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Abifarin,A.O.; Pickett,R.C.

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COMBINING ABILITY AND HETEROSIS FOR YIELD, PROTEIN, LYSINE AND CERTAIN PLANT CHARACTERS IN 18 DIVERSE INBREDS AND 56 HYBRIDS IN SORGHUM BICHOLOR (L.) MOENCH

A.O. ABIFARIN and R.C. PICKETT

INTRODUCTION

The modern plant breeder is not only interested in yield but is becoming interested in nutritional quality as a breeding objective as well. This will be a service to the teeming millions in Asian and African countries, where food consumption is primarily cereal, and also to animal feeders around the world.

Sorghum is the third most important cereal food crop in the world and the most important in certain areas. Therefore, in order to satisfy the nutritional needs of the underdeveloped countries, it is imperative to develop high yielding sorghums with intermediate to high protein levels and satisfactory combinations of the limiting amino acids.

Sorghum breeders have at their disposal a great wealth of genetic variability. This may be used for obtaining good lines to be used in hybrid combinations or for the development of open pollinated sorghum varieties. Combining ability studies involving various selections from the world collection will aid in determining the most effective use of this gene pool. Both general and specific combining ability have been used as an indication of the types of gene action controlling plant characters.

In this study restorer lines were chosen irrespective of their height and other characters but for the possession of good panicle size. The study is to show whether or not good combiners for grain yield are also good combiners for protein, lysine, and other agronomic characters, and to determine heritabilities and intercharacter correlations.

LITERATURE REVIEW

Combining ability has been defined by Kambal and Webster (1965) as the performance of a line in hybrid combinations and is usually subdivided into two categories: general and specific combining ability. Sprague and Tatum (1942) and Rojas and Sprague (1952) defined general combining ability as average performance of a line in hybrid combination. Specific combining ability was said to refer to those cases in which certain combinations do relatively better or worse than would be expected on the basis of the average performance of the lines.

Sprague and Tatum (1942) stated that general combining ability is associated with additive gene action and specific combining ability with non additive gene action, such as dominance and epistasis. Kambal and Webster (1965) made a complete set of crosses between 10 male sterile lines and 19 restorers. They found that both general and specific combining ability were important sources of variation in yield and other traits, but that general combining ability was predominant. Kramer (1959), Liang *et al.* (1968) found that both general and specific combining ability were important in the expression of grain yield in sorghum. However, Niehaus and Pickett (1966) in a study involving F_1 and F_2 generations of grain sorghum reported that grain yield variances for general combining ability were of greater magnitude than those for specific combining ability.

Additive gene effects are more important than the non additive effects for most of the traits in sorghum. Bell and Atkins (1967), among others, found significant differences among general combining ability effects of the restoring lines for all characters, while significant differences among specific combining effects were expressed only for 100 seed weight.

Heterosis or hybrid vigour is the main attraction in a hybrid program. The findings of workers such as Bartel (1949) and Quinby (1963) demonstrated that heterosis for grain yield exists in sorghum.

Some of the early reports on protein and amino acid improvement in sorghum were those of Heller and Sieglinger (1944) and Barham *et al.* (1946). The latter reported on the importance of environment on protein content of varieties before the advent of hybrids. In recent years, as the importance of sorghum for animal and human food increases, quality improvement of the grain is gaining ground as revealed by many reports on variations in protein and amino acid content by many researchers such as Tragdon (1960), Algeo (1961), Bressani and Rios (1962) and Deyoe and Shellenberger (1965). Using the existing variability in this crop, it has been found possible to improve the protein content as reported by Scheoeff (1963), that increase from 7.8 to 11.4 per cent was possible by soil fertilization. In 1964 Miller *et al.* found that wide variations in protein content existed with ranges from 6.6 to 12.8 per cent in 1961 and from 5.9 to 12.1 per cent in 1962.

Relationships of protein with amino acides and other characters have been reported. Worker and Ruckman (1968) showed a positive correlation between protein levels and seed size and temperature but a negative correlation with yield.

MATERIAL AND METHODS

Fourteen diverse inbreds selected from good yield combiners in the world collection of sorghum grown at Purdue were crossed into four male sterile lines to investigate their combining ability for protein, lysine and certain other characters. Variability existed for morphological characters and diversity of origin. The four female parents were random samples from populations of male sterile lines. They were Combine Kafir-60 (CK 60), Martin, Redlan and

Wheatland. These will be referred to as C, M, R & W respectively in the ensuing report. Table 1 contains information for identifying both male and female parents.

During the summer of 1968 the 56 F_1's from the crosses with male steriles, the four 'B' lines of the male-sterile lines, the 14 male parents and RS 610 as a check were grown in a replicated trial at the Purdue University agronomy farm. Rows were 76 cm (30 inches) apart and 366 cm (12 feet) long. There were 4 rows per plot. Enough seeds were planted to allow some thinning at the three-inch stage to obtain a population of about 300 000 plants per hectare (120 000 plants per acre) or approximately 7 plants per 30.5 cm of row. A summary of the characters measured is shown below:

Character	*Unit of Measurement*
1. Maturity	days
2. Leaf number	actual count
3. Plant height	centimeters
4. Leaf area index	square centimeters
5. Panicle exsertion	centimeters
6. Panicle length	centimeters
7. Threshing percentage	percentage grain in head
8. Panicle grain weight	grams
9. 100 seed weight	grams
10. Protein content*	percentage of seed
11. Lysine content	percentage of protein
12. Grain yield	kg/ha
13. Protein yield	kg/ha
14. Lysine yield	kg/ha

* Protein content is the proportion of nitrogen content on a fat free basis determined by microKjeldahl multiplied by 6.25.

Statistical Analysis

The experimental design used was a randomized complete block, replicated four times. Replications on blocks and genotypes were considered random for the analysis of variance. The model assumed for the analysis of variance for the 75 entries and for that of the parent was:

$$X_{ij} = +i+j+ij$$

where

X_{ij} = variable to be analyzed for the ith replication and jth treatment;
= population mean;
p_i = effect of the ith block;
j = effect of the jth treatment;
ij = random experimental-unit effect.

Analysis of variance was run for all the 14 characters in one set using all the 75 genotypes and in another using only the 18 parents. The form of the

Table 1. — Identification of the male and female parents used in the male sterile crosses*

Code	1963 Hydera-bad No.	I.S. No.	Group		Pedigree
			No.	Name	
1	1042	2822	38-Caudatum-Kafir		Red Swazi local
2	3914	5437	38-Caudatum-Kafir		Iyungu cholam
3	922	855	28-Caffrorum-Durra		SA 1797 Gurno
4	1748	129	38-Caudatum-Kafir		Hegari 6645-11-1-1-2
5	1738	115	38-Caudatum-Kafir		DD Wh. Heg. SA 6645
6	5365	6974	38-Caudatum-Kafir		280 Geterita Gondalz 12
7	5300	3441	33-Caudatum		178 Abu Kudar
8	1027	8295	38-Caudatum-Kafir		EC 21496 Z-8
9	5270	3568	33-Caudatum		132 Wad Yabis
10	2499	3977	22-Caffrorum		SA 9602-1-Short DD SS Yek
11	2191	2936	22-Caffrorum		SA 8026-2-5-2
12	2197	2942	22-Caffrorum		SA 8026-1-24-M-2
13	Unknown				Inbred Selection from CK 60 × H 7910
14	Unknown				Inbred Selection from 7763/55H × 1308
15	RS 610				

* Most of this information was obtained from the *Indian Journal of Genetics and Plant Breeding*, Volume 27, 1967.

analysis of variance was as follows:

Source	*df*	*M.S. Expectations*
Replication	$r-1$	
Genotypes	$t-1$	
Error	$(r-1)(t-1)$	

Where r = number of replications = 4;
t = number of genotypes; for all entries = t = 75 and for parents t = 18.

A separate analysis of variance was run for the 56 hybrids. The linear model assumed was

$$X_{ijk} = +p_i+a_j+B_k+aB_{jk}+ijk$$

where

X_{ijk} = variable to be analyzed for the ith replication jth female and kth male;
= population mean;
a_j = effect of the jth female parent;
B_k = effect of the kth male parent;
B_{jk} = interaction effect of the jth female parent and kth male parent;
E_{ijk} = random experimental error.

In this analysis male and female effects expressed the general combining ability while the male by female interaction represented the specific combining

ability. This approach has been used by Malm (38), Cockerham (11) in his factorial matings-design (AB) and Comstock et al. (12) mating-design II. A table of the analysis of variance for each character assuming a random model is presented below:

Source	*df*	*M.S. Expectations*
Replication	$r-1$	
Female – sterile lines	$f-1$	$\sigma^2+r^2_{\sigma FM}+rb^2_{\sigma F}$
Male parents	$m-1$	$\sigma^2+r^2_{\sigma FM}+ra^2_{\sigma M}$
F × M	$(f-1)(m-1)$	$\sigma^2+{}^2_{\sigma FM}$
Error	$(r-1)(m-1)$	σ^2

r = no. of replications;
f = no. of male sterile lines;
m = no. of male parents.

RESULTS AND DISCUSSION

Analyses of Variance and Means

Tables 2, 3, and 4 contain the results of the analyses of variance for all genotypes, parents and hybrids, respectively. Real differences were indicated among the genotypes for all characters in tables 2 and 4. However, among the parents (table 3), there were no significant differences for threshing percentage, panicle grain weight and 100 seed weight. For hybrids (table 4) and all genotypes (table 2) blocks (replicates) removed an important source of environmental variation for all characters except leaf number per plant, 100 seed weight, protein percentage, lysine yield, plant height for hybrids and threshing percentage for all the entries. On the other hand among the parents, blocks were important in removing some variations for only days to half bloom, plant height, and panicle exsertion.

The high C.V. for lysine yield and protein yield may be due to the accumulation of errors in measuring grain yield and percentage lysine and percentage protein. In sorghum panicle exsertion is an extremely variable characteristic, thus the relatively high C.V. obtained. The high C.V. for panicle grain weight is partly due to the large number of plots per block and partly due to some uneveness in plant stand as a result of the unfavourable weather conditions during the first four weeks after planting.

In this study the major emphasis was grain yield, and selection of parental lines was on this basis. Outstanding yields were obtained from most of the hybrids, as presented in tables 5-6. Grain yields for the 56 hybrids range from 5 854 to 17 288 kilograms per hectare. The mean yield of the control, RS 610, was 7 645 kg/ha. The yields of the parents used were from 4 601 to 10 363 kg/ha (table 7).

Percentage protein for hybrids ranged from 9.1 to 14.1 per cent and those for parents were 9.9 to 15.7 per cent. Lysine ranged from 1.69 to 2.27 per cent for hybrids and 1.60 to 2.19 per cent for the parents. Protein and lysine yields

Table 2. — Analyses of variance for 14 characters for the 18 parents RS 610 and 56 hybrids grown on Purdue agronomy farm in 1968

Source	df	Mean squares						
		Days to half bloom	Leaf No.	Height	Flag leaf area	Panicle exsertion	Panicle length	Threshing %
Blocks	3	55.4256**	1.7822	259.8611**	33 609.6196**	215.3656	21.3656	45.0797
Genotypes	74	234.0222**	8.7350**	19 070.2703**	7 552.9554**	54.0881**	64.2113**	66.2718**
Error	222	4.6373	0.9579	62.9519	1 876.8296	12.3470	6.9313	18.6754
C.V.		2.22%	7.49%	4.18%	25.73%	46.54%	9.73%	5.54%

Source	df	Mean squares						
		Panicle grain weight	100 seed weight	Protein %	Lysine %	Grain yield	Protein yield	Lysine yield
Blocks	3	1 597.5996**	0.0838	1.133	0.124**	5 078,465.3125**	87 303.541**	22.902
Genotypes	74	2 809.1066**	0.5541**	0.090**	0.090**	7 268 611.4375**	69 129.873**	30.741**
Error	222	365.5617**	0.1385	0.522	0.025	1 152 088.2813	15 075.974	6.591
C.V.		25.52%	10.27%	6.37%	8.12%	22.71%	23.26%	25%

** Significant at the .01 level.

Table 3. — Analyses of variance for 14 characters of the 18 parent lines grown on Purdue agronomy farm in 1968

Source	df	Mean squares						
		Days to half bloom	Leaf No.	Height	Flag leaf area	Panicle exsertion	Panicle length	Threshin %
Replications	3	11.7176	1.0000	112.3843*	3 244.4809	85.5885**	12.1598	19.0870
Genotypes	17	229.9191**	8.7418**	4 534.1708	6 856.9025	73.7376**	94.7169**	85.6988
Error	51	4.0607	1.24510	31.9921	1 301.2378	12.8109	15.03252	49.7968
C.V		2.08%	9.00%	3.96%	23.67%	60.32%	15.49%	9.40%

Source	df	Mean squares						
		Panicle grain weight	100 seed weight	Protein %	Lysine %	Grain yield	Protein yield	Lysine yield
Replications	3	965.1991	0.0494	0.2387	0.0526	406 878.7917	6 173.7335	2.6223
Genotypes	17	584.0041	0.3598	9.6221**	0.1013**	2 679 823.7917**	19 971.1810**	7.6449*
Error	51	492.7579	0.0734	0.5408	0.0276	528 976.6446**	6 420.4338	2.9544
C.V.		43.44%	11.22%	6.19%	8.79%	20.80%	19.64%	22.39%

* Significant at the .05 level.
** Significant at the .01 level.

Table 4. — Analyses of variance for 14 characters for the F_1 56 hybrids grown on Purdue agronomy farm in 1968

Source	df	Mean squares						
		Days to half bloom	Leaf No.	Height	Flag leaf area	Panicle exsertion	Panicle length	Threshing
Replications	3	45.6072**	1.2262	159.6719	33 820.4810**	150.1174**	16.2511*	35.9903*
Genotypes	55	226.3805**	7.6675**	20 088.6606**	7 482.3912**	44.9002**	49.1801**	46.9948**
Error	165	4.9132	0.8898	74.4454	2 053.9654	12.1359	4.5337	9.5408
C.V.		2.28%	7.07%	4.19%	26.03%	43.48%	7.67%	3.91%

Source	df	Mean squares						
		Panicle grain weight	100 seed weight	Protein %	Lysine %	Grain yield	Protein yield	Lysine yield
Replications	3	589.4401	0.2191	1.239	0.093*	4 946 388.5000*	85 662.737**	21.698**
Genotypes	55	2 567.8858**	0.5783**	4.019**	0.082**	6 161 971.6258**	60 748.422**	26.516**
Error	165	332.6193	0.1575	0.492	0.024	1 374 332 2031	17 994.624	7.882
C.V.		22.00%	9.77%	6.29%	7.89%	22.80%	23.61%	25.11%

* Significant at .05 level.
** Significant at .01 level.

Table 5. — Mean values of grain yields, grain weight per panicle, seed weight, % protein, % lysine, protein yield and lysine yield for 56 F_1's grown in 1968

Hybrids	Grain yield (kg/ha)	Grain wt. panicle (gm)	100 seed wt. (gm)	Protein %	Lysine %.	Protein yield (kg/ha)	Lysine yield (kg/ha)
1 W×2	17 288	123.7	2.8	10.8	1.98	1 876	37.3
2 C×5	15 893	81.0	2.5	9.1	2.27	1 448	32.9
3 C×2	15 506	108.0	3.1	10.3	2.00	1 605	32.1
4 R×7	14 700	103.5	2.5	10.5	2.17	1 545	33.8
5 R×2	14 358	106.2	2.9	10.6	1.98	1 535	30.4
6 C×7	14 166	123.2	2.8	10.7	2.11	1 520	32.0
7 R×8	14 061	100.5	3.3	11.3	1.88	1 588	29.8
8 M×8	14 044	130.2	3.2	11.7	1.91	1 653	31.6
9 R×4	13 900	77.2	2.4	10.0	2.26	1 396	31.6
10 W×5	13 405	83.5	2.3	9.4	2.21	1 247	27.5
11 W×8	13 274	128.0	3.5	11.3	1.85	1 513	27.7
12 R×1	13 218	103.7	3.2	11.3	1.91	1 499	28.7
13 R×5	13 141	90.7	2.3	9.5	2.09	1 252	26.1
14 M×5	13 035	84.2	2.3	10.5	2.00	1 390	27.5
15 M×1	12 960	120.0	3.0	12.2	1.84	1 589	29.3
16 R×9	12 833	112.0	2.7	10.6	1.96	1 359	26.8
17 R×3	12 758	83.2	2.9	11.0	1.81	1 400	25.4
18 W×4	12 605	91.5	2.4	9.7	2.05	1 229	25.2
19 W×1	12 397	121.7	3.4	11.1	1.85	1 380	25.0
20 M×4	12 360	73.0	2.3	12.0	1.74	1 452	25.4
21 C×8	12 289	106.7	3.3	10.6	2.07	1 304	27.1
22 C×4	12 184	87.5	2.4	9.2	2.19	1 122	24.6
23 M×2	12 145	106.2	3.0	11.5	1.88	1 406	26.2
24 W×3	12 053	85.0	2.9	11.0	1.83	1 312	24.1
25 M×7	11 980	123.7	2.6	11.9	2.19	1 421	31.3
26 M×9	11 864	102.0	2.4	12.0	1.93	1 423	22.4
27 M×3	11 567	66.5	2.8	12.0	1.69	1 395	23.5
28 R×11	11 511	91.2	2.4	10.7	2.01	1 234	24.8
29 C×9	11 500	114.5	2.9	10.1	2.05	1 160	23.7
30 C×10	11 311	63.0	2.5	10.3	2.14	1 180	25.4
31 C×3	11 294	69.2	2.9	11.0	1.76	1 248	22.0
32 W×7	11 262	112.7	2.5	10.9	2.00	1 228	24.2
33 C×11	10 488	74.2	2.5	11.0	2.09	1 153	23.9
34 W×12	10 357	61.2	2.4	11.3	2.20	1 179	25.8
35 W×9	9 785	85.5	3.0	11.2	1.85	1 100	18.9
36 C×1	9 707	91.5	3.2	11.9	1.93	1 147	22.0
37 M×11	9 647	67.5	2.3	11.7	1.93	1 137	21.8
38 R×10	9 568	73.2	2.3	9.9	2.25	956	21.4
39 M×14	9 316	41.5	2.3	14.3	1.78	1 337	23.7
40 W×11	9 236	67.0	2.4	9.9	2.09	903	19.1
41 M×10	9 155	61.0	2.4	11.5	2.01	1 063	21.2
42 W×13	9 034	68.5	3.0	12.2	1.83	1 099	20.0
43 R×13	9 024	54.2	2.7	11.0	1.88	1 013	18.6
44 R×12	8 781	60.0	2.6	10.3	2.06	907	18.8
45 R×6	8 576	53.5	2.5	11.2	1.92	969	18.6
46 C×12	8 458	78.5	2.7	11.4	1.95	971	18.9
47 W×14	8 441	62.5	2.6	12.6	1.80	1 073	19.2
48 M×12	7 478	62.2	2.5	11.8	2.04	885	17.8
49 C×6	7 415	60.5	2.5	11.7	1.88	871	16.3
50 R×14	7 284	62.7	2.3	11.8	1.86	856	16.0
51 C×13	7 226	41.2	2.4	11.9	1.82	862	15.8
52 W×10	7 097	59.2	2.2	10.7	2.04	754	15.6
53 M×6	6 996	45.0	2.2	12.8	1.85	891	16.5
54 M×13	6 753	46.2	2.5	13.4	1.86	915	17.2
55 W×6	6 661	45.2	1.4	11.3	2.04	751	15.3
56 C×14	5 854	46.5	2.3	12.0	1.89	702	13.3
RS 610	7 645	55.2		12.1	1.93	930	17.7
LSD .05 level	1,624	25.3	0.36	1.0	0.22	186	6.0
LSD .01 level	2,301	35.8	0.51	1.4	0.31	263	8.4

Table 6. — Mean values of days to half bloom, leaf number, leaf index, height, panicle exsertion, and treshing percentage for 56 F_1 hybrids grown in 1968

Hybrids	Days to half bloom	Leaf number	Leaf area index (cm^2)	Height (cm)	Panicle exsertion	Panicle length	Threshing %
1 W×2	107.5	14.2	223.0	297.5	10.8	27.0	79.8
2 C×5	99.7	14.0	159.2	208.7	3.2	27.2	82.7
3 C×2	102.2	15.7	141.2	298.7	9.6	25.8	83.6
4 R×7	112.7	16.0	206.5	307.5	9.3	25.9	80.0
5 R×2	108.7	14.0	202.4	308.7	13.1	25.8	82.1
6 C×1	107.7	15.2	184.6	290.0	8.0	28.3	81.2
7 R×8	103.0	14.7	138.2	306.2	5.2	22.5	82.5
8 M×8	97.2	13.7	177.0	287.0	9.5	25.0	84.4
9 R×4	96.7	13.0	196.5	202.5	4.7	26.1	82.2
10 W×5	104.5	14.0	303.4	175.0	5.0	27.7	76.1
11 W×8	102.2	15.0	171.5	287.5	4.3	24.4	83.2
12 R×1	102.2	14.5	156.5	300.0	6.0	26.7	82.1
13 R×5	101.2	14.2	182.9	218.7	4.2	25.9	79.6
14 M×5	99.5	14.2	181.3	212.5	6.2	27.2	80.3
15 M×1	102.2	14.7	218.0	302.5	7.6	29.1	81.3
16 R×9	108.5	14.2	179.7	295.0	8.2	25.0	80.5
17 R×3	91.7	13.0	114.3	200.0	7.8	22.7	82.6
18 W×4	96.7	12.7	214.1	166.2	3.5	28.5	80.1
19 W×1	102.2	14.7	182.8	283.7	1.3	28.5	83.4
20 M×4	90.7	13.2	194.1	195.0	9.5	27.0	81.6
21 C×8	95.7	14.5	130.8	272.5	9.3	23.3	83.3
22 C×4	95.7	13.0	150.9	195.0	3.9	26.1	80.9
23 M×2	103.7	15.0	206.5	302.5	17.1	24.9	82.2
24 W×3	95.0	13.0	183.3	185.0	9.6	27.2	77.7
25 M×7	109.5	16.0	277.3	306.2	14.5	29.0	81.1
26 M×9	108.5	14.7	208.0	302.5	10.6	29.1	81.9
27 M×3	92.2	11.7	153.9	191.2	9.8	25.5	82.2
28 R×11	98.0	13.0	157.9	197.5	5.9	33.7	79.9
29 C×9	107.0	15.0	179.8	278.7	5.8	28.7	80.7
30 C×3	89.5	11.5	190.9	191.2	5.9	24.8	80.8
32 W×7	113.5	15.0	305.5	280.0	8.2	29.7	78.2
33 C×11	91.5	13.0	156.6	186.2	6.4	34.5	80.1
34 W×12	96.5	13.0	175.5	130.0	7.8	31.8	72.2
35 W×9	96.2	13.7	235.9	252.5	4.3	25.7	77.2
36 C×1	101.7	14.2	144.1	288.7	3.0	27.2	81.7
37 M×11	88.5	11.5	213.5	177.5	14.0	34.9	78.8
38 R×10	96.5	13.5	181.0	150.0	5.1	34.6	74.0
39 M×14	89.2	12.7	117.9	116.2	13.3	24.7	76.3
40 W×11	96.5	12.5	215.8	157.5	6.1	34.6	77.9
41 M×10	90.5	12.7	182.7	138.7	12.5	34.1	73.8
42 W×13	94.5	12.2	153.1	123.7	6.9	26.1	74.7
43 R×13	95.2	12.7	113.8	137.5	8.1	27.9	72.8
44 R×12	95.5	13.0	139.7	152.5	11.1	30.5	74.5
45 R×6	84.5	10.7	149.6	140.0	9.7	27.7	79.2
46 C×12	89.2	12.7	112.7	127.5	4.8	27.6	78.9
47 W×14	95.0	12.7	173.7	103.7	7.3	26.0	77.6
48 M×12	91.7	12.0	161.8	148.7	13.5	30.2	76.4
49 C×6	84.7	11.2	144.7	138.7	7.4	29.2	80.0
50 R×14	95.0	12.7	132.3	110.0	5.2	24.6	76.8
51 C×13	88.0	11.2	119.4	128.7	10.6	22.2	73.6
52 W×10	95.2	13.7	187.6	131.2	5.2	35.1	73.8
53 M×6	82.2	10.0	122.0	132.5	10.8	31.2	72.1
54 M×13	88.7	11.7	122.9	132.5	13.1	24.5	72.7
55 W×6	84.5	11.2	161.9	123.7	9.2	31.6	73.3
56 C×14	89.2	11.7	113.5	110.0	6.3	22.5	77.9
RS 610	81.5	10.5	133.1	138.0	10.8	12.1	77.6
LSD .05 level	3.1	1.3	62.8	12.0	48.0	3.0	4.3
LSD .01 level	4.4	1.8	89.0	17.0	68.0	4.2	6.1

Table 7. — Mean of the parental lines and RS 610 for grain yield and other characters

Parents	Yield (kg/ha)	Days to bloom	Leaf No.	Height (cm)	Flag leaf area	Thresh-ing %	Panicle grain wt.	100 seed wt.	Panicle exsertion	Panicle length	Protein %	Lysine %	Protein yield	Lysine yield
18	10 363	96.2	12.1	143.7	117.6	76.9	58.2	2.6	7.6	21.5	10.8	1.85	1 110	21.0
8	10 360	103.2	14.2	187.5	190.4	78.7	63.7	2.6	−3.3	21.3	10.7	1.93	1 114	21.5
7	10 090	111 5	15.5	185.0	261.8	79.9	64.7	2.2	8.5	22.9	10.4	2.00	1 050	21.1
1	9 757	96.2	12.0	166.2	146.3	80.4	66.2	2.5	1.2	21.3	10.4	1.99	1 020	20.4
2	8 658	96.2	12.0	175.0	207.1	78.2	67.5	2.3	3.0	20.4	9.9	1.96	854	16.8
9	8 394	112.2	16.0	211.2	220.6	77.5	50.2	1.7	4.6	26.2	10.7	2.07	900	18.5
19	7 729	89.5	11.7	131.2	146.0	76.0	48.0	2.3	10.5	29.6	14.2	1.60	1 105	17.7
RS 610	7 645	81.5	10.5	137.5	133.1	77.6	55.2	2.4	10.8	24.4	12.1	1.93	930	17.7
13	7 620	91.2	11.7	123.7	152.6	76.3	46.5	2.8	10.4	22.3	12.8	1.62	978	15.8
16	7 480	95.2	12.5	108.7	157.1	79.0	60.2	2.8	5.6	28.7	11.6	1.81	872	15.5
4	7 005	89.2	11.7	108.7	124.8	67.2	66.7	2.1	5.0	20.0	11.3	2.04	792	16.2
6	6 652	81.5	9.7	125.0	115.1	72.7	40.7	2.7	11.2	29.6	12.7	1.67	850	14.2
5	6 579	94.5	11.5	107.5	149.2	64.8	29.7	2.1	−1.9	22.2	12.0	2.00	785	15.7
17	6 444	89.0	10.5	130.0	120.9	75.7	52.5	2.4	8.5	23.8	10.5	1.86	689	13.0
11	6 306	101.7	12.0	156.2	139.7	75.1	49.5	2.2	7.4	32.6	12.7	1.96	829	16.2
3	5 960	98.0	12.0	172.5	117.9	77.4	41.7	2.4	12.4	18.7	12.2	1.79	726	12.7
10	5 940	98.0	11.7	125.0	121.1	72.7	42.5	2.3	6.9	35.3	10.9	2.19	663	14.4
14	5 334	97.2	12.5	91.2	129.8	75.6	34.2	2.4	4.4	23.3	13.8	1.82	731	13.2
12	4 601	99.7	12.5	117.5	124.5	66.3	36.5	2.9	4.8	30.8	15.7	1.80	720	12.9
LSD .05	996	2.7	1.5	7.6	49.0	9.5	30.4	.38	5.0	5.2	1.1	0.23	112	9.5
LSD .01	1 411	3.9	2.2	10.8	69.3	13.5	43.0	.54	7.0	7.4	1.5	0.32	159	13.4

ranged from 702 to 1 876 and 13.3 to 37.3 kg/ha, respectively. Protein yields of parents were from 663 to 1 114 kg/ha and 12.7 to 21.5 kg/ha for lysine yield.

Combining ability analyses of variance are presented in tables 8-10. The male and female effects estimate general combining ability (GCA) while the interaction, female × male gives SCA. For all the characters studied the GCA computed from males was highly significant. However, the GCA estimated from the female effects was not significant for leaf number, panicle grain weight, grain yield, protein yield and lysine yield. The significant SCA obtained were for days to half bloom and plant height.

Table 8. — Combining ability analyses of variance and estimates of narrow sense heritabilities of days to half bloom, leaf number, plant height and leaf area index from the 56 male sterile F_1 hybrids

Source	df	Mean squares			
		Days to half bloom	Leaf No.	Height	Leaf area index
G.C.A. (female effects)	3	252.024**	1.678	5 632.887**	35 973.333**
G.C.A. (male effects)	13	821.091**	28.180**	82 890.728**	16 310.212**
S.C.A. (female × male effects)	39	26.171**	1.291	266.621**	2 348.175
Error	165	4,913	0.890	74.445	2 053.968
Heritability		89%	83%	99%	72%

* Significant at the .05 level
** Significant at the .01 level

The results from the combining ability analysis of variance indicated that all the characters studied were more under the influence of additive genes rather than those to dominance and epistasis. This is in agreement with the findings of Niehaus *et al.* (1966) and that of Beil *et al.* (1967). The predominance of general combining ability over specific combining ability expressed in this study indicates the fixability of the characters. Thus it would be possible to

Table 9. — Combining ability analyses of variance and estimates of narrow sense heritability of threshing per cent, 100 seed weight, panicle exsertion and panicle length from 56 male sterile F_1 hybrids

Source	df	Mean squares				
		Panicle exsertion	Panicle length	Threshing %	Panicle grain weight	100 seed weight
G.C.A. (female effects)	3	326.280**	53.620**	74.227**	242.036	0.279
G.C.A. (male effects)	13	78.180**	181.226**	148.718**	9 470.218**	0.690**
S.C.A. (female × male effects)	39	12.162	4.823	10.992	446.020	0.070
Error	165	12.136	4.534	9.541	332.619	0.068
Heritability		76%	91%	72%	84%	86%

* Significant at the .05 level
* Significant at the .01 level

make improvement on any of these characters. This is also an advantage where inbreds rather than hybrids are used for grain production. Significant GCA and SCA for number of days to half bloom and plant height were as would be expected, since the number of the controlling genes and the interactions of the genes for these characters are important. It has been shown in sorghum (Quinby *et al.* (1946)) that the presence and interactions of genes for maturity and height are important for the expression of these characters.

Table 10. — Combining ability analyses of variance and estimates of narrow sense heritabilities of grain yield, percentage protein, percentage lysine, protein yield and lysine from 56 male sterile F_1 hybrids

Source	df	Mean squares				
		Protein %	Lysine %	Grain yield	Protein yield	Lysine yield
G.C.A. (female effects)	3	23.886**	0.135**	2 378 062.754	36 299.448	8.147
G.C.A. (male effects)	13	9.443**	0.217**	21 081 592.476**	187 511.600**	81.574**
S.C.A. (female × male effects)	39	0.683	0.033	1 479 835.206	20 374.734	9.507
Error	165	0.492	0.024	1 374 332.444	17 994.644	7.882
Heritability		85%	62%	77%	68%	41%

* Significant at the .05 level
** Significant at the .01 level

The relative importance of female and male effects for the characters is indicated by significance and non-significance of female and male effects. In all the characters, male parents contributed more to the hybrid performances than the females. Diversity of the male parents could account for this. Both male and female parents were highly significant for percentage protein and percentage yield. However, male parents were highly significant for percentage protein and percentage yield, whereas female parents were not.

HERITABILITY

In the estimates of narrow sense heritabilities (tables 8-10), lysine yield was found to have the lowest value while heritability of 99% was found for plant height. It is important to note that protein % was more heritable than grain yield. The latter was 77% and the former 85%. Lysine heritability value was 62%. These indicate that these characters are largely controlled by additive gene action and could be selected for a breeding program.

HETEROSIS

Hybrid vigour was expressed for all the characters studied with the exception of protein percentage. Using the weighted grand means of parents

and those of F_1 percentage, heterosis was calculated for each character as the increase of the overall F_1 mean over the overall weighted parental mean. This is presented in table 11. The highest mean heterosis was obtained for panicle grain weight (58%), followed by that of plant height (50%).

Table 11. — Average performance of parents, F_1's and percentage heterosis

Variables	Parents	F_1's	Heterosis (%)
Days to half bloom	95.18	97.12	1**
Leaf number	12.20	13.33	6**
Height	136.90	205.84	50**
Flag leaf area	146.30	174.13	19**
Panicle exsertion	6.69	8.01	20**
Panicle legth	25.34	27.80	10**
Threshing %	75.69	79.00	4**
Panicle grain weight	52.37	82.91	58**
100 seed weight	2.44	2.60	6**
Protein	11.83	11.20	−5**
Lysine %	1.91	1.97	3**
Grain yield	7 691.10	11 060.00	44**
Protein yield	900.00	1 221.60	36**
Lysine yield	16.60	22.84*	48**

** Significant at the 0.1 level

Although there was 3% heterosis for percentage lysine, a negative value of −5% for protein percentage was found.

CORRELATIONS

The study of intercharacter correlation is of great importance in plant breeding. Breeders are looking for characters that are related to yield and quality traits. These characters are more readily seen and easy to select.

Table 12. — Intercharacter phenotypic correlation

Character	Leaf No.	Height	Leaf area	Panicle exsertion	Panicle length
Days to bloom	.897**	.804**	.584**	−.086	−.120
Leaf number		.820**	.466**	−.120	−.150
Plant height			.411**	.012	−.228
Leaf area				.037	.282*
Panicle exsertion					.026
Panicle length					
Threshing %					
Panicle grain weight					
100 seed weight					
Protein %					
Lysine %					
Grain yield					
Protein yield					

* Significant at the .05 level.
** Significant at the .01 level.

In this study the question of intercharacter relationships was considered seriously.

In table 12 intercharacter phenotypic correlation coefficients are presented. Among the hybrids, grain yield was positively and significantly correlated with all the characters with exception of panicle exsertion, panicle length, protein percentage and lysine percentage. There was near significant correlation between yield and lysine %. The high correlation between yield and height indicates that much yield reduction can occur when height is reduced. From this result, breeding for shorter types should be done only for special conditions and to meet existing requirements for mechanical operations in certain areas. However, where the needs are not so important, taller plants that will resist lodging are preferable for obtaining high yields and large panicle size. Percentage protein was positively and highly significantly correlated with panicle exsertion. Surprisingly, this was the only character thus correlated with protein. One hundred seed weight was positively but non-significantly correlated with protein. Lysine percentage was negatively and significantly correlated with protein. Number of days to half bloom, leaf number, flag leaf area, and panicle length were all positively and significantly correlated with lysine.

To further investigate the types of relationships existing between some of these characters, table 13 was constructed. This table shows a highly significant positive phenotypic and large genotypic correlation between protein and panicle exsertion. The positive but non-significant correlation obtained for seed weight and protein was mainly due to the environmental correlation.

With percentage lysine, characters whose phenotypic correlation coefficients were found to be significant with this also had large genotypic correlation values. The genotypic correlation coefficient for yield with lysine was positive and large. Thus it indicates a possible joint improvement of yield and lysine

coefficient for the 56 F_1 hybrids grown in 1968 †

Threshing %	Panicle grain weight	100 seed weight	Protein %	Lysine %	Grain yield	Protein yield	Lysine yield
.446**	.816**	.337*	−.364**	.320*	.687**	.638**	.603**
.536**	.838**	.458**	−.310*	.289*	.692**	.670**	.612**
.728**	.911**	.632**	−.210	.068	.757	.789**	.607**
.141	.468**	−.086	−.300*	.304*	.381**	.324*	.281**
−.187	.127	−.141	.475**	−.175	−.123	.058	.083
−.324*	−.154	−.406**	−.174	.419**	−.227*	−.302	−.080*
	.726**	.556**	−.248	−.040	.714**	.775**	.476
		.624**	−.309*	.145	.777**	.929**	.604
			.017	−.287*	.418**	.510**	.316*
				−.693**	−.483**	−.138	−.375**
					.258	−.004	.342
						.930**	.778**
							.732**

† With 54 degrees of freedom values of .264 and .342 are significant at the .05 and .01 level respectively.

Table 13. — Phenotypic, genotypic and environmental corelation coefficients among sallent charcters for the 56 hybrids

Characters correlated	Correlation Coefficients		
	Phenotypic †	Genotypic	Environ-mental
Percentage protein with leaf number	−.310*	−.370	.134
Percentage protein with plant height	−.210	−.224	−.021
Percentage protein with 100 seed weight	.017	−.025	.288
Percentage protein with panicle exsertion	.475**	.591	.014
Percentage protein with panicle length	−.174	−.202	.066
Percentage lysine with days to half bloom	.320*	.386	−.005
Percentage lysine with leaf number	.289*	.356	.042
Percentage lysine with height	.068	.080	.054
Percentage lysine with 100 seed weight	−.289*	−.299	−.264
Percentage lysine with panicle exsertion	1.175	−.225	−.048
Percentage lysine with panicle length	.419**	.531	−.034
Grain yield with percentage protein	−.483**	−.483	−.586
Grain yield with percentage lysine	.258	.337	.032
Grain yield with days to half bloom	.687**	.800	−.150
Grain yield with 100 seed weight	.418**	.494	.090
Grain yield with panicle length	.227	−.273	.020
Grain yield with panicle exsertion	−.123	−.194	.094
Grain yield with height	.757**	.861	−.002
Grain yield with leaf number	.652**	.838	−.014
Grain yield with panicle grain weight	.774*		

† With 54 degrees of freedom values of 0.264 and 0.342 are significant at the 0.05 and 0.01 level respectively.
* Significant at the .05 level.
** Significant at the .01 level.

under some environmental conditions. However, negative phenotypic, genotypic and environmental correlations occurred between yield and protein.

These findings are encouraging for future work in protein and lysine improvement. If these morphological and other characters maintain this relationship with protein and lysine, we thus have new tools to handle our quality improvement program. Breeders can thus select for plants with good panicle exsertion and obtain acceptable levels of protein content. This will be faster and cheaper. For lysine, one has only to select for materials that are late maturing with many leaves per plant and good panicle length with small seeds. This will reduce the amount of chemical analysis required for determination of lysine percentage in sorghum.

Unfortunately, however, not all of these characters are correlated with yield. Especially for protein, panicle exsertion is correlated negatively with yield; so selection only for long panicle exsertion will lower grain yields though percentage protein will increase. Thus this must be done cautiously. Lysine content, on the other hand looks more promising, as it is in itself genotypically correlated with yield and some characters which indicated significant correlations with lysine are correlated with yield.

The finding of negative correlation between yield and protein in this study agrees with what many workers such as Worker *et al.* (1968) and Lowe (1958)

have reported for sorghum. However, progress in the grain quality and quantity can still be realized. Protein yield per hectare that can be obtained from high yielding hybrids with protein level of 10% or better as found in this study can be improved upon. The most important thing is to improve yields while the genotypes still hold their own or are improved for acceptable protein levels. Maximization of protein can thus be achieved by improving the grain yields among genotypes that can maintain their good protein content and are also able to make reasonable response to protein improvement program. Since lysine has been considered as percentage of protein, lysine yield can be improved upon as yields and protein percentage are improved and lysine as a percentage of protein is held even or improved.

CONCLUSION

Results from this experiment indicate that high yielding materials exist in this sorghum population. All the fourteen sorghum characters evaluated were shown to be more under additive genetic actions as indicated by large GCA and small SCA. This was responsible for the high narrow sense heritability obtained for many of the fourteen characters studied. Many of the characters revealed favourable correlations with yield. Protein was found to be favourably correlated with panicle exsertion, lysine with panicle length and days to half bloom. It is possible to improve yield and lysine together, but raising the protein level may not be as easy. However, protein yield could be improved if acceptable protein levels are maintained or improved by the high grain yielders. These results illustrate possible progress in yield and quality work in sorghum. The magnitude of the additive gene action indicates the feasibility of developing pure homozygous lines of high grain yield and reasonable grain quality. These lines could either be utilized as such or in a hybridization program.

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