbon	- 0.294	21.73	8	- 0.115	2.49	10
N 109	- 0.816	16.51	11	- 0.048	2.06	11
Dale	0.047	20.12	10	0.036	2.78	7
N 100	- 1.117*	22.08	7	- 0.136*	3.00	5
Sugar Drip	- 0.538	20.47	9	- 0.095	2.61	9
$S.E._{GCA\ Lines}$	0.312			0.039		
Testers (Males)	$GCA_{Testers}$			$GCA_{Testers}$		
S.70	1.172**	38.59	1	0.204**	4.91	1
S.186	- 0.603**	37.02	2	- 0.094*	4.48	2
Garawi	- 1.013**	28.27	4	- 0.143**	3.53	4
Ankolib	0.445	23.49	5	0.033	2.88	6
$S.E._{GCA\ Testers}$	0.104			0.017		

*, **: Significantly different from zero at 0.05 and 0.01 probability level respectively.

Table 7 shows that 6 hybrids expressed significant ($p < 0.01$) negative SCA effects for days to flower 3 of which involved the line Hastings. For leaf to stem ratio, significant positive specific effects were displayed by 2 hybrids, namely, N100 x Ankolib and E-35-1 x Ankolib.

GCA and SCA variance estimates

Table 8 shows that, for all characters, variances of the main effects were significant ($p < 0.01$) and mostly higher in magnitude than the interaction effects. However, inte-

Table 5. Estimates of general combining ability (GCA) in forage sorghum for yield-related traits based on data combined over years and locations.

Parents	Days to flower	Plant height (cm)	Stem diameter (cm)	Leaf/stem ratio (%)
GCA Lines (Females)				
E-35-1	3.793**	1.943	0.071**	- 0.099
Hastings	0.392	- 0.173	0.020	- 0.373
Blue Ribbon	- 1.570**	0.853	- 0.014	- 0.415
N 109	- 1.252**	- 0.858	- 0.029	0.079
Dale	- 0.054	1.259	- 0.017	0.212
N 100	- 0.547*	- 1.941	- 0.036*	0.446
Sugar Drip	- 0.763**	- 1.084	0.005	0.150
S.E. $_{GCA\ Lines}$	0.120	0.951	0.009	0.159
GCA Testers (Males)				
S.70	- 0.075	1.275	0.014	- 0.470**
S.186	- 1.521**	0.173	- 0.016	- 0.593**
Garawi	- 1.138**	- 0.161	- 0.035*	0.586*
Ankolib	2.734**	- 1.286	0.038*	0.478*
S.E. $_{GCA\ Testers}$	0.164	0.388	0.006	0.099

*, **: Significantly different from zero at 0.05 and 0.01 probability level respectively.

Table 6. Estimates of specific combining ability (SCA) in forage sorghum for green (GMY) and dry (DMY) matter yield based on data combined over years and locations.

Hybrid		GMY			DMY		
		SCA	(t/ha)	Rank	SCA	(t/ha)	Rank
E-35-1	X S.70	- 0.354	50.1	1	- 0.084	6.68	1
E-35-1	X S.186	1.009*	48.9	2	0.042	6.17	4
E-35-1	X Garawi	1.242*	48.3	3	0.216*	6.54	2
E-35-1	X Ankolib	- 1.898**	43.3	7	- 0.174	5.88	5
Hastings	X S.70	1.016*	44.6	6	0.090	5.44	7
Hastings	X S.186	- 0.660	34.3	22	- 0.095	3.99	26
Hastings	X Garawi	0.896	39.2	11	0.034	4.23	21
Hastings	X Ankolib	- 1.252*	35.7	19	- 0.028	4.57	17
B.Ribbon	X S.70	- 0.871	38.8	12	- 0.129	4.78	13
B.Ribbon	X S.186	- 0.229	35.4	20	- 0.039	4.16	23
B.Ribbon	X Garawi	- 0.253	34.1	23	0.024	4.20	22
B.Ribbon	X Ankolib	1.352**	43.3	7	0.144	5.09	11
N 109	X S.70	- 0.720	37.7	15	- 0.083	5.12	10
N 109	X S.186	0.034	34.6	21	0.033	4.58	16
N 109	X Garawi	0.036	33.4	25	- 0.106	4.01	25
N 109	X Ankolib	0.651	39.6	10	0.156	5.33	8
Dale	X S.70	1.054*	45.6	4	0.219*	6.28	3
Dale	X S.186	0.491	38.6	13	0.075	4.96	12
Dale	X Garawi	- 0.761	33.6	24	- 0.085	4.33	20
Dale	X Ankolib	- 0.783	37.9	14	- 0.208*	4.49	18
N 100	X S.70	0.892	41.6	9	0.156	5.57	6
N 100	X S.186	- 0.866	31.0	27	- 0.113	3.88	27
N 100	X Garawi	0.280	33.2	26	0.027	4.15	24
N 100	X Ankolib	- 0.306	35.8	18	- 0.070	4.39	19
Sugar Drip	X S.70	- 1.016*	37.6	16	- 0.167	4.75	14
Sugar Drip	X S.186	0.221	36.0	17	0.096	4.63	15
Sugar Drip	X Garawi	- 1.441**	29.8	28	- 0.109	3.86	28
Sugar Drip	X Ankolib	2.236**	45.2	5	0.180	5.26	9
S.E.		0.325			0.061		

*, **: Significantly different from zero at 0.05 and 0.01 probability level respectively.

Table 7. Estimates of specific (SCA) combining ability in forage sorghum for yield-related traits based on data combined over years and locations.

Hybrid	Days to flower	Plant height (cm)	Stem diameter (cm)	Leaf/stem ratio (%)
E-35-1 X S.70	0.484	- 3.440	0.034	- 0.259
E-35-1 X S.186	0.497	4.059*	0.029	0.119
E-35-1 X Garawi	0.244	2.332	- 0.004	- 0.544
E-35-1 X Ankolib	- 1.225**	- 2.952	- 0.059**	0.684*
Hastings X S.70	- 0.922*	2.287	- 0.001	- 0.109
Hastings X S.186	- 0.922*	2.046	- 0.007	0.296
Hastings X Garawi	- 1.059**	- 0.308	0.002	- 0.110
Hastings X Ankolib	2.902**	- 4.025*	0.005	- 0.076
B.Ribbon X S.70	- 0.183	- 1.383	- 0.013	0.398
B.Ribbon X S.186	0.321	- 0.314	- 0.013	0.048
B.Ribbon X Garawi	0.587	- 0.148	0.003	0.365
B.Ribbon X Ankolib	- 0.725*	1.845	0.024	- 0.811*
N 109 X S.70	- 0.124	0.791	- 0.007	- 0.202
N 109 X S.186	0.239	- 1.867	- 0.008	0.056
N 109 X Garawi	0.332	0.070	0.011	0.314
N 109 X Ankolib	- 0.447	1.006	0.004	- 0.168
Dale X S.70	0.931*	0.945	- 0.027	0.137
Dale X S.186	- 0.019	1.543	0.014	- 0.872*
Dale X Garawi	0.268	- 1.460	0.019	0.472
Dale X Ankolib	- 1.181**	- 1.028	- 0.005	0.263
N 100 X S.70	- 0.463	2.911	0.031	- 0.362
N 100 X S.186	- 0.259	- 4.410*	- 0.008	- 0.125
N 100 X Garawi	- 0.323	1.123	0.006	- 0.455
N 100 X Ankolib	1.045**	0.376	- 0.029	0.942**
Sugar Drip X S.70	0.276	- 2.112	- 0.017	0.397
Sugar Drip X S.186	0.143	- 1.057	- 0.007	0.479
Sugar Drip X Garawi	- 0.050	- 1.610	- 0.037	- 0.042
Sugar Drip X Ankolib	- 0.369	4.779*	0.061**	- 0.834*
S.E.	0.239	1.284	0.013	0.223

*, **: Significantly different from zero at 0.05 and 0.01 probability level respectively.

raction of SCA variance (σ^2 $SCA_{LxT\ x\ Y}$) with years was exceptionally sizable, especially for plant height. The variances of GCA for lines (σ^2 GCA_{Lines}) were higher than those for testers (σ^2 GCA_{Tester}) for most characters. The exception being days to flower and leaf to stem ratio. The interaction effects of σ^2 GCA_{Lines} with years were higherthan those of σ^2 GCA_{Tester} for plant height, days to flower and stem diameter. Higher order interactions of SCA variance (σ^2 $SCA_{LxT\ Y\ x\ LO}$) were considerably low for all characters. The variance ratio of general to specific effects (σ^2 GCA / σ^2 SCA) is above unity for all characters, except for plant height. The SCA variance for plant height was about more than three times greater than the sum of its GCA variance for line and tester. Number of days to flower showed the highest σ^2 GCA / σ^2 SCA ratio compared to other characters. Table 9 shows that the contribution of lines was greater than that of testers for GMY, DMY, plant height and stem diameter. On the other hand, the contribution of testers was greater than that of lines for leaf to stem ratio. Equal contributions to the total variance were noticed for number of days to flower. The contribution of either lines or testers was greater than that of lines x testers for all characters with the exception of plant height

DISCUSSIONS

The data presented in Table 2 point to the high degree of genetic variability existing among parents and hybrids for all characters studied. The variability among hybrids was less than that among parents for all characters. The contrast of parents' vs hybrids was sizable and highly significant for all characters, pointing to the potential of heterotic effects among hybrids. Both hybrids and parents performed consistently over locations, but not

Table 8. Variance components and ratio for general (σ² GCA) and specific (σ² SCA) genetic effects, their interactions over years (Yr) and locations (LO) for green (GMY), dry (DMY) matter yield and yield-related traits based on data from 28 forage sorghum hybrids.

Variance components[#]	GMY (t/ha)	DMY (t/ha)	Days to flower	Plant height (cm)	Stem diameter (cm)	Leaf/stem ratio (%)
σ^2 $GCA_{Lines\ (L)}$	13.33**	0.371**	26.85**	6.467**	0.010**	0.205**
σ^2 $GCA_{Tester\ (T)}$	7.016**	0.186**	31.94**	4.367**	0.008**	3.042**
σ^2 SCA_{LxT}	10.16**	0.145**	8.692**	41.04**	0.006**	1.569**
σ^2 $GCA_{L\ x\ YR}$	- 0.488	- 0.026	0.088**	9.621**	0.002**	- 1.072
σ^2 $GCA_{T\ x\ YR}$	- 0.032	0.017*	- 0.290	0.004*	0.0001	- 0.383
σ^2 $GCA_{L\ x\ LO}$	- 0.035	0.000	- 0.027	1.273	0.000	0.028
σ^2 $GCA_{T\ x\ LO}$	- 0.015	- 0.001	- 0.017	0.347	0.000	- 0.013
σ^2 $GCA_{L\ x\ YR\ x\ LO}$	0.283	- 0.002	0.001	1.972	0.0002	0.051
σ^2 $GCA_{T\ x\ YR\ x\ LO}$	- 0.017	- 0.001	0.075	- 0.340	0.000	0.011
σ^2 $SCA_{LxT\ x\ YR}$	12.41**	0.221*	4.296**	145.95**	0.007**	4.826**
σ^2 $SCA_{LxT\ x\ LO}$	0.097	- 0.002	0.047	1.359	0.000	0.194
σ^2 $SCA_{LxT\ YR\ x\ LO}$	- 11.31	- 0.239	- 2.438	- 90.54	- 0.005	- 4.487
Error mean square	35.207	0.761	7.997	291.41	0.018	14.06
σ² GCA / σ² SCA ratio	2.003	3.841	6.764	0.264	3.0	2.069

*, **: Significant at 0.05 and 0.01 probability level respectively.
: Negative component interpreted as zero.

Table 9. Contribution of lines, testers, and lines x testers to the total variance for six characters in forage sorghum based on data combined over years and locations.

Character	Contribution (%)		
	Lines	Testers	Lines x Testers
Green matter yield (t/ha)	48.6	22.7	28.7
Dry matter yield (t/ha)	55.1	24.6	20.3
Days to flower	44.4	44.3	10.7
Plant height (cm)	26.1	14.3	58.5
Stem diameter (cm)	46.0	31.5	21.8
Leaf/stem ratio (%)	15.0	50.6	34.6

over years with hybrids being more consistent in their performance over environments than parents. The testers were more variable than lines for most characters (Table 3). This is expected since they represent diverse groups of forage sorghum (grass, sweet and grain forage sorghums), whereas the lines represent one group (sweet sorghum). The interaction of lines with testers was highly significant for most characters indicating the presence of specific effects.

Given that testers are more genetically diverse, more significant GCA cases were noted among them than lines (Tables 4 and 5). The insignificant GCA effects noted for plant height (Table 5) might be attributed to the high interaction of lines and testers with years observed for this character (Tables 3). The mean squares of lines for leaf to stem ratio though significant, was relatively low, which might explain the absence of significant GCA effects for this character among lines.

E-35-1 from lines and S.70 from testers appeared to be the best general combiners for forage yield and may be expected to do well in hybrid combinations with other parents. The line E-35-1 was involved in 3 out of the 4 top yielding hybrids. Unfortunately, it turned to be the poorest combiner for earliness (Table 5). Earliness was one of the most desirable characters under the local system of forage production. Furthermore, E-35-1 and S. 70 were poor general combiners for leaf to stem ratio, especially the latter. Leaf to stem ratio was considered by many workers (e.g. Chacon and Stobbs, 1976; Chacon et al., 1978; Forbes and Colman, 1993) as being essential in determining forage quality, diet selection and forage intake. The line Dale although ranking third in general effects for yield, could be regarded as the best choice as it possesses acceptable GCA effect for yield while maintaining desirable general effects for other traits. The best general combiners for earliness were Blue Ribbon, N109 from lines and S.186 from testers. Most of the top yielding hybrids showed significant SCA values for forage yield, indicating the involvement of specific effect in the expression of yield of these hybrids. However, ranking of hybrids' yields along with their respective SCA effects (Table 6) showed that the highest mean values for a trait did not necessarily imply significant SCA effects or vice versa. Such patterns of combining ability effects were encountered by Ross et al. (1983) and Satyanarayana (1998).

Both additive and non-additive gene actions are expected to be important in the expression of the studied characters, with the preponderance of additive gene actions for days to flower, forage yield, stem diameter, leaf to stem ratio and non-additive actions for plant height (Table 8). The magnitude of GCA/SCA variance ratio for number of days to flower was specifically sizable, indicating the predominance of additive gene action; however, the specific effects were also highly significant, suggesting the involvement of non-additive effects in controlling this character. For forage yield, these results were in agreement with those reported by Blum (1968), Gupta et al. (1976) and Dangi et al. (1980); and disagree with the results obtained by Gupta and Paliwal (1976) and Sanghi and Monpara (1981). The data presented by Blum (1968) showed that GCA variance was 20.5 times greater than SCA variance for forage yield. Gupta et al. (1976) reported up to 12 GCA/SCA variance ratios for the same character. In this study the magnitude of GCA/SCA variance ratio was much lower (< 4) indicating the relative importance of non-additive gene action in controlling forage yield. For days to flower, our results agree with those of Liang (1967), Bijapur (1980) and Meng et al. (1998), but disagree with those of Kukadia and Singhania (1980) and Sanghi and Monpara (1981). For stem diameter, our results agree with those of Kirby and Atkins (1968) but for leaf to stem ratio, they disagree with those of Kukadia and Singhania (1980). On the other hand non-additive gene actions were more important than additive ones in controlling plant height (Table 8). This was in accordance with Sanghi and Monpara (1981) but was not in agreement with those of many workers (e.g. Kirby and Atkins, 1968; Shankaregowda et al., 1972; Singhania, 1980 and Meng et al., 1998).

The low interaction of GCA variance with years as compared to those of SCA variance indicate that general effects were more stable over years compared to specific effects (Table 8). Kambal and Webster (1965) studying general and specific effects in grain sorghum reported similar results.

Being predominately controlled by additive genes, days to flower could be improved by selection in early generations. With respect to forage yield, stem diameter and leaf to stem ratio which were under control of both additive and non-additive effects, reciprocal recurrent selection is usually suggested as it permits simultaneous exploitation of both general and specific effects. This breeding technique has been recently adapted for crops like sorghum (Brengman, 1995) where mass genetic recombination is facilitated by the use of the dominant fertility restoration gene ‘Rf_1’ in A_1 cytoplasm. However, such system will not work under the A3 cytoplasm due to the lack of genes that restore fertility. Nonetheless, the chance to capitalize on heterotic effects still exists for forage yield since appreciable non-additive effects were indicated by the highly significant mean squares observed for SCA and contrast of parents vs hybrids. Heterosis breeding is, therefore, suggested for improving forage yield. The results obtained for contributions of lines, testers and their interaction to the total variance (Table 9) substantiate the previous findings that general effects were more important than specific ones in the expression of these characters.

Conclusion

The line Dale seemed to receive the top priority as it desirable GCA effects for many characters. E-35-1 from lines and S.70 from testers could make a good couple to improve yield under production systems where lateness in flowering is not a major problem. Blue Ribbon and N109 were promising general combiner for earliness. Selection in early generations might be effective in improving characters predominately controlled by additive genes like days to flower. Heterosis breeding was recommended for forage yield improvement. For improvement of leaf to stem ratio, selection program based on more genetically diverse material with increased number of lines was suggested.

AKNOLOWEDGMENTS

Thanks are due to J F Pedersen, Research geneticist-University of Nebraska, USDA-ARS and the Agricultural Research Division, Institute of Agriculture and Natural Resources, University of Nebraska, for providing the female lines in A3 cytoplasm

REFERENCES

Baker RJ (1978). Issues in diallel analysis. Crop Sci. 18: 533-536.
Biel GM, Atkins RE (1967). Estimates of general and specific combining ability in F1 hybrids for grain yield and its components in grain sorghum, *Sorghum vulgare* Pers. Crop Sci. 7: 225-228.
Bijapur UK (1980). Evaluation and stability parameters of experimental rabi sorghum (*Sorghum bicolor* L. Moench) hybrids under three environments. Plant Breeding Abstract. 52(2): 1320.
Blum A (1968). Estimates of general and specific combining ability for forage yield in F1 hybrids of forage sorghum. Crop Sci. 8: 392-393.
Brengman RL (1995). The Rf1 gene in grain sorghum and its potential use in alternative breeding methods. Queensland Department of Primary Industries. Information Series No QI95003 p. 16.
Chacon EA, Stobbs TH (1976). Influence of progressive defoliation of a grass sward in the eating behaviour of cattle. Aust. J. Agric. Res. 27:

709-727.

Chacon EA, Stobbs TH, Dale MB (1978). Influence of sward characteristics on grazing behaviour and growth of Hereford steers grazing tropical grass pasture. Aust. J. Agric. Res. 29: 89-102.

Dangi OP, Ram H, Lodhi GP (1980). Line x tester analysis for combining ability in forage Sorghum. Sorghum Newsl. 23: 8-9.

Duvick DN (1999). Commercial strategies for exploitation of heterosis: The Genetics and Exploitation of Heterosis in Crops. Wisconsin, USA. p. 19-29.

Forbes TDA, Coleman SW (1993). Forage intake and ingestive behavior of cattle grazing old world bluestems. Agron. J. 85: 808-816.

GenStat for Windows (2006). 9th edition, Version-9.1.0.174, VSN International. UK.

Gupta SC, Paliwal RL (1976). Diallel analysis of forage yield and quality characters in sorghum. Egypt. J. Genetic. Cytol. 5: 281-287.

Gupta SC, Paliwal RL, Nanda JS (1976). Combining ability for forage yield and quality characters in sorghum. (*Sorghum bicolor* L. Moench). Egypt. J. Genetic. Cytol. 5: 89-97.

Groz HJ, Haskins FA, Pedersen JF, Ross WM (1987). Combining ability effects for mineral elements in forage sorghum hybrids. Crop Sci. 27: 216-219.

Kambal AE, Webster OJ (1965). Estimates of general and specific combining ability in grain sorghum. *Sorghum vulgare* Pers. Crop Sci. 5: 521-523.

Kelley TG, Rao PP, Walker TS (1991). The relative value of cereal-straw fodder in the semi-arid tropics of India: Implications for cereal breeding programs at ICRISAT. Progress Report, ICRISAT, India, 105: 33.

Kirby JS, Atkins RE (1968). Heterotic response for vegetative and mature plant characters in grain sorghum, *Sorghum bicolor* (L.) Moench. Crop Sci. 8: 335-339.

Kukadia MU, Singhania DL (1980). Diallel analysis of certain quantitative traits in forage sorghum. Indian J. Agric. Sci. 50: 294-297.

Liang GHL (1967). Diallel analysis of agronomic characters in grain sorghum. *Sorghum vulgare* Pers. Can. J. Genet. Cytol. 9: 269-276.

Maunder AB (1992). Identification of useful germplasm for practical plant breeding programs: Plant Breeding in the 1990s. Wallingford, UK. Pp. 147-149.

Meng CG, An XM, Zhang FY, Zheng JB, Wang LX, Li PL (1998). Analysis of combining ability of newly developed sorghum male-sterile lines. Acta Agriculturae Boreali-Sinica (Summary: En) 13: 81-85.

Mohammed Maarouf I (2007). Potential of locally developed forage sorghum hybrids in the Sudan. Sci Res. Essay. 2: 330-337.

Mohammed MI, Gamal EK, Ghada HA, Mohammed IE (2008). Improvement of the traditional forage sorghum cultivar 'Abu Sab'in'. Sudan J. Agric. Res., 11: 25-33.

Ross WM, Groz HJ, Haskins FA, Hookstra GH, Rutto JK, Ritter R (1983). Combining ability effects for forage residue traits in grain sorghum hybrids. Crop Sci. 23: 97-101.

Sanghi AK, Monpara BA (1981). Diallel analysis in forage yield and its components in sorghum. Madras Agric. J. 68: 296-300.

Satyanarayana PV (1998). Studies on combining ability and heterosis in rice. International Rice Research Notes 23(3): 10.

Shankaregowda BT, Madhav R, Mensinkal SW (1972). Heterosis and line x tester analysis of combining ability in selected lines of sorghum (*Sorghum vulgare* Pers.). II. Combining ability. Mysore J. Agric. Sci. 6: 242-253.

Singhania DL (1980). Heterosis and combining ability studies in grain sorghum. Indian J. Gen. Plant Breed. 40: 463-471.