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Heterosis and Combining Ability for Quality Traits in Forage Sorghum

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Abstract: A study was conducted to investigate the possibility of exploiting heterosis in breeding for improved quality in forage sorghum [Sorghum bicolor (L.) Moench] and to identify parents with desirable genetic effects. 28 hybrids produced by crossing 7 introduced females in A3 cytoplasm with 4 local males were evaluated for quality trait. Line x tester analysis was performed to study general and specific combining ability. The magnitudes of mid-parent and better-parent heterosis were investigated. Hybrids with best heterotic and specific effects for some traits were also among the best in per se performance for the same traits. Some hybrids depicted a good compromise between yield and some quality traits. Hybrids low in NDF and CF percentages appears to be attainable without sacrificing high yield levels. Two lines with good GCA effects for NDF and CP were identified. It was concluded that exploiting heterosis in forage sorghum to improve quality traits might be promising.

Key words: Quality, Forage, Sorghum, Heterosis, Combining ability, Hybrid, NDF, CP, Garawi, Ankolib.

INTRODUCTION

Sudan owns a huge herd of animal wealth estimated to be around 116 million head. The sorghum stover constitutes the bulk of animal feed in Sudan. The traditional cultivar ‘Abu Sab’in’ is the most widely grown forage sorghum [Sorghum bicolor (L). Moench] cultivar; however, it suffers from low quality. In addition, the local production system (cut and carry) favors high yields at the expense of the feeding value. Up to date, no locally developed forage hybrid has been released in the country. Many introduced hybrids were tested and released by the Agricultural Research Corporation (ARC). Although these hybrids are good forage yielders, the farmer’s preference was, however, in favor of the traditional cultivar Abu Sab’in. The choice for locally developed hybrids was therefore, thought crucial in resolving problems pertaining to the poor adoption of introduced hybrids. This has been investigated by Mohammed 2007. The data obtained demonstrate the possibility of developing local hybrids having superior forage yield to both the introduced hybrids and the traditional cultivar Abu Sab'in. The importance of heterosis in developing high yielding forage sorghum hybrids is well documented but not is its importance in nutritional aspects. The objectives of this study were to investigate the possibility of exploiting heterosis in breeding for improved quality in forage sorghum and to identify parents with desirable genetic effects.

MATERIALS AND METHODS

Parents:

Seven introduced females (lines) in A3 cytoplasm and 4 local male parents (testers) were crossed in Dec. 2001. The females (Table 1) include: Blue Ribbon, Hastings, E-35-1, N 100, N 109, Sugar Drip and Dale. They were chosen from the materials received from USDA-ARS, and the Agricultural Research Division, Institute of Agriculture and Natural Resources, University of Nebraska. The male parents were chosen from materials developed by Forage Improvement Program, Shambat Research Station (Sh. R. S) ARC, Sudan. They were S. 70 and S.186 (selections from the traditional cultivar Abu Sab’in), ‘Garawi’ a cultivated forage type of Sudan Grass [*Sorghum sudanense* (Piper) Stapf] and ‘Ankolib’ a local sweet sorghum cultivar.

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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

The Experiment:

The resulting 28 hybrids and their 11 parents were sown in RCB design with 3 replicates in the Experimental Farm of Sh. R. S (lat.15°39' N; Long. 32°31'E) on 12 July 2002. The plot size was 7.5 x 0.7 m ridge. 3 to 4 seeds were sown in holes spaced at 10 cm along the ridge. The plants were later thinned to one plant per hole. Nitrogen (urea) was applied two weeks after sowing at a rate of 55 kg N/ha. Harvesting was carried out 15 days after each entry had completed 50% flowering, which simulates the local practice of harvesting forage sorghum.

Data Recording:

Green matter yield (GMY) was estimated by harvesting 6.5 m from each plot leaving 0.5 m from each side. 0.5 kg random sample (leaf + stalks) from each harvested plot in 2 replicates was used for dry matter determination and analysis of quality traits. Proximate analysis for neutral detergent fiber (NDF), crude fiber (CF), crude protein (CP), ash, and ether extracts (E.E) was carried, following the standard procedures (A.O.A.C. 1980).

Statistical Analysis:

Line x tester analysis (Kempthorne, 1957) was used to study combining ability estimates. The critical difference (C.D.) was used to check the significance of combining ability estimates (Singh and Chaudhary, 1985). Over mid and better parent heterosis were worked out following Singh and Narayanan (1993).

RESULTS AND DISCUSSION

Table 2 shows that differences between entries were highly significant for all quality traits. The entries also differed significantly ($p < 0.01$) in dry matter yield (data not shown). Partitioning of the entry source of variation revealed that the greater part of variability observed for NDF and E.E could be attributed to hybrids. The contrast of parents vs hybrids was sizable and highly significant for most characters, pointing to the potential of heterotic effects in improving quality traits. This was further indicated by the highly significant sum of squares of line x testers observed for all characters.

Table 2: Mean squares for percentages of neutral detergent fiber (NDF), crude fiber (CF), crude protein (CP), ash and ether extract (E.E) of 28 forage sorghum hybrids and their parents (Shambat, 2002).

Source of variation	d.f.	Mean Squares				
		NDF	CF	CP	ASH	E.E.
Rep	1	11.10 NS	45.57**	2.084 NS	4.228**	1.000**
Entry	38	143.47**	18.19**	3.576**	3.228**	0.303**
Parent (P)	10	11.14 NS	14.26**	6.823**	3.300**	0.136 NS
P vs H	1	154.73**	53.64**	2.545*	7.010**	0.039 NS
Hybrid (H)	27	192.07**	18.33**	2.412**	3.061**	0.375**
Line (L)	6	316.14 NS	9.601 NS	3.059 NS	3.566 NS	0.092 NS
Tester (T)	3	160.81 NS	9.286 NS	0.286 NS	4.717 NS	0.705 NS
L x T	18	155.921**	22.74**	2.550**	2.616**	0.415**
Error	38	9.94	2.627	0.613	0.459	0.078
CV (%)		5.04	4.58	13.76	7.85	21.0

*, ** = significant at 0.05 and 0.01 probability level respectively
N.S. = non-significant at 0.05 probability level

The seemingly poor performance of most entries for CP and NDF (Table 3) is expected since harvesting was delayed to simulate the local practice. Nevertheless, the hybrids Dale x S.70, Hastings x S.186 and Dale x Garawi were significantly better in NDF percentages than their parents, showing apparently low values averaging 34.5 % , 37.0 % and 45.5 % respectively. The same is true for CF percentage with regard to some hybrids, the best of which was N 100 x Garawi (27.5 %). The hybrids averaged slightly lower in CP than their parents. The best hybrids for CP percentage were Dale x S.186, Hastings x S.70 and Hastings x Ankolib, with respective values of 7.48 %, 7.26 % and 7.18 %. The hybrids Dale x S. 70, Blue Ribbon x Ankolib and Hastings x S. 70 merit special consideration. In addition to their remarkable dry matter yield, they also did well with respect to some quality traits.

Table 3: Dry matter yield (DMY), neutral detergent fiber (NDF), crude fiber (CF), crude protein (CP), ash and ether extract (E.E) of forage sorghum hybrids and their parents (Shambat, 2002).

		DMY	NDF	CF	CP	ASH	E.E.
Hybrids		(T/h)		Percentage			
E-35-1	X S.70	6.34	70.0	32.5	4.65	8.06	1.23
E-35-1	X S.186	6.40	67.5	40.0	4.48	7.30	0.83
E-35-1	X Garawi	6.39	75.5	34.5	6.81	8.20	1.61
E-35-1	X Ankolib	6.05	66.5	38.0	5.49	10.22	1.20
Hastings	X S.70	5.39	57.0	31.5	7.26	9.40	0.80
Hastings	X S.186	4.64	37.0	37.0	6.38	7.80	0.80
Hastings	X Garawi	4.07	71.5	37.0	5.41	8.41	1.98
Hastings	X Ankolib	4.95	62.0	35.0	7.18	9.76	1.60
B.Ribbon	X S.70	4.69	67.5	36.5	5.83	8.46	2.00
B.Ribbon	X S.186	4.05	56.0	33.0	5.47	8.87	1.18
B.Ribbon	X Garawi	3.84	64.0	40.0	6.82	10.20	0.80
B.Ribbon	X Ankolib	6.38	56.5	34.5	6.29	11.20	1.18
N 109	X S.70	5.19	58.0	38.5	4.62	8.49	1.60
N 109	X S.186	4.67	60.0	31.0	5.28	7.16	0.81
N 109	X Garawi	4.26	60.0	32.0	5.49	8.64	1.20
N 109	X Ankolib	5.61	70.0	39.0	6.60	9.85	1.20
Dale	X S.70	6.23	34.5	34.5	6.38	8.62	0.82
Dale	X S.186	4.65	67.0	34.0	7.48	9.59	1.59
Dale	X Garawi	4.26	45.5	33.5	5.94	8.92	1.60
Dale	X Ankolib	4.61	57.5	32.0	3.17	8.10	1.60
N 100	X S.70	6.21	63.5	37.0	4.85	7.25	1.21
N 100	X S.186	3.62	62.5	33.0	6.29	7.38	0.79
N 100	X Garawi	4.60	65.0	27.5	3.35	7.78	1.20
N 100	X Ankolib	4.74	62.0	36.5	5.00	8.76	2.00
Sugar Drip	X S.70	5.05	59.5	31.5	4.87	12.70	1.20
Sugar Drip	X S.186	4.00	62.5	37.5	5.06	8.59	1.20
Sugar Drip	X Garawi	3.93	75.0	33.0	5.14	8.71	2.43
Sugar Drip	X Ankolib	5.22	72.5	36.0	4.47	8.51	1.21
Mean hybrids		5.00	61.6	34.9	5.57	8.82	1.32
S.E ±		0.54	2.30	1.08	0.560	0.49	0.16
			Females				
E-35-1		3.62	60.0	37.0	6.85	8.10	1.20
Hastings		2.96	63.5	32.5	3.95	8.87	1.62
Blue Ribbon		2.36	65.5	39.0	7.11	8.21	1.58
N 109		2.17	64.0	36.0	8.13	9.30	1.61
Dale		2.83	63.0	37.2	3.65	7.12	1.41
N 100		3.14	65.5	33.5	5.00	6.19	1.21
Sugar Drip		3.03	67.0	36.0	5.96	7.41	1.20
			Males				
S.70		4.84	66.0	38.0	6.70	9.05	1.58
S.186		3.99	65.5	36.5	4.70	6.19	0.82
Garawi		3.87	63.5	42.5	9.42	9.96	1.60
Ankolib		3.40	69.0	35.5	4.26	9.28	1.20
Mean parents		3.29	64.8	36.7	5.98	8.15	1.37
S.E ±		0.34	2.15	1.34	0.44	0.44	0.27
Grand Mean		4.52	62.5	35.4	5.69	8.63	1.33
S.E ±		0.49	2.23	1.15	0.55	0.48	0.20
LSD (0.05)		1.38	6.38	3.28	1.58	1.37	0.57

Table 4: General (GCA) and specific (SCA) combining ability estimates in forage sorghum for percentages of neutral detergent fiber (NDF), crude fiber (CF), crude protein (CP), ash and ether extract (E.E) based on data obtained from 28 hybrids and their parents (Shambat, 2002)

Name		NDF	CF	CP	ASH	E.E.
				GCA Lines (Females)		
E-35-1		8.232*	1.393	-0.216	-0.374	-0.100
Hastings		-4.768*	0.268	0.984*	0.024	-0.021
Blue Ribbon		-0.643	1.143	0.528	0.864*	-0.025
N 109		0.357	0.268	-0.076	-0.284	-0.116
DALE		-10.518**	-1.357	0.169	-0.011	0.085
N 100		1.607	-1.357	-0.701	-1.026*	-0.016
Sugar Drip		5.732*	-0.357	-0.689	0.809*	0.193
S.E.		*1.115*	*0.573*	*0.277*	*0.240*	*0.099*
				GCA Testers (Males)		
S.70		-3.071*	-0.286	-0.079	0.178	-0.051
S.186		-2.714*	0.214	0.204	-0.720*	-0.289*
Garawi		3.571*	-0.929	-0.008	-0.125	0.230
Ankolib		2.214	1.000	-0.116	0.667*	0.111
S.E.		*0.843*	*0.433*	*0.209*	*0.181*	*0.075*
				SCA (Hybrids)		
E-35-1	X S.70	3.196	-3.464*	-0.628	-0.563	0.061
E-35-1	X S.186	0.339	3.536*	-1.081	-0.425	-0.101
E-35-1	X Garawi	2.054	-0.821	1.460	-0.120	0.166
E-35-1	X Ankolib	-5.589	0.750	0.249	1.108	-0.126
Hastings	X S.70	3.196	-3.339*	0.782	0.379	-0.448
Hastings	X S.186	-17.161**	1.661	-0.381	-0.322	-0.205
Hastings	X Garawi	11.054**	2.804	-1.140	-0.308	0.457
Hastings	X Ankolib	2.911	-1.125	0.739	0.251	0.195
B.Ribbon	X S.70	9.571**	0.786	-0.193	-1.401*	0.761**
B.Ribbon	X S.186	-2.286	-3.214	-0.836	-0.092	0.179
B.Ribbon	X Garawi	-0.571	4.929**	0.725	0.642	-0.719*
B.Ribbon	X Ankolib	-6.714**	-2.500	0.304	0.851	-0.221
N 109	X S.70	-0.929	3.661*	-0.798	-0.223	0.448
N 109	X S.186	0.714	-4.339*	-0.421	-0.655	-0.105
N 109	X Garawi	-5.571	-2.196	0.000	0.230	-0.233
N 109	X Ankolib	5.786	2.875	1.219	0.648	-0.110
Dale	X S.70	-13.554**	1.286	0.717	-0.366	-0.529
Dale	X S.186	18.589**	0.286	1.534	1.503*	0.474
Dale	X Garawi	-9.196**	0.929	0.205	0.237	-0.029
Dale	X Ankolib	4.161	-2.500	-2.456**	-1.374*	0.084
N 100	X S.70	3.321	3.786	0.057	-0.721	-0.038
N 100	X S.186	1.964	-0.714	1.214	0.308	-0.225
N 100	X Garawi	-1.821	-5.071**	-1.515	0.112	-0.328
N 100	X Ankolib	-3.464	2.000	0.244	0.301	0.590*
Sugar Drip	X S.70	-4.804	-2.714	0.064	2.894**	-0.256
Sugar Drip	X S.186	-2.161	2.786	-0.029	-0.317	-0.018
Sugar Drip	X Garawi	4.054	-0.571	0.263	-0.793	0.688*
Sugar Drip	X Ankolib	2.911	0.500	-0.299	-1.784*	-0.413
S.E.		2.230	1.148	0.554	0.479	0.197

*, ** = significantly different from zero at 0.05 and 0.01 probability level respectively

Table 4 presents estimates of general (GCA) and specific (SCA) combining ability. The lines Dale and Hastings were promising general combiners for NDF and CP respectively. They exhibited the best performance in 3 out of 4 of their hybrid combinations for these traits (Table 3). Hastings was also a good combiner for NDF. Among testers, S.70 and S.186 exhibited significant desirable general effects for NDF. The best general combiners for ash, were Blue Ribbon and Sugar Drip from lines and Ankolib from testers. No significant desirable general effects were observed for CF and E.E.

With the exception of CP, desirable significant SCA effects were expressed by at least some hybrids for remaining traits. In most cases, these were the hybrids showing the best *per se* performance for the quality traits NDF, CF, ASH, E.E. (Table 3).

Table 5 shows that, in both types of heterosis, most of the hybrids displayed desirable (negative) values for NDF and CF with some cases being significant. For NDF, the respective ranges for over mid and better parent heterosis were: – 47.3 % to 22.3 % and – 46 % to 25.8 %. The hybrids Dale x S.70, Hastings x S.186 and Dale x Garawi exhibited highly significant negative values in both types of heterosis. For CF, the respective ranges for over mid and better parent heterosis were: – 27.6 % to 9.09 % and – 17.9% to 13.9 %. The hybrids N 100 x Garawi, N 109 x S.186 and Sugar Drip x S.70 showed the best over better parent heterosis.

Table 5: Heterosis over mid (MP) and better (BP) parent in forage sorghum for neutral detergent fiber (NDF), crude fiber (CF), crude protein (CP), ether extract (E.E) and ash (Shambat, 2002).

		NDF		CF		CP		ASH		E.E.	
		MP	BP	MP	BP	MP	BP	MP	BP	MP	BP
Hybrid		Percentages									
E-35-1	X S.70	11.1*	16.7**	-13.3**	-12.2**	-31.4**	-32.1**	-6.01	-10.9	-11.5	-22.2
E-35-1	X S.186	7.57	12.5*	8.84	9.59*	-22.4	-34.6**	2.17	-9.88	-17.8	-30.8
E-35-1	X Garawi	22.3**	25.8**	-13.2**	-6.76	-16.3	-27.7**	-9.19	-17.7*	15.0	0.63
E-35-1	X Ankolib	3.10	10.8*	4.83	7.04	-1.17	-19.9	17.6*	10.1	0.00	0.00
Hastings	X S.70	-12.0*	-10.2*	-10.6*	-3.08	36.3*	8.36	4.91	3.87	-50.0**	-50.6**
Hastings	X S.186	-42.6**	-41.7**	7.25	13.9**	47.5*	35.7*	3.59	-12.1	-34.4	-50.6**
Hastings	X Garawi	12.6**	12.6*	-1.33	13.9**	-19.1	-42.6**	-10.7	-15.6*	23.0	22.2
Hastings	X Ankolib	-6.42	-2.36	2.94	7.69	74.9**	68.5**	7.55	5.17	13.5	-1.23
B.Ribbon	X S.70	2.66	3.05	-5.19	-3.95	-15.6	-18.00	-1.97	-6.52	26.6	26.6
B.Ribbon	X S.186	-14.5**	-14.5**	-12.6**	-9.59*	-7.37	-23.1*	23.2*	8.04	-1.67	-25.3
B.Ribbon	X Garawi	-0.78	0.79	-1.84	2.56	-17.5	-27.6**	12.3	2.41	-49.7**	-50.0**
B.Ribbon	X Ankolib	-16.0**	-13.7**	-7.38	-2.82	10.6	-11.5	28.1**	20.7**	-15.1	-25.3
N 109	X S.70	-10.8*	-9.38	4.05	6.94	-37.7**	-43.2**	-7.47	-8.71	0.31	-0.62
N 109	X S.186	-7.34	-6.25	-14.5**	-13.9**	-17.7	-35.1**	-7.55	-23.0**	-33.3	-49.7**
N 109	X Garawi	-5.88	-5.51	-18.5**	-11.1*	-37.4**	-41.7**	-10.3	-13.3	-25.2	-25.5
N 109	X Ankolib	5.26	9.38	9.09	9.86*	6.54	-18.8	6.03	5.91	-14.6	-25.5
Dale	X S.70	-47.3**	-46.0**	-8.24	-7.26	23.3	-4.78	6.62	-4.75	-45.2*	-48.1**
Dale	X S.186	4.28	6.35	-7.73	-6.85	79.2**	59.2**	44.1**	34.7**	42.6	12.8
Dale	X Garawi	-28.1**	-27.8**	-15.9**	-9.95*	-9.10	-36.9**	4.45	-10.4	6.31	0.00
Dale	X Ankolib	-12.9*	-8.73	-12.0*	-9.86*	-19.9	-25.6	-1.22	-12.7	22.6	13.5
N 100	X S.70	-3.42	-3.05	3.50	10.5*	-17.1	-27.6*	-4.86	-19.9*	-13.3	-23.4
N 100	X S.186	-4.58	-4.58	-5.71	-1.49	29.7	25.8	19.2	19.2	-22.2	-34.7
N 100	X Garawi	0.78	2.36	-27.6**	-17.9**	-53.5**	-64.4**	-3.65	-21.9**	-14.6	-25.0
N 100	X Ankolib	-7.81	-5.34	5.80	8.96	7.99	0.00	13.3	-5.60	66.0**	65.3**
Sugar Drip	X S.70	-10.5*	-9.85*	-14.9**	-12.5**	-23.1	-27.3*	54.3**	40.3**	-13.67	-24.1
Sugar Drip	X S.186	-5.66	-4.58	3.45	4.17	-5.07	-15.1	26.3*	15.9	18.81	0.00
Sugar Drip	XGarawi	14.9**	18.1**	-15.9**	-8.33	-33.2	-45.4**	0.29	-12.6	73.6**	51.9**
Sugar Drip	XAnkolib	6.62	8.21	0.70	1.41	-12.5	-25.0	1.98	-8.30	0.83	0.83
Mean		-5.19	-3.11	-5.57	-1.47	-2.9	-16.09	7.61	-1.69	-1.9	-11.39
Range		-47.3	-46.0	-27.6	-17.9	-53.5	-64.4	-10.7	-23.0	-49.7	-50.6
		22.3	25.8	9.09	13.9	79.2	68.5	54.3	40.3	73.6	65.3

*, ** = significant at 0.05 and 0.01 probability level respectively

For crude protein (CP), most of the hybrids displayed negative values for over mid and better parent heterosis with respective ranges of – 53.5 % to 79.2 % and – 64.4% to 68.5 %. However, some hybrids expressed positive significant values, most of which were those involving the line Hastings, the best general combiner for CP. The hybrids Dale x S.186 and Hastings x Ankolib exhibited the highest heterosis values for CP in both types of heterosis. For ash percentage, over mid parent heterosis was positive for most of the hybrids, with few positive significant cases in both types of heterosis. The respective ranges for over mid and better parent heterosis were: – 10.7 % to 54.3 % and – 23 % to 40.3 %. The hybrids Sugar Drip x S.70, Dale x S.186, and Blue Ribbon x Ankolib showed the best over mid and better parent heterosis. For Ether Extract, most of hybrids displayed negative values for over mid and better parent heterosis with respective ranges of – 49.7 % to 73.6 % and – 50.6 % to 65.3 %. However, two hybrids namely, Sugar Drip x Garawi and N 100 x Ankolib displayed positive significant values in both types of heterosis.

It is interesting to note that the majority of hybrids shown by this study as being the best to display heterosis and SCA effects for some traits, were also among the best performing for the same traits; hence, utilizing heterosis in improving such traits might be rewarding. Furthermore, although quality traits and forage yield are usually reported to be adversely associated (Sanderson et al. 1993; Moyer et al. 2003), some hybrids in this study depicted a good compromise between yield and some quality traits (Table 3), pointing to the possibility of developing hybrids with better yield and quality.

Conclusion:

Exploiting heterosis in forage sorghum to improve quality traits might be promising. Hybrids low in NDF and CF percentages appears to be attainable without sacrificing high yield levels. Two lines with good GCA effects for NDF and CP were identified.

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