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Studies on Heterosis and Combining Ability for Yield Components in Grain Sorghum [*Sorghum bicolor* (L.) Moench]

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An experiment was conducted to estimate heterosis in forty eight F_1 hybrids of sorghum [*Sorghum bicolor* (L.) Moench] with respect to grain yield and its components using six lines and eight testers. The hybrids and their parents were evaluated to assess the combining ability and gene action governing the traits by using line x tester analysis at Directorate of Sorghum Research (DSR), Rajendranagar, Hyderabad during 2011-12. Non-additive gene action was predominant for all the traits under study. The line 234 A ; testers CB 111 and CB 119 emerged as good general combiners for yield and its component traits. Based on *sca* effects, three hybrids *viz.,* 234 A x CB 127, 151 A x CB 126 and 3183 A x CB 119 were identified as promising for good specific combiners for grain yield per plant and other traits. The hybrid 3183 A x CB 119 recorded maximum grain yield with 84.22, 69.78 and 26.93 per cent heterosis over the mid parent, better parent and standard check, respectively.

Key words: Sorghum, Line x Tester analysis, Combining ability and Standard heterosis

Sorghum [*Sorghum bicolor* (L.) Moench] is the fifth most important cereal crop grown in the world and plays a very important role in providing nutrition to human race. It is a major cereal grown as dual purpose crop adapted to drought prone areas of the world. For improvement in such an important crop, the most important pre-requisite is the selection of suitable parents, which could combine well and produce desirable hybrids and segregants. In order to achieve this, Line x Tester analysis (Kempthorne, 1957) for combining ability was adopted to obtain information on nature and magnitude of gene action governing the traits of economic importance and also an attempt has been made to estimate the heterosis with respect to yield and its component traits under study.

Materials and Methods

The experimental material comprised of six male sterile lines *viz.,* 234 A, 151 A, 3060 A, 3183 A, 339 A and 318 A which were crossed with eight testers *viz.,* CB 110, CB 111, CB 119, CB 124, CB 126, CB 127, CB 128 and CB 129 to develop 48 hybrids during *rabi* 2011-12. These hybrids along with their parents and check CSH-16 were grown in randomized block design with three replications at Directorate of Sorghum Research, Rajendranagar, Hyderabad during *kharif* 2011. Observations were recorded for days to 50 percent flowering, plant height (cm), panicle length (cm), panicle weight (g), number of primary branches per panicle, length of primary branch (cm), number of grains per primary branch, 100-seed weight (g), number of grains per panicle, starch content (%), protein content (%) and grain yield per plant (g). The data was subjected to Line x Tester analysis developed by Kempthorne (1957).

Results and Discussion

The analysis of variance of combining ability for yield and its component traits (Table 1) revealed significant variation for all the traits under study. Variance due to parents was highly significant for all the traits except starch content, indicating good amount of genetic variability present among the parents. Variance due to crosses was also highly significant for all the traits studied. The lines were highly significant for all the traits except panicle weight and starch content in the grain. Variance due to testers was highly significant for all the traits except starch content and protein content in the grain. The interaction effects (lines x testers) were found to be significant for all the traits except panicle length and length of primary branch reveals the presence of significant variability in the material studied. The magnitude of variance due to SCA was higher than that of GCA revealed that non-additive gene action was predominant in the inheritance of grain yield and all its component traits (Table 1). Similar observations were also reported by Chaudhary *et al.* (2006) and Premalatha *et al.* (2006). Non-additive gene action for grain yield per plant in the present study was in accordance with the reports of Aruna *et al.* (2010) and Mahdy *et al.* (2011) where as additive gene action governing the inheritance of grain yield per plant was reported by Prabhakar *et al.* (2013)

A perusal of results on *gca* effects (Table 2)

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Table 1. Analysis of variance for combining ability for yield and yield components in sorghum

Source	d.f	Days to 50% flower	Plant height (cm)	Panicle length (cm)	Panicle weight (g)	Number of primary branches/ panicle	Length of primary branch (cm)	Number of grains/ primary branch	100-seed weight (g)	Number of grains/ panicle	Starch content in grain (%)	Protein content in grain (%)	Grain yield/ plant (g)
Replications	2	6.40	126.13	6.42	125.52	77.16**	1.34	206.32*	0.046	31906.29	2.15	1.12	52.72
Treatments	61	39.52**	1748.3**	22.42**	1173.11**	221.18**	4.41**	1119.15**	0.38**	1389910.9**	23.96**	1.90**	911.44**
Crosses	47	17.81**	1508.2**	15.58**	949.79**	167.04**	2.54**	926.26**	0.31**	1303540.3**	28.65**	1.88**	724.56**
Line effect	5	63.90**	7338.8**	79.13**	1470.37	940.10**	11.63**	2107.15**	0.61**	1922380.3**	26.15	4.20*	1151.58*
Tester effect	7	35.86**	1969.2**	24.94**	2306.02**	196.62**	4.79**	2377.39**	0.89**	4713120.9**	22.99	2.71	1795.51**
L x T effect	35	7.61**	583.08*	4.63	604.17**	50.69**	0.79	467.34**	0.15**	533218.47*	30.13**	1.39**	449.36**
Error	122	3.99	119.92	5.88	287.30	13.40	0.66	51.86	0.05	326666.51	6.35	0.43	168.99
σ^2 gca		0.1623	14.729	0.1744	5.5027	1.8525	0.0278	7.3067	0.0025	12264.609	0.000	0.0079	4.3638
σ^2 sca		1.2095	154.38	-0.4194	105.6226	12.336	0.0433	138.4905	0.0323	68850.652	7.929	0.3183	93.457
σ^2 gca/ σ^2 sca		0.1341	0.0954	-0.4158	0.052	0.1501	0.6420	0.0527	0.0773	0.1781	0.000	0.0248	0.0466

* Significant at 5% level, ** Significant at 1% level

revealed several good combiners for different traits studied, but none of them was superior for all the traits. Among the lines, 234 A, 3060 A and 3183 A were found to be good general combiners for most of the traits and 151 A for earliness and starch content in grain which might be utilized as potential parents in future hybrid development programme. Likewise, among testers, CB 111 and CB 119 were found to be good general combiners for most of the traits, whereas CB 126 and CB 128 for earliness and CB 127 and CB 128 for protein content can be utilized in population improvement programme.

Table 2. Estimates of general combining ability (*gca*) effects for parents in respect of yield components in sorghum

Parents	Days to 50% flower	Plant height (cm)	Panicle length (cm)	Panicle weight (g)	Number of primary branches/ panicle	Length of primary branch (cm)	Number of grains/ primary branch	100-seed weight (g)	Number of grains/ panicle	Starch content in grain (%)	Protein content in grain (%)	Grain yield/ plant (g)
Lines												
234 A	1.14**	-0.74	-1.28*	7.72*	3.66**	-0.07	-0.33	0.006	170.80	0.87	-0.55**	6.19*
151 A	-1.76**	-25.07**	0.97	-10.77**	8.51**	-0.22	-9.52**	-0.076	-377.79**	1.10*	-0.24	-10.92**
3060 A	1.98**	2.31	2.74**	8.58*	1.20	0.87**	9.41**	-0.062	397.81**	-0.80	-0.17	4.40
3183 A	-1.55**	1.89	-1.59**	0.03	-1.66*	-0.67**	-3.39*	0.11*	133.15	-0.70	0.14	2.36
339 A	1.21**	28.93**	-1.73**	1.75	-1.54*	-0.70**	-9.05**	0.24**	-169.65	-1.28*	0.17	4.22
318 A	-1.02*	-7.32**	0.88	-7.32*	-10.17**	0.80**	12.88**	-0.22**	-154.33	0.81	0.65**	-6.26*
$S.Eg_i\pm$	0.4078	2.2354	0.4954	3.4599	0.7551	0.1666	1.4701	0.0498	116.666	0.5144	0.1349	2.653
$S.Eg_{i-}g_j\pm$	0.5767	3.1613	0.7006	4.893	1.0679	0.2356	2.0791	0.0704	164.991	0.7275	0.1907	3.7527
Testers												
CB 110	-0.72	-4.82	-0.78	3.70	-4.15**	-0.16	5.53**	0.052	-9.47	1.48*	0.22	4.90
CB 111	-0.47	16.92**	1.67**	7.64	-0.05	-0.04	9.28**	-0.29**	611.52**	-0.30	-0.71**	6.29*
CB 119	2.01**	-7.86**	0.46	11.14**	-4.04**	0.85**	13.52**	-0.20**	424.52**	0.49	-0.22	9.94**
CB 124	-0.24	-1.58	-1.76**	2.81	3.46**	-0.62**	-2.45	-0.024	-35.15	0.29	-0.07	3.23
CB 126	-1.96**	16.32**	0.78	-3.96	1.94*	0.43*	0.87	0.17**	-277.40*	-0.85	-0.22	-2.83
CB 127	1.24**	-7.92**	0.98	-2.30	4.62**	0.39*	-2.58	0.006	-227.57	-0.09	0.42**	-4.92
CB 128	-1.28**	-6.35*	-0.22	-25.17**	0.54	-0.38*	-24.72**	0.41**	-960.96**	-2.10**	0.41**	-21.62**
CB 129	1.42**	-4.69	-1.14*	6.14	-2.31**	-0.46*	0.53	-0.119*	474.53**	1.08	0.17	5.01
$S.Eg_j\pm$	0.4708	2.5812	0.5720	3.9952	0.8719	0.1924	1.6975	0.0575	134.715	0.5940	0.1557	3.064
$S.Eg_{i-}g_j\pm$	**0.6659**	**3.6504**	**0.8090**	**5.650**	**1.2331**	**0.2721**	**2.4007**	**0.0813**	**190.515**	**0.8401**	**0.2202**	**4.333**

* Significant at 5% level, ** Significant at 1% level

An overall picture of *sca* effects revealed that three hybrids *viz.,* 234 A x CB 127, 151 A x CB 126 and 3183 A x CB 119 were identified as promising for good specific combiners for grain yield per plant, panicle weight and number of grains per primary branch (Table 3). In turn, these hybrids also exhibited high mean performance and high heterosis for most of the traits. Therefore, these hybrids were recommended for heterosis breeding.

The hybrids, 3183 A x CB 111 and 339 A x CB 128 recorded significant negative *sca* effects for days to 50 percent flowering and the other hybrids *viz.,* 234 A x CB 124, 234 A x CB 128, 3060 A x CB 119, 3183 A x CB 128, 339 A x CB 110 and 318 A x CB 119 were found to be superior for starch content, whereas the hybrids *viz.,* 234 A x CB 110, 234 A x CB 128, 3060 A x CB 129, 339 A x CB 111 and 318 A x CB 126 were found to be superior for protein content.

In the estimation of heterosis, heterosis over the standard check or the local variety could be considered as the better criteria for evaluation of hybrids. The estimates of three types of heterosis revealed significant positive heterosis over mid and better parents for grain yield and yield components in majority of the crosses (Table 4).

The hybrid 3183 A x CB 119 exhibited superior heterotic expression for grain yield per plant and number of grains per primary branch and good specific combiner for these traits. This hybrid recorded maximum grain yield with 84.22, 69.78

Table 3. Estimates of specific combining ability (*sca*) effects of hybrids in respect of yield components in grain sorghum

Crosses	Days to 50% flower	Plant height (cm)	Panicle length (cm)	Panicle weight (g)	Number of primary branches/ panicle	Length of primary branch (cm)	Number of grains/ primary branch	100-seed weight (g)	Number of grains/ panicle	Starch content in grain (%)	Protein content in grain (%)	Grain yield/ plant (g)
234A x CB 110	0.54	-10.39	0.39	-11.83	-3.81	0.41	-9.01*	-0.15	-127.69	-3.51*	0.86*	-10.53
234A x CB 111	-0.84	-0.2	-0.06	1.22	1.81	-0.16	-12.30**	0.04	-428.03	0.82	-0.17	-1.58
234A x CB 119	0.66	-3.75	-0.18	-8.28	1.29	-0.45	2.09	-0.14	7.83	-2.47	-0.38	-8.56
234A x CB 124	0.19	-6.89	-2.68	-21.94*	-5.35*	0.02	5.86	0.02	-538.01	4.32**	-0.17	-13.19
234A x CB 126	0.91	16.19*	1.29	5.16	2.50	-0.79	10.32*	0.22	-143.5	2.82	0.17	1.54
234A x CB 127	-0.42	0.10	0.09	19.83*	-1.11	0.29	17.10**	0.07	996.66**	-2.68	-0.37	20.30**
234A x CB 128	-2.23	9.53	1.21	15.45	6.80**	0.59	3.45	-0.05	58.85	3.67*	0.89*	8.67
234A x CB 129	1.18	-4.58	-0.07	0.38	-2.14	0.08	-17.51**	-0.02	173.89	-2.97*	-0.82*	3.36
151A x CB 110	-0.54	-8.08	0.24	8.08	3.95	1.19*	13.90**	-0.20	595.37	-1.01	0.64	3.59
151A x CB 111	3.19**	-15.68*	0.38	-5.28	-3.68	-0.23	-9.66*	-0.14	-254.42	-5.46**	0.32	-6.79
151A x CB 119	-1.16	-3.29	-1.94	-16.78	-3.79	-0.63	-10.04*	-0.09	-363.35	-0.57	-0.09	-14.77
151A x CB 124	0.30	-4.77	-0.01	14.22	4.90*	-0.17	5.75	-0.27	691.92*	2.59	-0.65	11.59
151A x CB 126	-1.31	8.18	0.63	23.33*	-0.22	0.34	15.99**	0.21	429.89	0.006	-0.88*	22.66**
151A x CB 127	1.15	3.26	-0.43	-33.33**	-0.18	-0.77	-25.47**	0.12	-1017.02**	1.61	0.37	-24.90**
151A x CB 128	-0.99	18.19**	0.98	12.54	-2.41	0.40	1.19	0.40**	21.33	0.48	-0.43	9.79
151A x CB 129	-0.63	2.20	0.13	-2.78	1.45	-0.12	8.34*	-0.02	-103.71	2.35	0.72	-1.18
3060A x CB 110	0.56	30.94**	-1.56	14.96	-6.21**	-0.79	12.13**	0.44**	-206.3	1.66	-0.42	10.59
3060A x CB 111	-0.75	-4.66	-1.12	-5.97	-4.49*	0.15	-2.49	-0.14	232.96	1.61	-1.30**	-0.79
3060A x CB 119	0.62	-13.34*	0.91	-20.81*	-0.58	0.06	6.10	-0.39**	-233.7	3.65*	-0.86*	-19.77**
3060A x CB 124	0.29	-12.62*	1.41	6.18	9.50**	0.10	-12.71**	-0.16	494.7	1.75	0.34	5.59
3060A x CB 126	-0.06	4.80	-1.53	-5.70	-1.52	0.49	-10.34*	0.07	331.75	-1.95	0.25	-1.00
3060A x CB 127	-1.59	4.05	2.59	6.63	-5.20*	0.33	-5.25	0.16	-209.01	-2.24	0.58	2.76
3060A x CB 128	0.59	-2.18	-1.32	2.50	4.49*	-0.22	-0.39	0.08	-415.48	-4.36**	0.58	2.79
3060A x CB 129	0.34	-7.17	0.62	2.18	4.02	-0.13	12.96**	-0.05	5.08	-0.13	0.81*	-0.18
3183A x CB 110	-1.75	-2.63	-0.15	-0.89	0.25	0.08	-5.52	0.12	-358.84	2.88	-0.08	1.63
3183A x CB 111	-2.34*	13.28*	0.31	1.90	2.95	-0.17	15.69**	0.11	-31.71	-2.19	0.28	5.24
3183A x CB 119	0.76	7.73	0.49	29.40**	1.95	0.32	14.29**	0.30*	248.22	-0.69	0.62	29.15**
3183A x CB 124	-1.90	11.52	0.92	2.74	-2.29	-0.11	-6.52	0.17	-282.63	-5.69**	-0.41	2.30
3183A x CB 126	-0.19	-15.78*	-0.85	-21.14*	-2.86	-0.18	-7.21	-0.32*	-350.79	-0.44	-0.64	-18.29*
3183A x CB 127	2.94*	-6.2	-0.75	7.85	5.47*	0.80	-7.21	-0.19	275.98	1.99	-0.23	0.46
3183A x CB 128	2.99*	-9.17	1.22	-16.93	-1.44	-0.24	0.59	-0.34	510.9	4.78**	0.13	-12.03
3183A x CB 129	-0.51	1.23	-1.19	-2.92	-4.04	-0.48	-4.10	0.14	-11.12	-0.63	0.32	-8.47
339A x CB 110	1.81	0.65	1.57	-5.53	0.40	-0.20	1.22	-0.19	-70.37	3.73*	-0.24	-2.56
339A x CB 111	-0.04	1.57	0.58	1.52	2.74	-0.17	7.48	0.01	-42.43	2.85	0.78*	-2.94
339A x CB 119	0.73	18.69**	-0.57	15.35	1.76	-0.07	-12.07**	0.14	510.69	-3.50*	0.58	14.4
339A x CB 124	1.19	8.75	0.12	-7.64	-3.67	0.17	-10.77*	0.1	-389.29	-3.92**	0.25	-10.56
339A x CB 126	-0.29	-25.15**	-0.22	-3.20	0.64	0.41	-5.13	-0.31*	-11.85	-1.11	-0.33	-3.24
339A x CB 127	-0.49	5.09	0.07	1.80	0.49	-0.64	21.72**	0.22	-17.21	2.52	0.05	4.60
339A x CB 128	-2.96*	-31.48**	-2.37	-12.99	-0.80	-0.08	-12.75**	0.001	-187.21	-1.21	-1.41**	-11.36
339A x CB 129	0.05	21.86**	0.80	10.68	-1.56	0.59	10.31*	0.02	207.68	0.65	-0.36	11.66
318A x CB 110	-0.61	-10.48	-0.50	-4.78	5.41*	-0.68	-12.72**	-0.01	167.84	-3.75*	-0.76*	-2.73
318A x CB 111	0.79	5.50	-0.09	6.60	0.66	0.60	1.28	0.12	523.64	2.37	0.07	6.87
318A x CB 119	-1.62	-6.04	1.27	1.10	-0.63	0.77	-0.36	0.17	-169.68	3.59*	0.13	-0.44
318A x CB 124	-0.09	4.01	0.24	6.43	-3.08	-0.01	18.40**	0.14	23.32	0.94	0.65	4.26
318A x CB 126	0.95	11.76	0.69	1.55	1.46	-0.26	-3.62	0.12	-255.5	0.68	0.75*	-1.66
318A x CB 127	-1.58	-6.31	-1.57	-2.78	0.52	-0.02	-0.88	-0.39**	-29.39	-1.20	-0.40	-3.23
318A x CB 128	2.60*	15.11*	0.27	-0.57	-6.63**	-0.44	7.90	-0.09	11.6	-3.36*	0.23	2.12
318A x CB 129	-0.43	-13.54*	-0.31	-7.56	2.28	0.06	-9.99*	-0.06	-271.83	0.73	-0.68	-5.18
S.E. S_{ij} ±	**1.1533**	**6.3226**	**1.4012**	**9.7862**	**2.1357**	**0.4713**	**4.1581**	**0.1409**	**329.983**	**1.4551**	**0.3814**	**7.505**
S.E. $S_{ij}-S_{ik}$ ±	**1.5257**	**8.364**	**1.8536**	**12.9459**	**2.8253**	**0.6235**	**5.5007**	**0.1864**	**436.526**	**1.9249**	**0.5046**	**9.928**
S.E. $S_{ij}-S_{kl}$ ±	**1.631**	**8.9415**	**1.9815**	**13.8397**	**3.0204**	**0.6665**	**5.8804**	**0.1992**	**466.666**	**2.0578**	**0.5394**	**10.614**

and 26.93 per cent heterosis over the mid parent, better parent and standard check, respectively. All three types of heterosis for this trait were reported by Premalatha *et al.* (2006). Standard heterosis for this trait reported by Mahmoud and Ahmed (2010) and Makanda *et al.* (2010). It also showed higher mean performance for grain yield per plant and number of grains per primary branch may be further

Table 4. Magnitude of Relative Heterosis (RH), Heterobeltiosis (HB) and Standard Heterosis (SH) for days to 50% flowering, palnt height, panicle length and panicle weight

Crosses	Days to 50% flowering			Plant height			Panicle length			Panicle weight		
	RH	HB	SH	RH	HB	SH	RH	HB	SH	RH	HB	SH
234 A x CB 110	-4.62*	-5.31*	3.70	4.47	-3.34	-16.30**	17.98*	11.31	-10.95	30.09*	26.09	-11.00
234 A x CB 111	-7.66	-9.64**	1.90	6.04	-0.37	-1.87	16.09*	1.51	-3.81	22.02*	5.56	2.05
234 A x CB 119	-5.97**	-11.51**	8.25**	8.65	-1.46	-14.67**	18.43*	9.56	-8.57	24.51*	13.39	-2.56
234 A x CB 124	-5.53**	-7.27**	3.92	1.59	0.17	-13.25**	5.39	5.03	-25.48**	5.00	-2.78	-19.44
234 A x CB 126	-7.73**	-10.13**	2.33	15.35**	9.73*	5.27	15.69*	-0.36	-2.14	35.74**	35.25*	-3.84
234 A x CB 127	-5.24**	-7.87**	5.29*	5.38	0.52	-12.95**	20.18*	9.70	-5.71	33.86**	18.38	8.70
234 A x CB 128	-8.78**	-8.82**	-1.59	14.42**	6.26	-7.98	20.55*	10.66	-6.07	24.37	24.37	-12.21
234 A x CB 129	-6.02**	-11.52**	8.15**	8.64	-0.24	-13.61**	22.03*	21.31*	-13.93	46.54**	42.03**	0.26
151 A x CB 110	-6.60**	-11.11**	-2.65	4.65	0.15	-26.24**	19.92*	19.13*	-3.42	64.60**	36.00	-9.91
151 A x CB 111	-2.04	-8.05**	3.70	-3.32	-18.62**	-19.85**	20.38**	11.68	5.83	18.46	-14.29	-17.14
151 A x CB 119	-8.94**	-17.65**	0.74	8.20	5.77	-25.45**	13.31	11.70	-6.79	18.81	-10.71	-23.27*
151 A x CB 124	-5.72**	-11.24**	-0.53	1.27	-8.87	-23.28**	21.60**	13.66	-7.86	49.29**	13.58	-5.88
151 A x CB 126	-11.49**	-17.29**	-5.82*	11.07*	-5.49	-9.34*	15.54*	5.45	3.57	67.79**	34.898	-4.09
151 A x CB 127	-3.23	-9.72**	3.17	6.19	-1.44	-22.52**	20.28**	16.86*	0.45	-20.45	-41.50**	-46.29**
151 A x CB 128	-7.37**	-11.19**	-4.23	20.00**	14.40**	-15.06**	21.95**	19.21*	1.19	25.39	1.09	-28.64**
151 A x CB 129	-9.00**	-17.66**	0.63	12.288	8.32	-21.54**	25.51**	17.03	-5.12	52.80**	26.25	-16.37
3060 A x CB 110	-4.29*	-4.52	5.08	35.76**	30.99**	3.77	5.74	-5.81	-3.57	67.70**	66.41**	10.23
3060 A x CB 111	-7.21**	-8.33**	3.39	9.83*	-0.92	-2.41	8.33	4.30	6.79	20.06	0.53	-2.81
3060 A x CB 119	-5.74**	-10.47**	9.52**	10.06*	3.99	-17.62**	18.13**	7.21	9.76	17.09	2.98	-11.51
3060 A x CB 124	-5.10*	-5.95*	5.40	4.70	1.61	-14.46**	19.83**	1.16	3.57	38.86**	24.07	2.81
3060 A x CB 126	-8.79**	-10.32**	2.12	15.91**	5.81	1.51	1.84	-0.23	2.14	29.83*	24.46	-11.51
3060 A x CB 127	-6.60**	-8.33**	4.76	14.31**	13.88**	-9.79*	24.91**	14.88*	17.62*	26.38*	8.08	-0.77
3060 A x CB 128	-4.32*	-5.29*	4.23	14.82**	11.22*	-11.90**	6.04	-3.02	-0.71	15.63	11.23	-21.48*
3060 A x CB 129	-6.88**	-11.52**	8.15**	14.20**	9.32	-13.40**	19.39**	0.58	2.98	55.64**	54.44**	2.30
3183 A x CB 110	-11.32**	-12.56**	-4.23	18.47**	16.93**	-11.60**	5.94	4.49	-14.05	38.80**	38.13*	-8.50
3183 A x CB 111	-13.12**	-15.55**	-4.76	21.11**	7.03	5.42	8.94	1.76	-3.57	19.15	0.00	-3.32
3183 A x CB 119	-8.97**	-14.88**	4.13	25.57**	21.31**	-8.28*	11.93	11.13	-7.26	58.99**	40.18**	20.46
3183 A x CB 124	-11.86**	-14.07**	-3.70	20.49**	14.35**	-3.73	13.02	4.92	-13.69	26.10*	12.96	-6.39
3183 A x CB 126	-12.58**	-15.43**	-3.70	7.29	-4.08	-7.98	-1.32	-9.33	-10.95	2.53	-1.44	-29.92**
3183 A x CB 127	-3.64	-6.94**	6.35*	10.74*	8.62	-14.61**	7.15	4.85	-9.88	18.93	1.95	-6.39
3183 A x CB 128	-4.40*	-5.00*	2.43	13.13**	12.11*	-15.24**	11.11	9.40	-7.14	-16.24	-19.2	-42.97**
3183 A x CB 129	-11.52**	-17.23**	1.16	21.87**	19.32**	-9.79*	6.25	-1.59	-19.05**	39.28**	38.61*	-8.18
339 A x CB 110	-2.44	-3.38	5.82*	26.14**	15.70**	2.11	16.40*	14.58	-8.33	30.47*	26.45	-10.74
339 A x CB 111	-6.19**	-8.42**	3.28	20.32**	14.07**	12.35**	12.51	2.26	-3.10	16.82	1.06	-2.30
339 A x CB 119	-5.57**	-11.33**	8.47**	37.19**	23.38**	8.89*	9.91	5.99	-11.55	41.83**	29.17*	11.00
339 A x CB 124	-3.76	-5.76*	5.61*	24.37**	21.50**	7.23	12.15	7.07	-17.02*	13.33	4.94	-13.04
339 A x CB 126	-9.13**	-11.71**	0.53	8.59*	4.24	0.00	3.39	-7.52	-9.17	20.22	19.78	-14.83
339 A x CB 127	-5.01*	-7.87**	5.29*	23.10**	16.38**	2.71	13.33	7.76	-7.38	11.18	-1.67	-9.72
339 A x CB 128	-9.54**	-9.72**	-2.65	6.95	-1.54	-13.10**	-2.05	-6.31	-20.48**	-13.04	-13.04	-38.62**
339 A x CB 129	-7.28**	-12.90**	6.46*	39.08**	26.62**	11.75**	18.71*	13.06	-12.38	51.40**	46.74**	3.58
318 A x CB 110	-6.53**	-10.14**	-1.59	8.24	6.95	-19.31**	11.17	5.93	-6.43	20.45	16.13	-17.14
318 A x CB 111	-5.48*	-10.39**	1.06	12.38**	-0.76	-2.26	13.39*	9.55	3.81	12.63	-2.12	-5.37
318 A x CB 119	-9.43**	-17.30**	1.16	11.46*	7.78	-18.67**	21.55**	18.19*	4.40	18.37	8.33	-6.91
318 A x CB 124	-6.16**	-10.76**	0.00	11.13*	5.37	-11.30**	16.82*	5.01	-7.24	17.74	9.57	-9.21
318 A x CB 126	-7.93**	-13.10**	-1.06	17.05**	4.55	0.30	10.91	5.33	3.45	14.9	14.7	-18.16
318 A x CB 127	-7.13**	-12.50**	0.00	5.38	3.26	-18.83**	10.25	8.76	-3.93	-2.19	-13.09	-20.2
318 A x CB 128	-1.72	-4.81*	2.65	22.33**	21.36**	-8.43*	13.54	11.32	-1.67	-9.91	-10.39	-36.06**
318 A x CB 129	-8.53**	-16.45**	2.12	7.33	5.19	-20.63**	17.36*	5.26	-7.02	20.07	15.77	-17.39

exploited in multilocation evaluation before releasing for cultivation.

The hybrids *viz.,* 234 A x CB 126, 3060 A x CB 110, 3183 A x CB 119 and 339 A x CB 129 were tall and high yielding compared to parents. Better parent heterosis for plant height was reported by El-Dardeer *et al.* (2011). Almost all hybrids showed significant negative heterobeltiosis for days to 50 percent flowering except two hybrids, 3060 A x CB 110 and 339 A x CB 110. The results of heterosis for earliness were in accordance with the findings of Kenga *et al.* (2005), Premalatha *et al.* (2006) and Boratkar *et al.* (2014).

For number of primary branches per panicle, as

Table 4. (Continued) Magnitude of Relative Heterosis (RH), Heterobeltiosis (HB) and Standard Heterosis (SH) for number of primary branches per panicle, length of primary branch, number of grains per primary branch and 100-seed weight

Crosses	Number of primary branches per panicle			Length of primary branch			Number of grains per primary branch			100-seed weight		
	RH	HB	SH	RH	HB	SH	RH	HB	SH	RH	HB	SH
234 A x CB 110	-6.04	-23.78**	-6.65	18.27*	10.93	-13.44*	14.91*	-11.74*	2.01	10.04	9.75	-17.60**
234 A x CB 111	2.43	-12.33**	7.37	14.92	10.14	-17.89**	-2.55	-30.95**	2.53	9.76	4.16	-22.20**
234 A x CB 119	-0.14	-17.65**	0.86	13.35	1.19	-11.95	37.88**	5.47	23.32**	8.4	0.66	-24.82**
234 A x CB 124	-3.32	-16.63**	2.11	16.3	14.65	-21.64**	46.40**	24.79**	9.71	0.41	-10.42	-14.70*
234 A x CB 126	-8.39**	-9.18*	11.24*	-17.65**	-36.75**	-19.38**	35.92**	5.47	18.39**	37.48**	30.01**	-2.89
234 A x CB 127	1.37	-10.27**	9.89*	20.02**	9.42	-9.17	30.52**	-2.43	22.10**	15.00*	12.59	-12.23*
234 A x CB 128	1.69	-5.76	15.42**	18.73*	12.17	-13.81*	10.52	-5.27	-17.83**	19.68**	12	-4.03
234 A x CB 129	-3.71	-19.66**	-1.6	25.35**	17.77	-19.51**	27.36**	16.58	-13.05*	13.34	8.46	-18.99**
151 A x CB 110	22.86**	5.88	11.53**	30.54**	18.76*	-7.32	36.02**	1.51	17.33**	5.32	4.38	-21.63**
151 A x CB 111	10.57**	1.04	6.43	15.39	7.19	-20.09**	-7.29	-35.87**	-4.78	-0.63	-5.12	-30.03**
151 A x CB 119	8.74*	-4.58	0.51	12.43	-2.47	-15.13*	14.48*	-14.89**	-0.48	7.75	0.64	-25.78**
151 A x CB 124	27.65**	17.61**	23.88**	14.97	12.84	-25.06**	37.14**	12.98	-0.68	-12.36*	-22.24**	-25.96**
151 A x CB 126	1.28	-5.04	14.30**	-5.7	-29.19**	-9.75	35.32**	1.98	14.47*	34.22**	27.70**	-5.83
151 A x CB 127	18.42**	12.24**	18.22**	7.54	-4.81	-20.98**	-29.33**	-48.59**	-35.66**	14.43*	11.34	-13.21*
151 A x CB 128	4.01	3.6	9.13*	17.73*	7.86	-17.12**	-3.41	-20.01**	-30.61**	34.33**	24.97**	7.09
151 A x CB 129	18.11**	4.97	10.57*	24.06**	20.30*	-23.06**	60.50**	41.51**	5.54	10.82	6.7	-21.31**
3060 A x CB 110	-4.03	-16.76**	-13.64**	-5.69	-16.16*	-15.89*	28.80**	18.08**	36.48**	45.36**	30.41**	-2.09
3060 A x CB 111	-0.75	-8.68*	-5.26	7.94	-5.92	-5.62	1.59	-16.24**	24.36**	10.97	4.81	-29.70**
3060 A x CB 119	3.25	-8.80*	-5.38	9.24	2.00	2.33	30.04**	18.60**	38.66**	6.1	2.47	-34.40**
3060 A x CB 124	24.65**	15.65**	19.98**	6.01	-11.91	-11.63	8.38	3.64	-0.15	0.38	-18.38**	-22.28**
3060 A x CB 126	-9.07**	-15.35**	1.89	-10.15*	-19.72**	2.33	1.84	-5.38	6.21	43.46**	35.97**	-9.47
3060 A x CB 127	1.43	-3.17	0.46	9.58	0.13	0.45	-2.45	-13.67*	8.03	28.37**	13.28	-11.69*
3060 A x CB 128	4.24	3.86	8.55	-1.33	-12.88*	-12.6	-3.04	-7.87	-11.24	34.80**	14.31*	-2.05
3060 A x CB 129	11.77**	0.00	3.75	9.24	-12.67	-12.39	54.26**	36.84**	31.83**	22.19**	14.48	-21.87**
3183 A x CB 110	11.51*	4.07	-8.45	5.24	-0.66	-22.48**	-1.68	-11.33*	2.49	22.85**	21.12**	-6.42
3183 A x CB 111	15.73**	15.21**	1.34	5.82	2.08	-23.90**	8.01	-12.20**	30.36**	14.89*	7.31	-17.08**
3183 A x CB 119	12.40**	7.02	-5.86	14.82*	3.12	-10.27	27.26**	14.19*	33.51**	29.58**	18.47*	-8.46
3183 A x CB 124	11.86**	11.36*	-1.15	4.83	2.66	-28.88**	2.28	-0.46	-7.53	7.51	-2.63	-7.28
3183 A x CB 126	-8.00*	-20.38**	-4.16	-17.98**	-36.70**	-19.32**	-6.99	-15.00*	-4.59	16.65*	8.58	-16.10**
3183 A x CB 127	22.57**	18.43**	11.72**	18.09*	8.33	-10.08	-16.03**	-26.84**	-8.45	6.63	6.16	-17.24**
3183 A x CB 128	-0.39	-8.27*	-4.13	-1.24	-6.09	-27.84**	-15.87*	-18.65**	-24.43**	11.11	5.65	-9.47
3183 A x CB 129	3.61	0.03	-12.01**	6.87	-0.23	-30.88**	17.63*	6.03	-1.5	22.69**	15.54*	-10.73
339 A x CB 110	8.29	-1.75	-8.07	3.32	-4.55	-25.52**	10.79	-10.28	3.7	7.18	-1.28	-11.99*
339 A x CB 111	11.99**	8.16	1.20	7.90	1.82	-24.10**	4.38	-22.63**	14.88*	7.47	-5.84	-16.05**
339 A x CB 119	8.66*	0.51	-5.96	11.85	-1.56	-14.34*	3.71	-16.38**	-2.23	18.31**	1.63	-9.39
339 A x CB 124	6.43	3.70	-2.98	11.11	10.89	-26.36**	2.05	-7.40	-18.59**	2.78	-0.5	-5.25
339 A x CB 126	-5.52	-16.04**	1.06	-10.91	-32.34**	-13.76*	-0.57	-18.56**	-8.59	12.93	-1.37	-12.06*
339 A x CB 127	11.45**	11.00*	4.71	1.34	-8.95	-24.42**	19.45**	-6.09	17.52**	18.57**	11.13	-0.93
339 A x CB 128	-2.11	-7.24	-3.05	2.73	-4.41	-26.55**	-31.36**	-37.34**	-45.65**	19.59**	17.26*	4.55
339 A x CB 129	4.57	-1.95	-8.26	25.59**	19.82*	-20.74**	48.10**	45.17**	8.27	13.63*	0.31	-10.57
318 A x CB 110	23.62**	13.77*	-13.28**	-5.15	-15.57*	-15.57*	-7.72	-12.36*	12.62	11.94	6.4	-20.11**
318 A x CB 111	13.43**	-1.60	-14.22**	12.29	-2.00	-2.00	-4.37	-10.81*	32.43**	9.13	8.67	-26.49**
318 A x CB 119	8.85	-1.73	-21.84**	15.99**	8.46	8.46	10.27*	5.31	35.32**	18.08*	14.91	-22.27**
318 A x CB 124	11.82*	-3.73	-14.55**	3.80	-13.63*	-13.63*	27.94**	7.73	38.43**	0.83	-13.77*	-17.89**
318 A x CB 126	-2.6	-25.38**	-10.18*	-17.13**	-26.05**	-5.75	-2.33	-8.50	17.57**	30.12**	29.10**	-12.67*
318 A x CB 127	16.56**	-2.14	-7.68	5.05	-3.88	-3.88	-7.92	-9.13	16.77*	-7.65	-13.76	-32.77**
318 A x CB 128	-9.69*	-27.16**	-23.87**	-4.37	-15.44*	-15.44*	-5.34	-20.72**	1.88	15.00*	2.89	-11.83*
318 A x CB 129	16.26**	3.61	-15.15**	10.82	-11.3	-11.3	8.41	-14.34**	10.08	7.83	7.35	-26.73**

* Significant at 5% level, ** Significant at 1% level

many as eleven hybrids were found to be superior than the check CSH-16. Both mid parent heterosis and better parent heterosis for panicle weight was reported but none of them were found to be superior than the check. For number of grains per primary branch, as many as eighteen hybrids showed significant positive standard heterosis ranged from 14.47 per cent (151 A x CB 126) to 38.66 per cent (3060 A x CB 119). For number of grains per panicle, seven hybrids *viz.,* 234 A x CB 127, 234 A x CB 129, 3060 A x CB 111, 3060 A x CB 124, 3060 A x CB 129, 3060 A x CB 119 and 318 A x CB 111 showed significant positive standard heterosis. Three hybrids, 318 A x CB 124, 318 A x CB 126 and 318 A x

Table 4. (Continued) Magnitude of Relative Heterosis (RH), Heterobeltiosis (HB) and Standard Heterosis (SH) for number of grains per panicle, starch content in the grain, protein content in the grain and grain yield per plant

Crosses	Number of grains per panicle			Starch content in the grain			Protein content in the grain			Grain yield per plant		
	RH	HB	SH	RH	HB	SH	RH	HB	SH	RH	HB	SH
234 A x CB 110	22.73	20.08	5.87	-2.87	-5.04	-6.15*	7.61	4.67	5	34.62**	29.91*	-11.93
234 A x CB 111	8.13	-8.18	15.92	0.72	-1.26	-2.42	-6.97	-8.81	-13.52**	22.89*	7.74	-3.06
234 A x CB 119	13.14	-5.22	23.72	-3.58	-4.97	-6.08*	-12.21**	-17.57**	-10.94*	32.89**	26.69	-5.28
234 A x CB 124	4.56	4.54	-7.79	7.20**	4.82	3.59	-8.65*	-14.03**	-7.58	14.22	6	-16.05
234 A x CB 126	8.73	7.48	-3.02	4.01	0.89	-0.29	-0.62	-0.66	-5.7	42.65**	35.98*	-7.82
234 A x CB 127	32.66*	17.5	34.28*	-5.16	-6.15*	-7.25*	-6.15	-11.98*	-4.69	37.22**	20.49	8.02
234 A x CB 128	7.43	-7.11	-18.1	0.93	0.3	-0.88	5.83	-0.36	7.03	24.57	19.63	-18.9
234 A x CB 129	52.40**	48.01**	30.49*	-4.18	-4.84	-5.96	-10.80*	-14.78**	-11.25*	56.86**	49.53**	1.37
151 A x CB 110	58.82**	31.99	11.34	0.14	-3.14	-2.15	2.81	0.22	5.86	60.12**	35.18*	-14.78
151 A x CB 111	14.41	-17.49	4.17	-9.47**	-12.19**	-11.29**	-4.45	-11.02*	-6.02	14.96	-14.79	-23.34*
151 A x CB 119	1.83	-27.30*	-5.11	-1.5	-3.95	-2.97	-11.44**	-12.44**	-5.39	22.79	-2.97	-27.46**
151 A x CB 124	57.66**	28.75	13.56	3.75	0.36	1.39	-14.81**	-15.55**	-9.22	48.84**	15.2	-8.77
151 A x CB 126	33.84	8.35	-2.24	-1.07	-5.05	-4.08	-12.97**	-17.38**	-12.73*	83.08**	56.19**	-4.01
151 A x CB 127	-36.56*	-52.77**	-46.03**	0.51	-1.62	-0.61	-1.68	-2.89	5.16	-26.67*	-45.58**	-51.21**
151 A x CB 128	5.74	-1.2	-36.47*	-4.54	-6.16*	-5.2	-8.54*	-9.31	-2.58	24.55	5.58	-34.11**
151 A x CB 129	50.57**	25.89	4.6	2.97	1.16	2.2	1.15	0.44	6.09	54.08**	31.44	-19.22
3060 A x CB 110	24.95	19.42	10.52	4.62	4.4	-1.03	-0.72	-3.82	-3.52	71.43**	68.84**	6.44
3060 A x CB 111	31.40**	13.86	43.75**	1.49	1.41	-3.71	-14.26**	-15.61**	-20.63**	28.30*	7.75	-3.06
3060 A x CB 119	10.51	-5.57	23.27	5.29	4.63	0.44	-12.87**	-18.51**	-11.95*	21.21	10.17	-17.64
3060 A x CB 124	45.72**	42.30**	31.69*	2.9	2.7	-2.64	0	-6.25	0.78	42.66**	26.40*	0.1
3060 A x CB 126	30.21*	28.57	18.99	-3.83	-4.79	-9.74**	4.26	3.79	-1.48	43.67**	43.30**	-11.93
3060 A x CB 127	0.18	-9.34	3.6	-5.05	-6.01	-9.06**	6.56	-0.43	7.81	18.91	0	-10.35
3060 A x CB 128	-5.46	-19.88	-25.86	-11.75**	-13.01**	-15.12**	6.86	0.22	7.66	19.49	18.27	-26.19*
3060 A x CB 129	50.68**	42.97**	32.32*	-0.4	-1.76	-4.25	8.55	3.3	7.58	57.11**	56.70**	-3.7
3183 A x CB 110	8.32	1.96	-2.55	5.4	3.95	0.91	1.9	1.47	2.66	52.26**	52.26**	-4.01
3183 A x CB 111	14.65	0.72	27.18	-5.38	-6.42*	-9.16**	1.18	-3.86	-2.73	31.68**	11.97	0.74
3183 A x CB 119	15.06	-0.35	30.08*	-2.4	-2.94	-5.79	0.37	-2.82	5	84.22**	69.78**	26.93**
3183 A x CB 124	7.77	3.62	-0.97	-9.56**	-10.79**	-13.41**	-7.3	-10.03*	-3.28	33.63**	20	-4.96
3183 A x CB 126	-3.87	-6.56	-10.7	-2.51	-4.6	-7.40*	-5.02	-7.95	-6.88	11.96	10.55	-30.31**
3183 A x CB 127	5.32	-3.3	10.51	0.39	0.23	-2.71	-1.53	-4.76	3.13	12.03	-4.59	-14.47
3183 A x CB 128	18.7	-0.72	-5.12	1.14	0.88	-1.56	1.95	-1.02	6.33	-7.88	-8.34	-42.22**
3183 A x CB 129	38.27**	29.24	23.52	-2.16	-2.36	-4.84	3.2	1.73	5.94	38.93**	37.19*	-13.52
339 A x CB 110	22.55	14.98	-3	5.65*	4.06	1.29	-4.77	-10.04*	1.48	46.90**	45.10**	-6.23
339 A x CB 111	17.23	-7.06	17.34	1.3	0.05	-2.61	0.31	-9.35*	2.27	22.54*	5.28	-5.28
339 A x CB 119	26.00*	-1.32	28.81	-7.69**	-8.33**	-10.77**	-4.92	-6.93	5	64.55**	53.39**	14.68
339 A x CB 124	6.32	-2.27	-13.8	-7.88**	-9.26**	-11.67**	-6.24	-8.45	3.28	17.62	6.8	-15.42
339 A x CB 126	10.17	0.23	-9.57	-4.57	-6.75*	-9.23**	-1.17	-9.0*	2.66	36.06**	32.72*	-14.23
339 A x CB 127	-2.42	-19.64	-8.17	0.18	-0.13	-2.78	-4.03	-5.96	6.09	18.28	1.77	-8.77
339 A x CB 128	-8.11	-14.1	-36.49*	-8.90**	-9.01**	-11.21**	-16.28**	-18.28**	-7.81	-5.24	-6.86	-39.81**
339 A x CB 129	53.96**	45.49*	20.88	-1.24	-1.31	-3.81	-7.96	-11.50*	-0.16	70.35**	66.18**	7.39
318 A x CB 110	19.41	14.8	4.94	-3.91	-6.59*	-6.59*	-5.78	-11.49*	1.03	36.79**	32.66*	-16.37
318 A x CB 111	24.56*	7.37	35.56*	2.34	-0.24	-0.24	-2.47	-12.32**	0.08	26.11*	4.58	-5.91
318 A x CB 119	-2.71	-17.29	7.97	4.81	2.71	2.71	-5.27	-7.8	5.23	35.22**	21.19	-9.4
318 A x CB 124	10.91	8.96	-0.39	1.36	-1.47	-1.47	0.67	-2.26	11.56*	28.15*	12	-11.3
318 A x CB 126	-8.3	-8.9	-16.72	0.04	-3.52	-3.52	6.28	-2.67	11.09*	28.08*	25.77	-22.70*
318 A x CB 127	-10.62	-19.56	-8.07	-3.61	-5.18	-5.18	-4.39	-6.84	6.33	-0.85	-17.67*	-26.19*
318 A x CB 128	-9.8	-23.18	-29.78	-10.20**	-11.28**	-11.28**	1.27	-1.71	12.19*	3.65	1.02	-36.96**
318 A x CB 129	21.87	16.32	6.33	0.66	-0.62	-0.62	-7.16	-11.23*	1.33	34.91**	32.47	-18.59

* Significant at 5% level, ** Significant at 1% level

CB 128 were superior than the standard check with regards to protein content in the grain.

Among the lines, 3060 A and among the testers, CB 119 and CB 111 performed well for most of the traits studied. For grain yield per plant the hybrids like 234 A x CB 127 and 3183 A x CB 119 were found to involve high x low and low x high combinations respectively in terms of *gca* indicating the role of non-additive gene action.

The present study revealed that the hybrids exhibited heterosis for grain yield were not heterotic for all the traits. The results indicated that exploitation of the heterosis or hybrid vigour might be one of the promising method to effect sorghum improvement for grain purpose.

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