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Estimation of heterosis among B x B, B x R and R x R crosses of rabi sorghum

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ABSTRACT
The present investigation was undertaken with the object of estimation of heterosis through half diallel mating design involving 4 Restorer lines and 3 maintainer lines. Out of 21 crosses 3 crosses showed significant positive heterobeltiosis and standard heterosis over the check for grain yield per plant. Significantly high heterobeltiosis and standard heterosis over M 35-1 was exhibited by the crosses BJV-44 X IS31651 and BJV-44 X IS26025 only. The significant heterosis was observed only in B x R crosses rather than B x B and R x R crosses which indicates comparatively high diverse between the B and R lines. The observed heterosis in B x R crosses was substantial over the check M 35-1. These findings indicates there is further need to increase genetic diversity between the parents to increase heterosis.
Key words : *Diallel, Heterosis, Heterobeltiosis, Restorer and Maintainer*

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INTRODUCTION

Sorghum [*Sorghum bicolor* (L.) Moench] is one of the most important cereal crop grown in Africa, Asia, USA, Australia, and Latin America. India has the largest share of world sorghum area (16.3%) and ranks fourth in the production after Mexico, Nigeria and USA. World's sorghum production of 64.16 million tonnes comes from an area of 41.00 million hectare with productivity of 1564 kg per hectare (FAO, 2016). In India, sorghum is grown over an area 6.25 million hectare with the production of 6.0 million tonnes and productivity of 1010 kg per hectare. In Karnataka, the crop has a total acreage of 1.41 million hectare with a total production of 1.30 million tonnes having productivity 1105 kg per hectare (Anonymous, 2016).

Due to excellent grain and fodder quality, post-rainy sorghums are used as food and fodder for livestock. They usually produce high biomass (grain and stover) and have high lustrous grain with semi-corneous endosperm. Although several hybrids have been developed and released for *rabi* season cultivation, the area covered under hybrids is almost negligible. Hybrid vigour and its commercial exploitation has paid rich dividends in *kharif* sorghum leading to quantum jump in sorghum production. However, the progress in *rabi* sorghum is limited. Although several hybrids have been developed and released for *rabi* season cultivation, the area covered with hybrids is almost negligible. The yield levels of present promising *rabi* hybrids like CSH 15R (2518 kg ha^{-1}) and SPH-1801 (2696 kg ha^{-1}) were below than the *rabi* variety CSV 22, which yielded 3427 kg ha^{-1} (AICRP 2016-17). This shows clear low productivity levels of *rabi* hybrids. Thus high yielding hybrids with grain quality adapted to different agroecological situations of *rabi* season characterized by terminal drought, low temperatures and biotic stresses like shoot fly infestation needs to be developed (Gite *et al.,* 2006). In this regard identification and diversification of parental lines is very much essential.

MATERIALS AND METHODS

The present experiment on sorghum was conducted at botanical garden, Department of genetics and plant breeding, UAS, Dharwad in *rabi* 2016-17. All the recommended agronomic practices were followed to raise a good crop. A total of 21 crosses obtained by crossing four newly identified strong restorer lines (IS26025, IS31651, IS24462 and IS 22616) on both milo (104A) and maldandi (M31-2A) CMS lines from minicore collection and 3 *rabi* lines (B-lines) 104B, M 31-2B and BJV-44. The resulting 21 F_1's along with their 7 parents were evaluated for various yield contributing traits of sorghum. The experiment was laid out in randomized block design with three replications with a row length of 4 m and a spacing of 45 x 15cm. The observations were recorded on randomly selected five plants for characters days to 50 % flowering, days to maturity, plant height (cm), panicle length (cm), panicle width (cm), 100 seed weight (g), panicle weight (g), primaries panicle^{-1} and grain yield plant^{-1} (g). The estimation of heterosis over the midparent, better parent and standard check was calculated using the procedure of Shull, 1908 and Fonseca and Patterson (1968) respectively.

RESULTS

The analysis of variance for yield and yield components recorded were presented in Table 1. Analysis of variance for parents and hybrids recorded significant differences for all the characters studied except 100 seed weight indicating the presence of sufficient variability among parents and hybrids. Mid parent heterosis for days to 50 per cent flowering ranged from –16.19 per cent (IS 31651 X IS 26025) to 29.41 per cent (IS 28614 X IS 24462) and two crosses (104B X IS 24462 and IS 28614 X IS 24462) recorded significant positive heterosis, while heterobeltiosis ranged from –25.11 per cent (IS 31651 X IS 26025) to 26.23 per cent (IS 28614 X IS 24462). Maximum heterosis in desirable negative direction over check was recorded by crosses M 31-2B X IS 28614 and IS 31651 X IS 28614.

Table 1: Analysis of variance for yield and its attributing traits in parents and single cross hybrids of Sorghum.

	DF	Days to 50% flowering	Days to maturity	Plant height (cm)	Panicle length (cm)	Panicle width (cm)	Panicle weight (g)	Primaries panicle^{-1}	Yield plant^{-1} (g)	100 seed weight (g)
Replicates	2	83.012	121.08	367.10	9.35	2.39	31.32	10.63	16.59	0.26
Genotypes	27	185.96 **	192.17 **	9193.49**	44.26**	3.782**	352.41**	503.94**	99.62**	0.44 *
Parents	6	140.63	113.74	11071.16**	34.584**	6.64**	139.60 *	993.91**	32.64	0.55
Hybrids	20	207.58 **	224.50 **	8440.57 **	41.48**	3.10**	311.76**	244.78*	113.39**	0.40
Parent Vs. Hybrids	1	25.39	16.11	12986.04 **	157.85**	0.09	2442.16**	2747.38**	226.21**	0.48
Error	54	65.33	64.28	1219.42	9.14	1.13	45.07	114.34	24.72	0.24

* and ** significant @ 5 and 1 per cent, respectively.

The range of mid parent heterosis for days to maturity was from -11.30 per cent (M 31-2B X IS 28614) to 14.77 per cent (104B X IS 24462). Out of 21 crosses 1 recorded significant negative mid-parent heterosis. The heterobeltiosis ranged from -13.55 (104B X IS 26025) to 12.58 (104B X IS 24462) and among all the crosses two crosses recorded negative significant heterosis over better parent (Table 2.). Out of 21 total crosses five crosses were showing negative significant heterosis over check. The cross with high negative significant heterosis over check recorded by M 31-2B X IS28614 followed by IS31651 X IS 28614. Heterosis for earliness in sorghum was also observed by Prabhakar *et al*. (2013) and Kumar and Chand (2015).

In single crosses the range of heterosis for plant height was -31.24 per cent (IS 24462 X IS 26025) to 67.29 per cent (M 31-2B X IS 31651) over mid parent, while the heterosis over better parent ranged from -37.78 per cent (IS 28614 X IS 24462) to 62.73 per cent (M 31-2B X IS 31651). Six crosses and three crosses recorded significant heterosis in positive direction over mid parent and better parent respectively. Four crosses showed negative significant heterosis over check. None of the crosses were significant in desirable direction over check. Heterosis for panicle weight was also reported by Rajguru *et al.* (2005).

Table 2: Estimates of mid parent (MP), better parent (BP)and standard heterosis for yield and its attributing traits in rabi sorghum

S. No	Crosses	Days to 50% flowering			Days to maturity			Plant height (cm)		
		MP	BP	SH	MP	BP	SH	MP	BP	SH
	B x B									
1	104B X BJV-44	4.98	0.48	6.56	-3.11	-5.25	-8.54	0.51	-13.16	-34.00**
2	104B X M 31-2B	7.05	6.77	3.53	4.30	3.41	-2.94	-5.70	-17.27	-39.33**
3	BJV-44 X M 31-2B	12.22	7.14	13.64	-7.00	-8.29	-11.46**	8.93	7.02	-18.67
	B x R									
4	104B X IS31651	-6.63	-8.33	-11.11	6.19	4.05	-4.00	33.69 *	20.19	-16.67
5	104B X IS28614	10.93	5.73	2.53	6.20	6.05	-1.86	11.74	-20.71 *	4.67
6	104B X IS24462	23.73 *	20.83	17.17	14.77 **	12.58 *	8.00	27.45	7.44	-13.33
7	104B X IS26025	-7.26	-15.74	0.00	-8.28	-13.55 **	-9.86	37.64 *	21.32	-12.00
8	BJV-44 X IS31651	-8.35	-13.81	-8.59	-4.32	-8.29	-11.46**	18.35	13.16	-14.00
9	BJV-44 X IS28614	9.90	0.48	6.56	-0.14	-2.21	-5.60	11.54	-12.12	16.00
10	BJV-44 X IS24462	16.03	8.57	15.15	1.70	1.38	-2.14	43.83 **	39.67 **	12.67
11	BJV-44 X IS26025	5.62	0.00	18.68	6.24	2.30	6.66	52.60 **	49.12 **	13.33
12	M 31-2B X IS31651	-8.51	-9.95	-13.14	-4.39	-7.10	-12.80**	67.29 **	62.73 **	19.33
13	M 31-2B X IS28614	-18.9	-22.51 *	-25.26**	-11.30 *	-11.93 *	-17.34**	14.29	-11.11	17.33
14	M 31-2B X IS24462	2.14	0.00	-3.53	7.90	6.74	2.40	1.30	-3.31	-22.00
15	M 31-2B X IS26025	-11.27	-19.57 *	-4.55	-3.10	-7.93	-4.00	23.40	22.73	-10.00
	R X R									
16	IS31651 X IS28614	-12.53	-15.14	-20.71*	-4.57	-6.63	-13.60*	3.97	-20.71 *	4.67
17	IS31651 X IS24462	6.52	5.95	-1.02	3.50	-0.49	-4.54	9.33	1.65	-18.00
18	IS31651 X IS26025	-16.19	-25.11 **	-11.11	1.80	-5.88	-1.86	-6.95	-9.01	-34.00**
19	IS28614 X IS24462	29.41 **	26.23 *	16.67	12.63 *	10.63	6.14	-22.76 *	-37.78 **	-17.87
20	IS28614 X IS26025	8.56	-5.53	12.12	2.98	-2.81	1.34	25.16 *	-3.03	28.00*
21	IS24462 X IS26025	-2.87	-13.62	2.53	-3.83	-7.67	-3.74	-31.24 *	-34.71 *	-47.33**
S.E		5.71	6.59	6.59	5.66	6.54	6.54	24.69	28.51	28.51

* and ** indicates significant at 5 and 1 per cent, respectively.

The range of heterosis in single crosses for panicle length was from -18.24 per cent (104B X M 31-2B) to 15.93 per cent (BJV-44 X IS 24462) over mid parent and from -27.38 per cent (IS 24462 X IS 26025) to 32.17 per cent (BJV-44 X IS 26025) over better parent (Table 2.). The crosses BJV-44 X IS 26025 and IS31651 X IS 26025 showed high positive significant heterosis for panicle length in desirable direction.

The mid parent heterosis for panicle width ranged from -36.58 per cent (IS 28614 X IS 26025) to 28.00 per cent (M 31-2B X IS 31651). Out of 21crosses three recorded significant positive heterosis. The heterobeltiosis range observed was from -47.00 per cent (IS 28614 X IS 26025) to 28.13 per cent (BJV-44 X IS 31651) and among all the crosses positive significant heterosis over better parent was not recorded. Only one cross BJV-44 X IS 26025 reported for positive significant heterosis for panicle width in desirable direction over check. Heterosis for panicle components was also reported by Jilani *et al.* (2000).

Table 2: Estimates of mid parent (MP), better parent (BP)and standard heterosis for yield and its attributing traits in rabi sorghum

S. No	Crosses	Panicle length (cm)			Panicle width (cm)			Panicle weight (g)		
		MP	BP	SH	MP	BP	SH	MP	BP	SH
	B x B									
1	104B X BJV-44	-2.74	-10.13	-1.37	-1.45	-8.11	-19.00	-1.10	-19.64	-33.33**
2	104B X M 31-2B	-18.24 *	-23.42 *	-15.96	-20.40	-26.27 *	-23.86	0.51	-11.61	-26.67
3	BJV-44 X M 31-2B	-12.50	-13.77	-17.38	-12.47	-23.96	-21.43	-4.52	-12.94	-45.18
	B x R									
4	104B X IS31651	18.60	6.96	17.38	22.45	13.51	0.00	73.33 **	27.68	5.93
5	104B X IS28614	17.56	-2.53	6.96	6.67	5.26	-4.71	14.40	-13.39	-28.16*
6	104B X IS24462	2.33	-16.46	-8.33	17.82	10.81	-2.43	44.36 **	22.32	1.49
7	104B X IS26025	19.72 *	12.03	22.92**	-20.94 *	-34.63 **	-11.86	46.88 **	12.50	-6.67
8	BJV-44 X IS31651	4.21	1.49	-5.54	28.93	28.13	-2.43	90.24 **	67.14 **	-13.33
9	BJV-44 X IS28614	24.37 *	10.45	2.79	20.00	10.53	0.00	50.49 *	37.14	-28.89
10	BJV-44 X IS24462	36.75 **	19.40	11.13	26.93	25.77	-2.43	70.50 **	61.95 **	-6.67
11	BJV-44 X IS26025	33.97 **	32.17 **	26.38**	21.90 *	-4.59	28.57*	201.00 **	178.57 **	44.44**
12	M 31-2B X IS31651	22.26 *	17.39	12.50	28.00 *	10.6	14.29	31.88	7.06	-32.60**
13	M 31-2B X IS28614	-7.44	-18.84	-22.21	-16.46	-21.66	-19.00	3.80	-12.94	-45.18**
14	M 31-2B X S24462	32.77 **	14.49	9.71	27.89 *	11.98	15.71	57.25 **	50.59 *	-5.18
15	M 31-2B X S26025	8.81	8.70	4.17	-9.20	-19.79 *	8.14	90.91 **	62.35 **	2.22
	R X R									
16	IS31651 X IS28614	24.68 *	13.39	0.00	-2.30	-10.53	-19.00	144.17 **	134.46 **	0.00
17	IS31651 X IS24462	44.49 **	29.13 *	13.88	21.50	19.63	-7.14	88.07 **	58.10 **	-8.89
18	IS31651 X IS26025	36.00 **	30.72 **	25.00*	-20.63	-38.16 **	-16.71	91.88 **	81.30 **	-20.00
19	IS28614 X IS24462	33.33 *	30.77 *	-5.54	3.12	-4.21	-13.29	7.12	-6.80	-46.29**
20	IS28614 X IS26025	23.29 *	8.21	3.46	-36.58 **	-47.00 **	-28.57*	21.21	19.19	-47.40**
21	IS24462 X IS26025	-15.86	-27.38 *	-30.54**	-19.28	-36.40 **	-14.29	29.33	14.18	-34.20**
S.E		2.13	2.46	2.46	0.75	0.87	0.87	4.74	5.48	5.48

* and ** indicates significant at 5 and 1 per cent, respectively.

In single crosses the range of heterosis for panicle weight was -4.52 per cent (BJV-44 X M 31-2B) to 201.00 per cent (BJV-44 X IS 26025) over mid parent. The heterosis over better parent ranged from -19.64 per cent (104B X BJV-44) to 7.93 (BJV-44 X IS 26025). Only one cross BJV-44 X IS26025 (44.44) reported positive significant heterosis for panicle weight in desirable direction over check. Heterosis for panicle weight was also reported by Premalatha *et al.* (2006).

The range of heterosis over mid parent for primaries per panicle was from -11.83 per cent (104B X BJV-44) to 140.82 per cent (IS 31651 X IS 24462) and nine crosses recorded positively significant heterosis over mid parent. Heterobeltiosis ranged from -19.15 per cent (BJV-44 X IS 31651) to 130.86 per cent (IS 31651 X IS 24462) and high significant heterosis over better parent was observed in three crosses. None of the cross exhibited significant heterosis in desirable direction over check. Heterosis for primaries per panicle was also reported by Patil and Biradar, 2005.

Table 2: Estimates of mid parent (MP), better parent (BP)and standard heterosis for yield and its attributing traits in rabi sorghum

S. No	Crosses	Primaries per panicle			100 seed weight (g)			Yield per plant (g))		
		MP	BP	SH	MP	BP	SH	MP	BP	SH
	B x B									
1	104B X BJV-44	-11.83	-12.77	-8.88	-9.88	-16.79	0.00	7.92	-5.64	-5.65
2	104B X M 31-2B	-1.97	-5.43	-3.33	2.96	-13.9	3.69	13.13	7.38	-10.50
3	BJV-44 X M 31-2B	8.64	3.72	8.33	-10.21	-19.44	-17.85	-19.86	-26.54	-26.54
	B x R									
4	104B X IS31651	14.03	-21.2	-19.45	13.81	-0.26	20.00	55.12 **	40.64 *	29.46
5	104B X IS28614	30.28	-1.63	0.55	-17.36	-22.08 *	-6.15	2.92	0.54	-21.08
6	104B X IS24462	40.41 *	-0.54	1.67	8.80	0.17	20.62	27.46	16.44	-12.81
7	104B X IS26025	45.60 *	4.35	6.67	12.71	-2.47	17.23	20.85	10.13	0.23
8	BJV-44 X IS31651	17.68	-19.15	-15.55	15.99	9.57	11.69	60.92 **	54.53 **	54.54**
9	BJV-44 X IS28614	18.49	-11.17	-7.22	-14.96	-16.84	-11.38	-16.3	-25.29	-25.31
10	BJV-44 X IS24462	33.75	-5.85	-1.67	10.51	10.17	12.31	-18.81	-34.27 *	-34.27*
11	BJV-44 X IS26025	40.44 *	0.00	4.45	17.84	9.77	11.69	44.97 **	38.46 *	38.46*
12	M 31-2B X IS31651	18.51	-16.37	-20.55	33.01 *	25.93	14.15	21.05	15.32	6.15
13	M 31-2B X IS28614	41.20 *	9.36	3.88	15.43	1.54	8.31	4.02	1.00	-15.85
14	M 31-2B X IS24462	31.63	-4.68	-9.45	15.99	4.36	5.54	14.35	-0.34	-16.96
15	M 31-2B X IS26025	45.97 *	7.02	1.67	22.96	18.09	3.69	42.35 **	36.34 *	24.12
	R X R									
16	IS31651 X IS28614	93.67 **	69.38 *	-11.67	4.68	-3.18	3.08	39.82 *	29.53	19.23
17	IS31651 X IS24462	140.82 **	130.86 **	-1.67	14.65	8.61	9.85	20.33	0.64	-7.35
18	IS31651 X IS26025	105.25 **	93.15 **	-14.45	12.30	10.65	0.31	1.58	1.02	-7.00
19	IS28614 X IS24462	21.03	9.94	-42.67**	-0.30	-2.79	3.69	25.13	11.92	-12.15
20	IS28614 X IS26025	65.90 *	53.4	-20.00	-13.50	-21.08	-16.00	23.42	14.93	4.62
21	IS24462 X IS26025	17.23	14.98	-49.07**	-7.81	-13.88	-12.92	-8.63	-23.24	-30.12
S.E		7.56	8.73	8.73	0.34	0.40	0.40	3.51	4.05	4.05

* and ** indicates significant at 5 and 1 per cent, respectively.

The range of heterosis over mid parent for 100 seed weight was from -17.36 per cent (104B X IS 28614) to 33.01 per cent (M 31-2B X IS 31651) (Table 2.). The heterobeltiosis observed was in the range of -22.08 per cent (104B X IS 28614) to 25.93 per cent (M 31-2B X IS 31651). None of the cross exhibited significant heterosis in desirable direction over check for 100 seed weight. Nirmala *et al.* (2005) did not observe much heterosis for test weight in sorghum

Hybrid performance with respect to mid parent heterosis for grain yield per plant ranged from -19.86 per cent to 60.92 per cent in the crosses BJV-44 X M 31-2B and BJV-44 X IS 31651 respectively. The range of heterosis over better parent was from -34.27 per cent (BJV-44 X IS 24462) to 54.53 per cent (BJV-44 X IS 31651) and five crosses exhibited positive significant heterosis over mid parent and four crosses over better parent heterosis. Two crosses BJV-44 X IS31651 (54.54) and BJV-44 X IS26025 (38.46) exhibited significant heterosis in positive direction over check. Heterosis for grain yield was also reported by Sajjanar *et al.* (2011).

DISCUSSION

Among the R x R crosses no significant heterosis over check was found. Among the B x B crosses also there was no significant heterosis over check variety. The significant crosses observed were of B x R-line only viz., BJV-44 x IS 31651 and BJV-44 x IS 26025 but these crosses were substantially heterotic than the check (M 35-1). These findings show crosses between individual R-lines and individual B-lines were not heterotic but cross combinations between B-lines and R-lines were substantially better which means genetic divergence could be substantially high between these B and R-lines. Nirmala *et al.* (2005) reported that low heterosis in *rabi* sorghum is because *rabi* lines are genetically narrow compared with *kharif* lines. Hence, genetic diversity of *rabi* lines has to be increased keeping grain quality. Reddy and sternhouse (1994) reported in sorghum that introduction of larger grain size and luster in the female parents of *kharif* hybrids by novel methods and hybridizing such female parents with *rabi* based R lines would increase the yield levels of *rabi* hybrids. The cross combination BJV-44 X IS 31651 which has shown significant heterosis than other crosses can be effectively utilized by converting BJV-44 in to a CMS line and utilizing IS 31651 as male pollinator parent.

The crosses which involving M 31-2B as one of the parent didn't showed much heterosis for grain yield per plant except the cross combination M 31-2B X 26025 showed heterosis over better parent. The cross combination M 31-2B x IS 26025 which showed significant heterosis over the better parent can be used to develop segregating population to isolate segregants for strong restoration on maldandi cytoplasm and with good maldandi grain quality traits.

Even though the selected R-lines were of different geographical background like IS 31651 (Zaire), IS 26025 (Mali), IS 28614 (Yemen) and IS 24462 (South Africa) but they could not produce high heterosis when crosses were attempted between them. Being geographically diverse does not mean to have all desirable yield contributing alleles which are necessary for heterosis at yield influencing loci in its genetic background. Kaul *et al.* (2003) reported in sorghum that there should be perfect complement of alleles at target loci between the hybrid parents and should be genetically diverse then only high heterotic hybrids can be developed.

Among the four R-lines IS 31651 found to be heterotic with the B-lines. IS 31651 which belongs to caudatum race will be desirable source in increasing *rabi* genetic background for genetic divergence with the existing durra races as durra races has good grain quality features. Even the other R-lines IS 26025 (Guinea race) found to show substantial heterosis with B-lines. The other R–lines IS 28614 (durra caudatum) and IS 24462 (caudatum-bicolor) did not show significant heterosis over the check with the B-lines.

The other observation of interest was, the most productive hybrids were observed to be high heterotic crosses also (Table 3.). Biradar *et al.* (1996) reported that high mean grain yield was not observed in high heterotic crosses. But in the present study the mean grain yield was highest in the crosses which were showing high heterosis. But in comparison with the standard check (M 35-1) heterosis in these crosses were not showing very high. Hence, it is clear from the study these lines are less diverse with each other which resulted in low heterosis. There is need for increase in genetic diversity between hybrid parents to exploit heterosis for rabi sorghum

Table 3: (A) Most productive and (B) Most heterotic crosses of the study

Crosses	(A)Most productive		Crosses	(B) Most Heterotic		
	Grain yield per plant	Test weight		Grain yield per plant	BP (%)	Check (%)
BJV-44 X IS31651	40.18	3.63	BJV-44 X IS31651	40.18	54.53**	54.54**
BJV-44 X IS26025	36.00	3.63	104B X IS31651	33.66	40.64**	29.46
104B X IS31651	33.66	3.90	BJV-44 X IS26025	36.00	38.46**	38.46**
M 31-2B X IS26025	32.27	3.37	M 31-2B X IS26025	32.27	36.34**	24.12

* and ** indicates significant at 5 and 1 per cent, respectively.

CONCLUSION

In diallel analysis considerable heterosis was observed for grain yield, panicle weight and number of primaries per panicle. The heterosis in grain yield was largely due to panicle weight. In present study, only two cross combinations BJV-44 x IS 31651 and BJV-44 x IS 26025 found to be heterotic over check variety M 35-1. This indicated there is need for creating desirable genetic diversity between parental lines.

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