Combining Ability Studies of Forage Yield and Protein Character in Sorghum*

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ABSTRACT

The forage yield and protein content in sorghum were studied for two seasons by using a series of sorghum hybrids obtained by crossing each of eight male-sterile lines to seven fertile lines. The GCA variances of males and their interactions for both traits were significant for individual seasons as well as for pooled data. The GCA of females for green forage yield and protein content were respectively significant during monsoon and summer. The SCA component for green forage yield was significant during monsoon, whereas for protein content it was significant during monsoon as well as for pooled seasons. The additive genetic variance was principally observed for green forage yield, whereas both additive and nonadditive components were involved for protein content.

INTRODUCTION

THE availability of cytoplasmic male sterility has put the sorghum hybrids on commercial footing and grain sorghum hybrids are under cultivation, but forage sorghum hybrids are not in use in India though they have become an integral part of agriculture in developed countries like USA and Japan. Isolation of lines that will contribute favourable genes or combinations of genes for fodder yield and quality is a prerequisite for scientific development of forage sorghum hybrids.

In sorghum, very few reports on combining ability and gene action are available for its fodder yield (Tarumoto and Qizumi, 1967; Blum, 1968; Tarumoto, 1969, 1970) and the nutritional quality of grain (Liang, Heyne, Chung and Koh, 1968; Collins and Pickett, 1972) but such information on fodder quality is not available, hence the present study was conducted.

METHODS

The experimental material consisted of two parental sets, one each of eight female and seven male parents and their 56 hybrids. The set of female parents had seven male-sterile grain sorghum lines (600 A, 605 A, 620 A, M 35 A, CK 60A, 3226A and 3197A) and one malesterile sudangrass (Rhodhesian A) line, whereas the set of male parents had two forage sorghum (S 1049 and 6-17$_g$-19), one sudangrass (Piper) and two each of dual (W 10 and C 10-2) and grain

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sorghum (BD 8 and BP 53) varieties. The F_1 seeds were produced by hand pollination.

The hybrids and their parents were grown during two seasons viz., summer and monsoon 1972. The maintainer counterpart of male-sterile lines were grown in lieu of female parents. During summer 1972 only 32 hybrids out of 56 possible combinations involving all female parents and four male parents (S 1049, 6-17$_2$-19, Piper and W 10) were studied alongwith their parents. The study of 24 hybrids involving C 10-2, BD 8 and BP 53 as male parents was deferred to monsoon 1972 as the hybrid seeds were immature at the sowing time. The experiment was sown on February 24, 1972. During monsoon 1972 all possible 56 hybrids were studied alongwith their parents. The experimental material was raised on August 7, 1972.

During both the seasons the experimental material was planted in a randomised block design using two replications. A single row of 3.05 m length represented a plot, the inter and intra row spacing being 60 cm and 7.6 cm respectively. The entire plot was harvested at the time of 50 per cent panicle emergence, weighed in kilogrammes and the produce was sun dried. Three plants were randomly selected from each plot, cut into small pieces and powdered for estimating the crude protein content by using modified Kjeldalh's method (Jackson, 1967). Nitrogen estimation for the produce of each plot was done in duplicate set and mean value was computed. The mean nitrogen content was multiplied by 6.25 and expressed as per cent protein content.

The following linear model similar to one used by Beil and Atkins (1967) was used for estimating general and specific combining ability effects and their interaction with seasons.

$$y_{ijkq} = \mu + g_i + g_j + s_{ij} + y_q + r_{kq} + (gy)_{iq} + (gy)_{jq} + (sy)_{ijq} + e_{ijkq}$$

Where, $_i$=1, 2,. . ., 7 (male parents)
$_j$=1, 2,. . . ., 8 (female parents)
$_k$=1, 2 (replications)
$_q$=1, 2 (seasons)

The term,

y_{ijkq}=the value during the $_q$th season in the $_k$th replication of the progeny of the $_j$th female and the $_i$th male parents.

μ=an effect common to all hybrids in both the replications.

g_i=an effect common to all progeny of the $_i$th male parent.

g_j=an effect common to all progeny of the $_j$th female parent.

s_{ij}=an effect specific to the progeny of the $_j$th female and $_i$th male parents.

y_q=the average effect of the $_q$th season.

e_{ijkq}=uncontrolled variation associated during the $_q$th season in the $_k$th replication with the progeny of the $_j$th female and the $_i$th male parents.

The interaction terms of the model have the meanings in context with above descriptions and are designated by appropriate *subscripts*.

The data of each character were analysed for individual and pooled seasons. The mean squares for males, females and males × females were used for estimating GCA of males, GCA of females and SCA during individual seasons, whereas the mean squares of the former three and their interaction with *seasons* for common entries obtained from the pooled analysis were used for estimating the GCA, SCA and their interactions with seasons, the format of which is presented in Table 1.

The *seven male* and *eight* female parents used for this study were considered as the representatives of the variability for the characters studied of the normal and male-sterile population. The seasons in which this experimental material was grown were considered as the random sample of a population of seasons. Hence the expectation of mean squares for random model have been used.

TABLE—I

Form of anova used for the estimation of GCA, SCA and their interactions with *seasons* for *various characters*.

Sources of variation	*d.f.*	*Expected mean squares*
g_i (GCA of male parents)	3	$\sigma^2_e + r\sigma^2_{fmy} + rf\,\sigma^2_{my} + ry\,\sigma^2_{fm} + ryf\,\sigma^2_m$
g_j (GCA of female parents)	7	$\sigma^2_e + r\sigma^2_{fmy} + rm\,\sigma^2_{fy} + ry\,\sigma^2_{fm} + rym\sigma^2_j$
s_{ij} (SCA)	21	$\sigma^2_e + r\sigma^2_{fmy} + ry\,\sigma^2_{fm}$
g_i × *seasons*	3	$\sigma^2_e + r\sigma^2_{fmy} + rf\,\sigma^2_{my}$
g_j × seasons	7	$\sigma^2_e + r\sigma^2_{fmy} + rm\,\sigma^2_{fy}$
s_{ij} × seasons	21	$\sigma^2_e + r\sigma^2_{fmy}$
Pooled error	86	σ^2_e

Legend: The letters e,y,f,m and r represent error, seasons, females, males and replications respectively.

The general and specific combining effects for each parent were calculated in the following manner,

$$g_i = (\bar{y}_{i.} - \bar{y}_{..})$$
$$g_j = (\bar{y}_{.j} - \bar{y}_{..})$$
$$s_{ij} = (\bar{y}_{ij} - \bar{y}_{i.} - \bar{y}_{.j} + \bar{y}_{..})$$

where $\bar{y}_{i.}$ is the mean performance of the $_i$th male parent all female lines in hybrid combination, $\bar{y}_{.j}$ is the mean performance of the $_j$th female parent with all male parents in hybrid combination, $\bar{y}_{ij}$ is the mean performance of the hybrid combination of the $_j$th female and the $_i$th male parents, and $\bar{y}_{..}$ is the mean performance of male and female parents in hybrid combination.

RESULTS AND DISCUSSION

Green forage yield:

All male parents had higher green forage yield in hybrid combinations as compared to their own performance during summer (Table 2). The W 10

TABLE—2

Mean performance of the F_1 hybrids with one parent in common and parental means for green forage yield (kg/plot) during individual and pooled seasons.

Parents	*Summer*		*Monsoon*		*Pooled seasons*	
	Means of Hybrids	*Means of Line/variety*	*Means of Hybrids*	*Means of Line/variety*	*Means of Hybrids*	*Means of Line/variety*
Males						
S 1049	5.28	3.59	6.69	3.17	5.99	3.38
6—17_2—19	5.85	4.04	5.88	4.32	5.87	4.18
Piper	5.98	4.48	5.39	4.50	5.69	4.49
W 10	7.14	5.42	7.60	5.27	7.37	5.34
C 10—2			10.04	4.83		
BD 8			12.31	7.05		
BP 53			12.79	8.25		
Mean	6.06	4.38	8.67	5.34	6.23	4.35
S Em±	0.30		0.36		0.45	
CD at 5%	0.85		1.00		1.32	
Females						
600	6.14	3.56	8.37	3.18	6.07	3.37
605	5.89	2.79	8.47	2.34	6.27	2.56
620	6.06	3.41	8.93	3.82	5.98	3.61
M 35	6.04	2.94	8.98	3.41	6.47	3.17
CK 60	6.43	3.35	9.45	3.33	6.65	3.34
3226	6.46	3.28	10.36	2.85	6.79	3.06
3197	5.64	3.33	8.51	2.66	6.13	2.99
Rhodhesian	5.86	11.99	6.30	5.06	5.47	8.52
Mean	6.06	4.33	8.67	3.33	6.23	3.83
S Em±	0.42		0.50		0.39	
CD at 5%	NS		1.41		NS	
CV%	21.13		18.41		19.81	

NS = Not significant

parent producing 7.14 kg/plot (39,016 kg/ha) of green forage differed significantly from remaining male parents in hybrid combinations. All females in hybrid combinations except Rhodhesian also produced more green forage as compared to their respective parent but the differences in yield among the females in hybrid combinations were nonsignificant. During monsoon, all males in hybrid combinations had increased green forage yield as compared to their respective parents. The BD 8 and BP 53 parents, producing 12.31 kg/plot (67,268 kg/ha) and 12.79 kg/plot (69,891 kg/ha) respectively of green forage differed significantly from the remaining male parents in hybrid combinations. All females in hybrid combinations also produced more green forage yield as compared to their own performance. Line 3226 produced significantly more green forage i.e., 10.36 kg/plot (56,612 kg/ha) than the rest of the females in hybrid combinations. On the basis of pooled analysis also, the green forage yield of all parents was less than their respective hybrids except Rhodhesian line, and W10 produced significantly more green forage i.e., 7.37 kg/plot (40,273 kg/ha) than the rest of the males in hybrid combinations.

The estimates of GCA effects revealed that W10 had highest positive value among males during summer as well as on the basis of pooled analysis, but during monsoon season variety BP 53 had the highest GCA effect (Table 3), the GCA differences during both seasons as well as for pooled analysis being significant (Table 4). Among females 3226 parent had highest positive value for GCA effect during both the seasons but the differences were significant during monsoon only. The estimates of SCA effect (Table 3), revealed that the hybrids CK 60 × S 1049, 3226 × BD 8, and 3226 × W 10 had the highest positive values for SCA effect during summer, monsoon and on the basis of pooled analysis but the differences were significant only during monsoon.

The ratio of total GCA to SCA variance revealed that the additive variance component was of higher magnitude than the non-additive component for green forage yield. An upward bias to the extent of the involvement of additive × additive and higher order interactions might be associated with the magnitude of additive variance as epistacy was ignored in the present model. The relative values of g_i and g_j revealed that the males had more additive genetic variance as compared to females which might be due to a wide spectrum of sorghum varieties used as male parents as compared to the female counterpart. The interaction of the GCA of males with seasons indicated the nonplasticity of this additive genetic component of males for seasons which needs to be considered while selecting the lines for either improvement or development of cultivars/hybrids for summer and monsoon cultivation. The highest value of SCA effect observed for 3226 × BD 8 hybrid during monsoon suggested that the additive component was primarily involved as both parents had high values for GCA effect. The pre-dominance of GCA variance for green forage yield in sorghum had been reported by Blum (1968) and Tarumoto (1969, 1970).

TABLE—3

Estimates of relative general and specific combining ability effects for green forage yield obtained from the F_1 hybrids for individual and pooled seasons.

	Females								
Males	*600*	*605*	*620*	*M 35*	*CK 60*	*3226*	*3197*	*Rhodh-esian*	$\hat{g}_i$
Summer				Specific effects ($\hat{s}_{ij}$)					
S 1049	–0.32	–0.27	0.68	–0.16	1.41	0.77	–0.54	–1.64	–0.78
6—17_s—19	0.96	–0.34	–0.36	–0.03	0.90	0.54	–0.57	–1.18	–0.21
Piper	0.37	0.21	–1.10	–0.79	1.14	0.54	–0.43	0.16	–0.08
W 10	–0.39	–0.96	0.79	0.76	–0.59	1.34	–1.93	1.05	1.08
$\hat{g}_j$	0.08	–0.17	0.00	–0.02	0.37	0.40	–0.42	–0.20	
Monsoon				Specific effects ($\hat{s}_{ij}$)					
S 1049	0.38	0.30	–0.24	0.77	0.37	2.67	0.82	–4.55	–1.98
6—17_s—19	–1.04	–0.88	–0.39	0.70	0.40	2.99	0.46	–2.75	–2.79
Piper	–0.77	–0.14	0.05	0.83	1.49	1.73	0.09	–3.25	–3.28
W 10	–1.29	0.43	0.38	0.97	2.78	2.35	–0.62	–4.18	–1.07
C 10—2	–3.77	–0.74	0.89	1.08	2.12	3.71	0.77	–4.97	1.37
BD 8	–1.19	–0.63	–0.35	1.26	3.44	5.65	–2.30	–5.87	3.64
BP 53	2.46	–1.65	4.02	–1.26	0.34	4.59	–0.94	–7.61	4.12
$\hat{g}_j$	–0.30	–0.20	0.26	0.31	0.78	1.69	–0.16	–2.37	
Pooled				Specific effects ($\hat{s}_{ij}$)					
S 1049	–0.03	0.24	–0.16	0.39	0.78	1.12	0.09	–2.58	–0.24
6—17_s—19	–0.09	–0.14	–0.73	0.45	0.49	1.27	0.18	–1.45	–0.36
Piper	–0.25	0.26	–0.91	0.11	1.15	0.64	0.02	–1.03	–0.54
W 10	–0.89	–0.04	–0.18	0.96	0.94	1.36	–1.09	–1.04	1.14
$\hat{g}_j$	–0.16	0.04	–0.25	0.24	0.42	0.56	–0.10	–0.76	

Protein content:

During summer all hybrids had increased protein content than their respective male parents, whereas among females, all but three hybrids had increased protein content than their respective female parents. The S 1049 and Line 6-17$_2$-19 had significantly more protein content than Piper and W 10 in hybrid combinations. The female parent 620 had significantly increased protein content than the remaining females in hybrid combinations. During monsoon all hybrids both among males as well as females had higher protein content than their respective parent. The 6-17$_2$-19 parent had significantly more protein content than the remaining males in hybrid combinations. On the basis of pooled analysis also all male and female parents had more protein content in hybrid combinations as compared to their own performance. The differences for protein content among males in hybrid combinations were significant and 6-17$_2$-19 parent ranked first, while differences among females in hybrid combinations were not significant.

The estimates of GCA effect (Table 6) revealed that the S 1049 had highest value among male parents during summer, whereas 6-17$_2$-19 parent ranked first during monsoon and on the basis of pooled analysis. The GCA differences were significant during individual seasons as well as for pooled data (Table 4). Among females Line 620 had highest value for GCA effect during summer and for pooled data, whereas Line 3197 had the highest estimate of GCA effect during monsoon (Table 6), the GCA differences, however, were significant during summer season only (Table 4). The estimates of SCA effect revealed that the 620 × 6-17$_2$-19, 3197 × C 10-2 and 620 × S 1049 hybrids had highest values during summer, monsoon and for pooled data respectively (Table 6), and the SCA differences were significant during monsoon and for pooled data (Table 4).

The ratio of total GCA variance revealed that both additive and nonadditive variances were equally important for this trait. In case of green forage yield the g_i and g_j values indicated that males had higher additive variance com-

TABLE—4

The variance components for general and specific combining ability and their interactions with seasons obtained from the F_1 hybrids grown during summer and monsoon 1972.

Component	*Green forage yield*			*Protein content*		
	Summer	*Monsoon*	*Pooled*	*Summer*	*Monsoon*	*Pooled*
g_i	0.5231†	9.5244†	0.4367†	0.2631†	0.9200†	0.2392†
g_j	–0.0967	1.0657†	0.1147	0.1213†	–0.6214	0.1147
S_{ij}	0.0003	0.9500†	–0.1424	0.1800	0.7200†	0.3058*
$g_i \times y$			0.2659*			0.0911*
$g_j \times y$			0.0104			0.0729
$S_{ij} \times y$			0.1077			0.1287

*and †indicate significance at 5 and 1% levels, respectively.

ponent as compared to females which might be due to diverse genotypes included in the set of male parents. All but one female lines were of grain type and hence they had comparatively less variance component. The interaction of the GCA of males with seasons revealed the differential behaviour of additive genetic variance component of males to seasons which suggested that S 1049 would be a good donor for this trait during summer but 6-17$_s$-19 would have to be used for monsoon for improving the protein content of sorghum fodder. The highest value for SCA effect observed for 3197×C 10-2 and 620×S 1049 hybrids during monsoon and for pooled analysis indicated that both additive as well as non-additive gene actions were involved in the former hybrid because 3197 parent had highest GCA value, whereas C 10-2 had low value. In case of latter cross the additive component was primarily involved as both parents had high GCA values. Collins and Pickett

TABLE—5

Mean performance of the F_1 hybrids with one parent in common and parental means for protein content during individual and pooled seasons.

Parents	*Summer*		*Monsoon*		*Pooled seasons*	
	Means of Hybrids	*Means of Line/variety*	*Means of Hybrids*	*Means of Line/variety*	*Means of Hybrids*	*Means of Line/variety*
Males						
S 1049	12.06	10.02	11.83	11.29	11.95	10.65
6—17$_s$—19	12.00	9.19	13.03	11.38	12.52	10.28
Piper	10.86	9.68	11.15	10.63	11.00	10.13
W 10	11.44	9.28	11.51	9.23	11.48	9.25
C 10—2			11.33	11.03		
BD 8			9.94	7.18		
BP 53			10.24	6.70		
Mean	11.59	9.53	11.29	9.63	11.74	10.08
S Em ±	0.17		0.21		0.37	
CD at 5%	0.50		0.59		1.07	
Females						
600	10.84	11.55	10.87	10.02	10.90	10.79
605	11.66	9.19	11.47	9.28	12.01	9.23
620	12.57	11.42	11.51	10.51	12.52	10.96
M 35	11.62	10.81	11.13	9.54	11.74	10.18
CK 60	11.41	11.55	10.99	9.04	11.51	10.55
3226	11.41	11.73	11.13	10.29	11.52	11.01
3197	11.62	9.67	11.68	10.46	11.80	10.07
Rhodhesian	11.60	9.15	11.58	8.54	11.90	8.84
Mean	11.59	10.63	11.29	9.77	11.74	10.20
S Em ±	0.25		0.29		0.38	
CD at 5%	0.71		NS		NS	
CV %	6.23		7.58		6.80	

(1972) have reported the presence of GCA variance component for grain protein in sorghum. The interaction of the GCA of males with seasons found in the present study is akin to the GCA × locality interaction observed by Liang *et al.* (1968) for the protein content of grain sorghum.

TABLE—6

Estimates of relative general and specific combining ability effects for protein content obtained from the F_1 hybrids for individual and pooled seasons.

Males	*Females*								
	600	*605*	*620*	*M 35*	*CK 60*	*3226*	*3197*	*Rhodhesian*	$\hat{g}_i$
Summer				Specific effects ($\hat{S}_{ij}$)					
S 1049	–1.39	1.53	2.00	0.14	0.28	–1.43	0.47	–0.63	0.47
6—17_s—19	–1.46	–0.64	2.63	–0.41	–0.63	0.38	–0.28	0.44	0.41
Piper	–2.15	–0.20	1.76	0.42	–0.84	0.21	0.42	0.40	–0.73
W 10	–0.98	–0.12	1.44	0.10	–0.24	–0.59	0.58	–0.14	–0.15
$\hat{g}_j$	–0.75	0.07	0.98	0.03	–0.18	–0.18	0.03	0.01	
Monsoon				Specific effects ($\hat{S}_{ij}$)					
S 1049	–0.91	1.44	1.56	0.00	0.08	–2.06	0.24	–0.26	0.54
6—17_s—19	–0.44	1.06	–1.13	–0.37	–1.30	1.03	–0.12	1.31	2.79
Piper	–3.12	0.89	1.23	–0.37	–0.29	0.36	0.45	0.94	–0.14
W 10	–0.95	–0.74	1.62	0.02	–0.78	–0.86	1.44	0.33	0.22
C 10—2	1.09	–0.35	–0.65	–2.52	–1.39	0.32	2.28	0.78	0.04
BD 8	–0.60	–1.14	0.04	1.19	0.00	–0.65	1.27	0.51	–1.35
BP 53	–1.12	1.01	0.40	–0.20	–0.52	–0.29	0.26	0.77	–1.05
$\hat{g}_j$	–0.42	0.18	0.22	–0.16	–0.30	–0.16	0.39	0.29	
Pooled seasons				Specific effects ($\hat{S}_{ij}$)					
S 1049	–1.41	1.62	1.96	0.13	0.18	–1.80	–0.21	–0.44	0.21
6—17_s—19	–1.19	0.35	0.93	–0.33	–0.96	0.65	–0.36	0.88	0.78
Piper	–2.89	0.50	1.68	0.09	–0.55	0.18	0.29	0.73	–0.74
W 10	–1.23	–0.29	1.70	0.12	–0.51	–0.72	0.86	0.10	–0.26
$\hat{g}_j$	–0.84	0.27	0.78	0·00	–0.23	–0.22	0.06	0.16	

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