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Heterosis studies over different environments in sorghum [*Sorghum bicolor* (L.) Moench]

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ABSTRACT : An experiment was conducted to estimate the heterosis in F_1 hybrids of sorghum with respect to grain yield and its components using 54 hybrids developed through line x tester mating design involving three females [Cytoplasmic-Genetic Male Sterile (CGMS) Lines] and 18 males (testers) and in three diverse environments. Result of analysis of variance for means revealed significant differences for all the twelve characters. The high standard heterosis was obtained for grain yield per plant and panicle weight; medium level of heterosis was found for plant height, leaves per plant, primaries per panicle, dry stover yield and harvest index and low for days to 50 per cent flowering, days to maturity, panicle length, 1000-grain weight and protein content. The highest positive heterobeltiosis and standard heterosis for grain yield per plant was 213.40 and 96.42 per cent, respectively.

KEY **W**ORDS : Heterosis, Line x tester, Sorghum, *Sorghum bicolor*

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Sorghum [*Sorghum bicolor* (L.) Moench] is the fifth important cereal crop after wheat, maize, rice and barley in the world. It is mainly grown in the Deccan plateau, central and western India apart from a few patches in northern India. Sorghum is one of the major crops among the millets grown in dry land. Sorghum is nutritionally superior to other fine cereals such as rice and wheat and hence, it is known as nutritious cereal. It is a multi purpose and bio-energy crop; the grain, stem and glumes are the useful parts.

In India, in the last three decades, productivity has gone up by 84 per cent in case of *Kharif* sorghum and 70 per cent in *Rabi* sorghum. Thus, due to sorghum hybrid technology the individual farm household is made economically viable at micro-level (Seetharama, 2006). The phenomenon of heterosis is proved to be the most important genetic tool in enhancing the yield of self as well as cross pollinated crop species in general and sorghum in particular. The exploitation of heterosis on commercial scale in pearl millet is regarded as one of the major breakthroughs in the improvement of its productivity. In genetic improvement, selection of better parents is one of the important steps for development of superior hybrids. An attempt has been therefore, made in the present investigation to know the extent of heterosis for grain yield and its component traits over different environments.

RESEARCH PROCEDURE

Three male sterile lines 8A, 28A and 86A of sorghum were crossed with18 testers used as male parents *viz.,* KR 125, KR 126, KR 128, KR 191, KR 196, KR 199, PMSC 43, GJ 38, GJ 39, GJ 42, GSF 5, CSV 21F, SPV 1616, SPV 669, PKV Ashwini, AKSSV 22, PKV 400, PVK 809 in line x tester fashion. The resulting 54 F_1's along with their 21 parents and one check CSH18 were grown in Randomized Block Design with three replications at college farm, N.M. College of Agriculture, Navsari Agricultural University, Navsari during late *Kharif* 2010-11, *Rabi* 2010-11 and summer 2011. Data on five randomly selected plants were recorded for 12 characters (except days to 50 per cent flowering and maturity which were recorded on plot basis) *viz.*, grain yield per plant (g), days to 50 per cent flowering, days to maturity, plant height (cm), number of leaves per plant, panicle length (cm), number of primaries per panicle, panicle weight (g), dry stover yield per plant (g), harvest index (%), 1000-grain weight (g) and protein content (%). Heterobeltiosis and standard heterosis was worked out over environments using standard procedure.

RESEARCH ANALYSIS AND REASONING

The pooled analysis of variance for genotypes (parents and their F_1s with one check) for all the twelve characters showed that variances were highly significant for all the characters. The partitioning of total variance into various components revealed that a large portion of variance for all the characters studied was attributed to genotypes and environments when they were tested against G x E component. Environmental variances were found to be significant for all the characters. Significant variability also existed among the genotypes for all the traits. The magnitude of variance for G x E interaction was also found to be significant for all the characters. Further, the magnitude of G x E variance for most of the characters was lower than that due to genotypes (Table 1).

Among parents, for grain yield per plant, two females and seven males had significant positive GCA effects, while one female and nine males recorded significantly negative GCA effects. The female 28A and male GJ 38 with highest positive GCA values were considered to be good general combiners for grain yield per plant (Table 2).

Grain yield represents the prime character of economic importance in pearl millet. A large number of crosses exhibited positive better parental heterosis with very high magnitude. The extent of heterosis ranged from -46.46 per cent (8A x GJ 42) to 213.40 per cent (28A x KR 191) over better parent (Table 3). In all, 36 crosses displayed significantly positive heterobeltiosis for grain yield per plant. The cross combination 28A x KR 191

Table 1 : Analysis of variance (Mean squares) of yield and yield contributing traits pooled over environments

Source	d.f.	Grain yield per plant	Days to 50 % flower	Days to maturity	Plant height	Leaves per plant	Panicle length	Primaries per panicle	Panicle weight	Dry stover yield per plant	Harvest index	1000-grain weight	Protein content
Environment	2	7316.53**	200.47**	246.39**	2013.27**	5.30**	88.88**	14910**	7989.62**	2434.26**	744.77**	148.37**	0.9936**
Rep./Env.	6	28.20	3.54	7.26	234.06	0.377	3.89	66.67	37.11	99.86	11.88	0.51	0.41
Genotypes	75	2079.30**	442.50**	514.02**	30225.9**	28.29**	230.24**	866.71**	2292.63**	5163.53**	200.79**	346.12**	49.45**
Parents(P)	20	706.04**	923.04**	923.04**	20669**	29.54**	179.44**	557.62**	909.4**	6796.72**	196.72**	171.98**	33.64**
Hybrids (H)	53	2271.7**	261.73**	277.97**	33942.8**	52.88**	182.39**	987.52**	2457.95**	4642.01**	165.89**	389.45**	47.11**
P vs H	1	21258**	470.09**	4325.9**	53889**	132.98**	3672.7**	1133.37**	23061.3**	3197.27**	2202.4**	1735.52**	538.22**
Gen. x Env.	150	140.35**	20.52**	22.93**	653.38**	2.20**	7.96**	130.77**	146.90**	102.79**	20.58**	3.02**	0.37**
Parents x Env	40	65.30**	41.64**	41.64**	602.64**	2.95**	9.86**	79.16**	87.26**	102.66**	13.73**	6.50**	0.52**
Hybrids x Env	106	171.42**	10.64**	13.20**	456.19**	1.95**	6.30**	133.83**	171.73**	98.58**	22.82**	1.65**	0.32*
(Pvs H) x Env	2	112.43**	121.55**	145.44**	1053.7**	2.36**	58.55**	249.53**	163.63**	424.91**	46.58**	4.19**	0.54**
Pooled error	450	17.14	2.15	4.41	142.25	0.2296	2.36	40.52	22.55	60.69	7.22	0.31	0.25

* and ** indicate significance of values at P=0.05 and 0.01, respectively

Table 2: Estimates of general combining ability (GCA) of parents pooled over environments

Parents	Grain yield per plant	Days to 50 % flower	Days to maturity	Plant height	Leaves per plant	Panicle length	Primaries per panicle	Panicle Weight	Dry stover yield per plant	Harvest Index	1000-grain weight	Protein content
Females												
8A	-14.79**	1.00**	1.18**	-51.98**	-0.35**	-3.20**	-6.97**	-15.1**	-17.54**	-3.30**	-6.12**	-0.86**
28A	8.59**	-1.93**	-2.15**	16.20**	-0.41**	2.66**	4.90**	8.20**	7.05**	2.46**	0.90**	0.82**
86A	6.19**	0.92**	0.96**	35.78**	0.76**	0.54**	2.07**	6.96**	10.48**	0.83**	5.21**	0.03
S.E.(g_i)	0.30	0.10	0.15	0.87	0.03	0.11	0.46	0.34	0.57	0.19	0.04	0.03
S.E.(g_i-g_j)	0.43	0.15	0.21	1.23	0.04	0.15	0.66	0.49	0.80	0.27	0.05	0.05
Males												
KR 125	1.74*	-0.88**	-1.35**	-42.14**	0.96**	1.14**	2.43*	2.12*	3.87**	0.40	0.21*	-3.39**
KR 126	-0.32	-2.06**	-1.72**	-21.70**	1.41**	3.80**	-5.64**	0.34	-10.41**	1.58**	-2.87**	-0.94**
KR 128	-8.68**	4.67**	3.20**	23.65**	1.42**	-2.08**	-5.85**	-8.21**	-1.49	--3.77**	-0.47**	-2.48**
KR 191	7.78**	-1.73**	-2.12**	-43.24**	0.05	4.37**	-3.41**	8.25**	-9.25**	5.11**	-1.22**	0.34**
KR 196	8.61**	-2.10**	-1.68**	-17.56**	-0.51**	-1.98**	-4.13**	8.85**	1.39	3.38**	-1.56**	-1.78**
KR 199	-3.32**	-10.99**	-11.05**	-55.12**	-0.56**	-0.08	1.04	-4.53**	-17.98**	2.87**	-3.47**	0.49**
PMSC-43	11.34**	-1.65**	-1.61**	40.28**	0.95**	0.86**	10.67**	12.03**	12.03**	2.33**	5.08**	2.74**
GJ 38	14.35**	-1.77**	-1.46**	-32.41**	-1.23**	3.46**	11.58**	14.14**	14.94**	2.92**	-1.28**	2.27**
GJ 39	-7.45**	4.00**	3.42**	-41.36**	-0.15	1.62**	-8.10**	-9.67**	-12.13**	-0.84	-1.93**	2.10**
GJ 42	-7.36**	-1.73**	-1.50**	-1.96	-1.87**	2.67**	-8.91**	-8.21**	-8.36**	-1.94**	-4.46**	1.80**
GSF 5	7.55**	8.86**	10.64**	86.37**	2.47**	-4.90**	10.67**	9.70**	36.29**	-2.67**	6.67**	1.88**
CSV 21F	3.91**	9.15**	9.23**	53.61**	2.25**	-5.81**	7.96**	6.02**	26.45**	-2.41**	4.73**	1.07**
SPV 1616	-5.51**	0.04	-0.50	-18.65**	-1.54**	-4.43**	8.00**	-636**	-12.15**	-0.33	-4.24**	1.95**
SPV 669	-1.54*	-0.80**	-0.61	35.86**	-1.86**	1.50**	-8.73**	-0.34	6.78**	-2.54**	0.29**	-2.57**
PKV Ashwini	-3.59**	-4.28**	-5.20**	35.15**	-1.57**	-1.29**	8.33**	-2.57**	-8.73**	-0.55	-1.78**	-2.75**
AKSSV 22	-5.74**	0.63*	0.97*	-20.57**	0.68**	1.63**	-5.10**	-7.12**	-9.13**	-1.10*	3.74**	-2.69**
PKV 400	-11.11**	-1.69**	-1.09**	8.14**	-0.55**	-2.37**	-5.31**	-12.6**	-5.13**	-3.52**	0.88**	0.67**
PVK 809	-0.65	2.34**	2.46**	11.66**	-0.34**	1.88**	-5.48**	-1.49	-6.98**	1.10*	1.72**	1.26**
S.E.(g_j)	0.74	0.26	0.37	2.14	0.08	0.27	1.14	0.85	1.40	0.48	0.10	0.09
S.E.(g_i-g_j)	1.05	0.37	0.53	3.03	0.12	0.39	1.62	1.20	1.98	0.68	0.14	0.12

* and ** indicate significance of values at P=0.05 and 0.01, respectively

gave the highest heterosis (213.40%) over the best parent followed by 28A x KR 126 (122.46%), 28A x KR 125 (93.85%) and 86A x KR 196 (88.08%). All these crosses invariably involved at least one of the parents as good general combiner (as revealed by the GCA values of the parents in Table 2). Interestingly, most of the higher ranking crosses in terms of heterobeltiosis also recorded higher ranks in *per se* performance which is attributed to the high yielding ability of the parents. The range of heterosis was -42.74 per cent (8A x PKV Ashwini) to 96.42 per cent (28A x PMSC-43) over standard check in respect to grain yield per plant. The identification and utilization of heterotic and useful crosses are very important in hybrid breeding approach in order to make commercial cultivation of beneficial hybrids. Among the 54 crosses studied, 31promising hybrids were significantly superior to standard check CSH 18 for grain yield per plant. Of these, the cross combination 28A x PMSC-43 had highest per se performance as well as ranked first for standard heterosis (96.42%), followed by 28A x GJ 38 (96.26%) and 28A x KR 191 (94.41%). These cross combinations also depicted significant heterotic effects for other component traits in desired direction. Present findings are consistent with earlier results of Madhusudhana (2002); Nirmala *et al.* (2004); Desai *et al.* (2006) and Showemimo *et al.* (2006).

Early flowering and maturity is desirable in sorghum for escaping the drought conditions. Hence, negative heterosis is useful for days to 50 per cent flowering and days to maturity.

Heterosis for days to 50 per cent flowering ranged from -30.31 per cent to 25.49 per cent and -8.41 to 23.77 over better parent and standard check, respectively. Out of 54 crosses studied, 37 and 05 exhibited significantly negative heterobeltiosis and standard heterosis, respectively. In respect to days to maturity, range of heterosis varied from -25.16 per cent to 15.70 per cent and -3.39 per cent to 23.64 per cent over better parent and standard check, respectively. The most of cross combinations manifested earliness for heterobeltiosis. Of these, 44 and 02 crosses rendered significant heterosis in desired direction over better parent and standard check, respectively. A large number of crosses manifested significantly negative heterobeltiosis for days to 50 per cent flowering and days to maturity indicating non-additive type of gene effects for this trait. The results are in agreement with Kide *et al.* (1985); Senthil and Palanisamy (1993); Tiwari *et al.* (2001); Ravindrababu *et al.* (2002) and Chaudhary and Narkhede (2004).

For plant height, the range of heterobeltiosis and standard heterosis lied between -60.24 per cent to 76.78 per cent and -49.61 per cent to 58.95 per cent, respectively. Out of 54 crosses studied, 30 and 30 rendered significant positive heterobeltiosis and standard heterosis, respectively. The high magnitude of heterosis and a large number of crosses exhibiting significant positive heterobeltiosis in plant height indicating the role played by non-additive gene effects in controlling the inheritance of this trait. These findings are in line with those of Veerabadhiran *et al.* (1994) and Desai *et al.* (2005).

Table 3: Range of heterosis and hybrids exhibiting highest heterobeltosis and standard heterosis for yield and yield contributing traits pooled over environments

Traits	Range of heterobeltiosis		Hybrid exhibited highest heterobeltiosis in desired direction	Range of standard heterosis		Hybrid exhibited highest standard heterosis in desired direction
	Min	Max		Min	Max	
Grain yield per plant	-46.46	213.40	28A x KR 191	-42.74	96.42	28A x PMSC-43
Days to 50 % flowering	-30.31	25.49	86A x KR 199	-8.41	23.77	86A x KR 199
Days to maturity	-25.16	15.70	86A x KR 199	-3.39	23.64	86A x KR 199
Plant height	-60.24	76.78	86A x PMSC-43	-49.61	58.95	8A x GSF 5
Leaves per plant	-41.67	46.07	8A x CSV 21F	-13.64	52.25	8A x GSF 5
Panicle length	-39.54	67.51	28A x GJ 42	-43.79	18.89	28A x KR 191
Primaries per panicle	-42.80	66.47	86A x PMSC-43	-28.09	55.09	28A x GJ 38
Panicle weight	-40.65	101.04	28A x KR 191	-32.35	76.24	28A x PMSC-43
Dry stover yield per plant	-55.81	63.99	28A x KR 191	-53.01	29.51	8A x GSF 5
Harvest Index	-30.15	47.04	28A x KR 191	-9.01	56.13	28A x KR 191
1000-grain weight	-38.27	40.63	28A x AKSSV 22	-42.06	22.04	86A x AKSSV 22
Protein content	-53.76	109.76	8A x CSV 21F	-46.96	15.86	28A x PMSC-43

In case of leaves per plant, the range of heterosis was -41.67 per cent to 46.07 per cent in heterobeltiosis and -13.64 per cent to 52.25 per cent in standard heterosis. Most of the crosses displayed positive heterobeltiosis and standard heterosis. Of these, 31 and 38 rendered positive significant heterosis over better parent and standard check, respectively. The high degree of heterosis and a large number of crosses exhibiting positive heterosis revealed that the trait governed by non-additive gene action. Similar results have been reported by Amsalu and Bapat (1990) and Premalatha *et al*. (2006). With regards to panicle length, the extent of heterobeltiosis and standard heterosis varied from -39.54 per cent to 67.51 per cent and -43.79 per cent to 18.89 per cent, respectively. Out of 54 crosses studied, nineteen and four displayed significant positive heterobeltiosis and standard heterosis for this trait, respectively. The cross combination 28A x GJ 42 and 28A x KR 191 registered the highest values of heterosis over better parent and the standard check, respectively. The heterotic effects for primaries per panicle were in the range from -42.80 per cent to 66.47 per cent and -28.09 per cent to 55.09 per cent over over better parent and standard check, respectively. Fifteen and nineteen out of fifty four crosses manifested significant positive heterosis over better parent and the standard check, respectively. Least of the crosses revealed significant heterosis in the positive direction for panicle length and primaries per panicle focusing thereby the preponderance of additive gene effects in governing the inheritance of these traits.

Heterosis for panicle weight ranged from -40.65 per cent to 101.04 per cent and -32.35 per cent to 76.24 per cent over better parent and standard check, respectively. The most of cross combinations exhibited significant heterobeltiosis and standard heterosis in desired direction. Of these, 34 and 32 crosses rendered significant positive heterosis over better parent and standard check, respectively. The extent of heterosis for stover yield per plant was in the range from -55.81 per cent to 63.99 per cent and -53.01 per cent 29.51 per cent over better parent and standard check, respectively. Out of 54 crosses studied, twenty five and seven rendered significant positive heterobeltiosis and standard heterosis, respectively. The cross combination 28A x KR 191(63.99%) displayed highest heterobeltiosis, followed by 86A x KR 126 (43.60%) and 86A x KR 125 (38.10%). The highest standard heterosis was recorded by the cross combination 8A x GSF 5 (29.51%), followed by 8A x CSV 21F (24.10%) and 28A x GSF 5 (24.03%). The high magnitude of heterosis and a large number of crosses exhibiting significant positive heterobeltiosis in panicle weight and stover yield per plant indicating non-additive type of gene effects for these traits. The present findings corroborate the findings of Nayeem and Bapat (1984); Manickam and Vijendra Das (1995); Nadanwankar and Chandak (1990); Agarwal and Shrotria (2005) and Sharma *et al*. (2005).

The range of heterobeltiosis and standard heterosis observed for harvest index was -30.15 per cent to 47.04 per cent and -9.01 per cent to 56.13 per cent, respectively. The heterotic effects for 1000-grain weight were in the range from -38.27 per cent to 40.63 per cent and -42.06 per cent to 22.04 per cent over better parent and standard check, respectively. Out of 54 crosses studied, thirty four and twenty two rendered significant positive heterobeltiosis and standard heterosis, respectively indicating preponderance of non-additive gene action in inheritance of this trait. In case of protein content, the range of heterosis was -53.76 per cent to 109.76 per cent in heterobeltiosis and -46.96 per cent and 15.86 per cent in standard heterosis. Most of the crosses displayed positive heterobeltiosis and standard heterosis. Of these, 36 and 29 recorded positive significant heterosis over better parent and standard check, respectively. The high degree of heterosis and a large number of crosses exhibiting positive heterosis revealed that the trait governed by non-additive gene action. The results are in agreement with Sharma *et al*. (2003); Khandelwal *et al*. (2005) and Desai *et al*. (2005) for harvest index, 1000-grain weight and protein content.

Therefore, for grain yield per plant, the cross combination 28A x KR 191 exhibited highest heterosis (213.40%) over better parent, followed by 28A x KR 126 (122.46%), 28A x KR 125 (93.85%) and 86A x KR 196 (88.08%). Further, the highest standard heterosis registered by cross combination 28A x PMSC-43 (96.42%), followed by 28A x GJ 38 (96.26%) and 28A x KR 191 (94.41%). The cross combination 86A x KR 199 rendered highest significant negative heterosis over better parent as well as standard check for both the traits days to 50 per cent flowering and days to maturity. Hence, these hybrids can be utilized further for commercial exploitation of hybrid vigour.

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