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Genetic analysis of heterosis in sorghum

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ABSTRACT

The nature and magnitude of gene effects for several quantitative and qualitative characters were estimated in 2 commercial hybrids of grain sorghum [*Sorghum bicolor* (Linn.) Moench]. Dominance and dominance × dominance type of non-allelic interactions were found to play a significant role in the expression of heterotic manifestations in both the hybrids. The magnitude and to some extent even the nature of gene effects governing heterosis for various characters were found to differ when estimated over the 2 years. Gene effects should hence be studied in different environments (over years and locations) so that the influence of the environment is precisely estimated before chalking out breeding strategies.

The mere presence or absence of heterosis in a cross does not reflect any particular type of gene action or interaction and a wide range of combinations of gene effects could be responsible for heterotic manifestations (Jinks and Jones, 1958). The gene effects can, however, be estimated in terms of genetic parameters (d, h, i, j and l) and heterosis analysed for its genetic basis (Rao and Murty, 1970; Vasudeva Rao and Goud, 1975; Dangi and Paroda, 1978; Paiswan and Atkins, 1978; Lodhi and Paroda, 1978). It is in this context that in the present study the heterosis was analysed for its genetic components in the 2 commercial hybrids of grain sorghum [*Sorghum bicolor* (Linn.) Moench].

MATERIALS AND METHODS

The parents, F_1, F_2 and F_3 generations of 2 commercial grain sorghum hybrids 'CSH 5' ('2077 A' × 'CS 3541') and 'CSH 6' ('2219 A' × 'CS 3541') were studied during the wet seasons (*kharif*) of 1978 and 1979 to estimate the nature of gene action governing heterotic manifestations. The advanced generations were the bulk of the harvest of the preceding generation. The experiment was laid out in a randomized complete-block design replicated 4 times, with each generation taken as a treatment. Data on several quantitative and qualitative characters were taken in 1978 and only some important yield contributing characters were studied in 1979. While sampling was done in case of uniform populations, a complete row was studied in the segregating populations. The gene effects were estimated following Hayman (1958) and Jinks and Jones (1958). In the absence of backcross generations the component of additivity (d) could not be separated from the additive × dominance interaction component (j) and a confounded effect of these two components d' (d–j) was estimated (Rao and Murty, 1970; Dangi and Faroda, 1978).

RESULTS AND DISCUSSION

In 'CSH 5' additive and additive × additive interaction effects together were of lower magnitudes compared with other gene effects during both the years for all

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Table 1. Estimates of genetic components of heterosis in 'CSH 5' in 1978

Character	m (F_2 mean)	d' (additive, additive × dominance)	h (dominance)	l (dominance × dominance)	i (additive × dominance)
Dry matter % (45 days)	13.15	0.00	— 1.00	4.71	— 0.22
Dry matter % (120 days)	33.23**	— 1.50**	9.03**	— 10.67	4.67
Days to 50% flowering	83.25**	— 1.88*	10.83	— 52.67*	7.71
NRA (50 days)	0.56**	— 0.02	0.24	— 0.28	0.01
NRA (flowering)	0.84**	1.52**	2.21**	7.15**	3.70**
NRA (grain-filling)	0.59**	0.11**	0.52*	0.21	0.41
Leaf length	67.85**	— 0.55	9.11	— 2.89	2.96
Leaf width	7.96**	9.65**	2.42	— 5.21*	3.64**
Leaf area/leaf	405.53**	16.73	165.10	—261.87	103.33**
Total leaf area	55.45**	1.49	20.80	— 10.43	10.12
Crude protein content	10.86**	0.79**	1.33*	— 8.45**	2.42**
Plant height	134.13**	9.48**	— 36.72	239.01**	—115.88**
Number of leaves or nodes	13.78**	— 0.19*	— 0.46	5.81	— 2.63
Internodal length	9.50**	— 0.92**	— 1.85	8.98	— 6.21**
Panicle length	24.86**	4.07**	1.45	17.68	6.21**
Whorls/panicle	11.19**	— 0.65	— 2.46	10.56*	— 5.21*
Secondary branches/whorl	4.59**	0.90**	1.07**	— 0.09	2.44**
Length of secondary branch	7.75**	1.89**	2.69*	0.48	6.06**
Grain weight/whorl	6.92**	— 1.40*	7.21**	— 0.37	1.02
Grain number/whorl	301.66**	— 35.86*	368.93**	— 72.23	67.52
Grain weight/panicle	44.52**	— 2.13	47.07**	39.25	10.61
250-grain weight	6.03**	0.24	— 1.31	0.78	0.69
Grain yield	30.85**	— 9.78*	11.05	79.53	— 33.97*
Stover yield	26.16**	— 4.91**	— 4.58	11.38	— 20.42**

*$P < 0.05$; **$P < 0.01$.

the characters except number of secondary branches/whorl and length of secondary branch (Tables 1, 2). This indicated a minor but significant contribution of additive and additive × additive interaction effects. The dominance and dominance × dominance interaction effects were of fairly high magnitudes for all the characters except the 2 mentioned above, indicating the importance of these effects in the inheritance and heterotic manifestations.

Except for panicle length and stover yield in 1978 and the number of leaves of nodes and number of whorls/panicle in 1979, the estimates of h were many times higher than the corresonding d' estimates. This indicated the presence of overdominance or non-allelic interactions for these characters during the corresponding year though the high estimates of h and epistatic interactions have been found to be together (Rao and Murty, 1970).

In 1978, excepting for nitrate-reductase activity (NRA) during flowering and grain-filling stages, panicle length, length of secondary branch, grain weight/panicle and grain yield, the l and h components had opposite signs for all other characters and the magnitude of l exceeded that of h for most of the characters. This indicates considerable duplicate epistasis for most of the characters (Rao and Murty, 1970). In spite of this, the crosses are heterotic. In the second year also, similar results were obtained for some characters in 'CSH 5'. For the number of nodes, panicle length, number of whorls/panicle, number of secondary branches/whorl, length of secondary branch, grain number/whorl, grain weight/panicle, 250-grain weight and stover yield, however, they were in the same direction and were of considerable magnitude.

Table 2. Estimates of genetic components of heterosis in 'CSH 5' in 1979

Character	m (F_2 mean)	d' (additive, additive × dominance)	h (dominance)	l (dominance × dominance)	i (additive × additive)
Plant height	135.39**	— 5.35**	— 35.24	235.65**	—101.11**
Dry matter %	28.26**	— 1.55	4.59	— 7.61	0.05
Number of leaves or nodes	13.64**	— 0.32	0.06	6.74	— 2.27
Internodal length	9.98**	— 0.29	— 2.60	12.09*	— 5.93**
Panicle length	24.39**	3.86**	4.95	14.07	9.06**
Whorls/Panicle	13.12**	1.08**	0.22	1.71	2.14*
Secondary branches/whorl	4.48**	0.66**	0.86*	0.75	1.77**
Length of secondary branch	7.56**	2.08**	2.56*	1.69	6.25**
Grain weight/whorl	4.27**	— 0.11	5.91**	— 4.23	4.11*
Grain number/whorl	156.58**	5.61*	123.46*	109.27	75.91**
Grain weight/panicle	28.12**	4.94**	35.17**	32.45*	27.70**
250-grain weight	5.21**	0.09	1.21*	1.20	0.94*
Grain yield	20.28**	— 0.47	43.58**	— 2.22	20.45**
Stover yield	44.39**	44.08**	9.08**	9.88	— 22.06**

*$P < 0.05$; **$P < 0.01$.

Table 3. Estimates of genetic components of heterosis in 'CSH 6' in 1978

Character	m (F_2 mean)	d' (additive, additive × dominance)	h (dominance)	l (dominance × dominance)	i (additive × additive)
Dry matter % (45 days)	15.00*	0.59*	0.08	0.27	1.74
Dry matter % (120 days)	33.31**	— 0.82	3.96	— 12.51	3.50
Days to 50% flowering	65.50**	— 5.25**	— 6.17*	— 0.67	— 5.92**
NRA (50 days)	0.52**	0.08*	— 0.05	0.42	0.00
NRA (flowering)	6.82**	1.72**	7.45*	— 6.34**	4.32*
NRA (Grain-filling)	3.83**	1.53**	2.12	— 1.74	2.73*
Leaf length	60.94**	— 2.81**	0.72	40.75**	— 15.79**
Leaf width	6.03**	— 0.31*	— 0.01	2.91	— 0.94
Leaf area/leaf	274.78**	— 27.45**	3.44	335.45*	—119.36**
Total leaf area	31.32**	— 6.51**	0.55	50.90	— 20.86**
Crude protein content	12.04**	1.04**	0.35	— 10.75**	2.22**
Plant height	124.06**	— 19.67**	— 14.45	142.15*	—105.32**
Number of leaves or nodes	11.38**	— 1.07**	0.19	3.14	— 2.05
Internodal length	9.89**	— 1.28**	— 1.92	8.45*	— 7.80**
Panicle length	23.40**	1.65**	1.58	17.69**	0.00..
Whorls/panicle	10.50**	— 1.28**	0.33	0.03**	— 4.02**
Secondary branches/whorl	4.01**	0.72**	— 0.16	0.77	1.54**
Length of secondary branch	6.76**	1.03**	— 0.36	9.61*	0.49
Grain weight/whorl	4.78**	— 0.78	1.09	13.46	— 3.00
Grain number/whorl	199.24**	2.91	71.30	472.65	— 10.54
Grain weight/panicle	32.14**	— 8.42*	— 1.64	137.83*	— 43.37
250-grain weight	6.13**	— 0.64**	— 1.20	1.56	— 2.44**
Grain yield	18.34**	— 5.38**	35.98	26.71	— 7.60
Stover yield	17.22**	— 9.10**	— 15.41**	48.60**	— 37.85**

*$P < 0.05$; **$P < 0.01$.

In 'CSH 6' also, the magnitude of additive and additive × additive interaction effects were of lower magnitudes compared with the dominance and dominance × dominance interaction effects (Tables 3, 4). This suggested that dominance and dominance × dominance interaction gene effects were more important for heterotic manifestations.

The additive and additive × additive interaction effects were, however, more important than the dominance and dominance × dominance interaction effects for the percentage of dry matter at 45 days, days to 50% flowering, nitrate-reductase activity during the grain-filling stage, and number of secondary branches/whorl in 1978 and for the number of secondary branches/whorl, length of secondary branch and stover yield in 1979.

The presence of over dominance or non-allelic interactions was indicated for yield and most of the yield-contributing characters like the percentage of dry matter at maturity, days to 50% flowering, nitrate-reductase activity at flowering and grain filling stages, internodal length, grain weight, grain yield and stover yield in 1978, for which the estimates were larger in magnitude than the corresponding d estimates. This was true in 1979 also for most of the important yield contributing characters like plant height, percentage dry matter at maturity, internodal length, panicle length, number of whorls/panicle, grain weight/whorl, grain number/whorl, grain weight/panicle, 250-grain weight and grain yield.

Duplicate epistasis (Rao and Murty, 1970) was present in 'CSH 6' in 1978 for the percentage of dry matter at 45 days, NRA at 50 days, flowering and grain-filling stages, leaf width, crude protein content, plant height, internodal length, number of secondary branches/whorl, length of secondary branch, 250-grain weight and stover yield, and in 1979 for plant height, percentage dry matter at maturity, internodal length, number of whorls/panicle, number of secondary branches/whorl, 250-grain weight and stover yield. For rest of the characters including grain yield in both the years the 2 components of dominance and dominance × dominance interaction were in the same direction and were of considerable magnitude.

Thus it is evident that dominance is a major component responsible for heterosis in both the hybrids. In 'CSH 5' for grain

Table 4. Estimates of genetic components of heterosis in 'CSH 6' in 1979

Character	m (F_2 mean)	d' (additive, additive × dominance)	h (dominance)	l (dominance × dominance)	i (additive × additive)
Plant height	121.62**	— 21.87**	— 39.31	201.55*	—130.01**
Dry matter %	33.35**	1.00	32.40**	— 51.12**	23.05**
Number of leaves or nodes	11.40**	— 2.00**	0.36	3.53	— 2.17*
Internodal length	10.62**	— 0.98**	— 3.51	13.03*	— 9.06**
Panicle length	22.55**	0.73*	4.05*	16.49**	1.07
Whorl/panicle	11.64**	— 0.56**	2.35	— 1.54	— 0.12
Secondary branches/whorl	4.02**	0.56**	— 0.18	1.12	1.34**
Length of secondary branch	6.75**	1.19**	0.67	6.79	1.93*
Length of secondary branch	6.75**	1.19**	0.67	6.79	1.93*
Grain weight/whorl	5.75**	— 0.34*	1.33	5.98*	— 0.82
Grain number/whorl	179.81**	15.46**	66.41**	142.22	51.50**
Grain weight/panicle	26.29**	1.98**	17.35**	55.69**	3.41
250-grain weight	5.88**	— 0.54**	1.91**	— 3.23**	— 0.02
Grain yield	34.33**	7.29**	15.27	37.50	2.59
Stover yield	32.60**	— 10.75**	— 4.69	16.80	— 34.33**

*$P < 0.05$; **$P < 0.01$.

yield both dominance and dominance × dominance interaction components were of considerable magnitude and in the same direction in 1978, while in 1979 component 1 was of a very small magnitude and also in the opposite direction. In 'CSH 6' these 2 components were in the same direction and were of fairly large magnitude in both the years. The favourable non-allelic interactions therefore play a significant role in yield increases obtained in these hybrids.

The estimates varied both in magnitude and direction in the 2 years. We therefore conclude that the genetic mechanism governing heterosis in sorghum is largely influenced by environmental variations. To get a clear picture, the nature of gene effects governing heterosis in different crosses should be estimated in different environments and preferably over years and locations. Only then would it be possible to advance a promising cross successfully in our breeding programme suited specifically to a particular agro-climate.

Nevertheless, different hybrids show considerable differences in yield with divergent mechanisms of gene effects and this is probably achieved by different developmental mechanisms (Rao, 1967).

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