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

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The present investigation was conducted to assess the magnitude of heterosis of rabi sorghum (*Sorghum bicolor* (L.) Moench) developed by crossing four lines and twelve testers (in a line × tester design) to produce 48 F_1 cross combinations at the Sorghum Improvement Project, MPKV., Rahuri, Maharashtra. To identify the high-yielding *Rabi* sorghum hybrids, promising hybrids were sorted out based on positive significant standard heterosis for grain yield per plant. A total of twenty-one hybrids exhibited significant standard heterosis for grain yield per plant. The best cross combination was 104A x RSR 1012 (86.59%) for maximum standard heterosis, followed by the cross 104A X RSR 1019 (73.17%) and 104 A X RSR 1003 (70.73%) for grain yield per plant. Heterosis has been considered a well-proven method for increasing yield and improving traits in crops, and the exploitation of heterosis for the hybrid development programme is considered one of the greatest breakthroughs in plant breeding.

Keywords: Average heterosis; heterosis; heterobeltiosis; standard heterosis; rabi sorghum.

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1. INTRODUCTION

Sorghum is the fifth most important cereal crop in the world after rice, wheat, maize, and barley [1], cultivated globally for food, fodder, feed, and fuel [2]. Sorghum have starch, protein, non-starch polysaccharides, and fatty acids in almost the same quantities [3]. The demand for gluten-free sorghum grains has grown significantly in recent years. Sorghum is a good source of nutrients, therefore it become a staple grain in the human diet in the near future. According Ji et al*.,* [4] was observed that weight loss, better glycaemic control, higher fat burning, and changes in gut bacteria are well-known advantages of a diet composed of coarse cereal including Sorghum. But sorghum lines have been reported to exhibit anti-oxidant and anti-inflammatory effects as well [5].

“Heterosis” or “hybrid vigour” is the increased or decreased vigour growth, fitness, or yield of a hybrid over the parental values, resulting from the crossing of genetically unlike parents. Heterosis is agronomically important because the superior performance can appear as biomass, yield, and abiotic and biotic stress tolerance. Breeding of F1 hybrid cultivars based on heterosis is used in many crops and vegetables [6]. Heterosis was proposed by Shull [7] as the development stimulus resulting from the union of different gametes and hybrid vigour to manifest effects of heterosis. Sorghum Production in 2021 was 62.10 million tons. This year's 60.32 estimated millions of tons could represent a decrease of 1.78 million tons or 2.87% in sorghum production around the globe. Sorghum production in India amount to 4,400,000 Metric Tons [8].

The exploitation of hybrid vigour and its commercial exploitation is an appropriate alternative for making further breakthrough in sorghum yield. A higher yield over high yielding check varieties and wider adaptability has been instrumental in rapid spread of hybrid sorghum in India. It was observed that estimates of degree of dominance were more than unity for grain yield and yield components except length of primary branch, which indicates over dominance, is the cause of heterosis. Commercial exploitation of heterosis in sorghum today is profitable proposition. It is obvious that the crosses should be compared with released hybrids rather than just their mid- or better-performing parent. Therefore, in the present investigation, the performance of the experimental crosses was compared with that of the most popularly released hybrid, CSH 15 R, in order to estimate the magnitude of standard heterosis, So that the crosses with high heterotic potential could be isolated for further evaluation and commercial cultivation. In this study, an effort was made to identify the high-yielding cross combinations produced by crossing newly developed parental lines of r*abi* sorghum. The promising hybrids were sorted out based on significant positive standard heterosis for grain yield.

2. MATERIALS AND METHODS

The present investigation was conducted at Sorghum Improvement Project, M.P.K.V., Rahuri, Maharashtra during rabi 2016-17. Four male sterile lines (185A, RMS2010-10A, RMS2010-24A, and 104 A) were crossed with twelve testers (RSR 950, RSR 1012, RSR 1013, RSR 984, RSR 1014, RSR 1019, RSR 986, RSR 987, RSR 1020, RSR 1027, RSR 1003, and RSR 955) in line x testers mating design used to develop 48 F_1’s hybrids. The resulting 48 F_1’s, along with their 16 parents and one check (CSH-15 R), were evaluated for grain yield and yield contributing traits in rabi sorghum 2017-18.

The parents and hybrids were grown in separate block in a Randomized Block Design (RBD) with two replications. Each entry was consisted two rows having 3 m length with inter and intra spacing at 45 cm and 15 cm, respectively. Data were recorded on five randomly selected plants in each replication for the characters viz., days to 50% flowering, days to physiological maturity (cm), plant height, 1000 grain weight (g), dry fodder per plant (g), harvest index (%) and grain yield per plant (g). Data were subjected to statistical analysis as per Arunachalam [9] for various characters and heterosis.

3. RESULTS AND DISCUSSION

The analysis of variance revealed that, the variation among the treatments were highly significant for all the studied characters (Table 1). Mean performance of parents, hybrids and standard check is presented in Table 2. The estimates of heterosis over better parent (BP) and standard check (SH) are presented in Table 3. In rabi sorghum. positive heterosis was desirable for all the characters studied except days to 50% flowering, days to maturity, plant height were negative heterosis is desirable. Details experimental character wise results and discussion of heterosis (H_1) heterobeltiosis (H_2) and standard heterosis (H_3) are explain in below.

3.1 Days to 50% Flowering (Days)

The hybrid 185 A X RSR 984 had the highest significant negative mid parent heterotic value and better parent heterotic value. The hybrids 185 A X RSR 984, 104 A X RSR 955, 185A X RSR 955 and 2010-10AxRSR 950 recorded highest significant negative heterosis over the check. Heterobeltiosis ranged from -10.70 to 25.59 per cent (Table 3). Out of 48 crosses 23 crosses showed negative significant heterobeltiosis. The heterosis in negative direction was considered to be desirable for this trait. Out of 48, 21 hybrids flowered earlier than their mid parents by exhibiting significant negative heterosis and 23 hybrids exhibited significant negative heterobeltiosis over their respective better parents. This hybrid was a combination of parents with high *gca* effects in desirable negative direction. Hence, this hybrid can be further utilized to have early segregants. The results of heterosis for earliness were in accordance with the findings of Amsalu and Bapat [10], Ganesh et al. [11], Lokapur [12], Kenga et al., [13] and Premalatha et al. [14].

3.2 Days to Maturity (Days)

The magnitude of heterosis over mid parent was -4.87 per cent (185A X RSR 1020) to 12.55 per cent (104A X RSR 986). The range of heterobeltiosis was from -6.07 per cent (2010-10A x RSR 950) to 15.47 per cent (104A X RSR 986). As the check CSH-15 R is late in maturity the standard heterosis ranged from 6.39 to 15.60 per cent. The crosses 185 A x RSR 950 (6.39%) and 185 A X RSR 1013 (6.67%) showed lowest standard heterosis followed by cross 185A X RSR1019 (6.77%) and 2010-10A x RSR 955 (7.52%).

3.3 Plant Height (cm)

Almost all the hybrids were found to be taller than their respective mid parents except 151 A x CB 111. Average heterosis for plant height ranged from -31.06 to 67.56 per cent (Table 3). The cross 2010-24A x RSR1027 exhibited highest negative average heterosis followed by 2010-24A x RSR 987 and 185A X RSR 987. Heterobeltiosis ranged from -8.99 (2010-24A x RSR 1027) to 83.88 per cent (2010-10A x RSR 1012) (Table 3). As the standard heterosis over standard check for plant height ranged from -34.80 to 25.37 per cent (Table 3). Maximum negative heterosis was found in crosses 2010-24A x RSR 1027 followed by 185A x RSR 950 and 185A X RSR987 or 1000 grain, while maximum positive standard heterosis was observed in 104A X RSR 1019. Similar significant standard heterosis for plant height was reported by Patel et al. [15] and Premalatha et al. [14]. Better parent heterosis for plant height was also manifested by El-Mottaleb and Asran [16].

3.4 1000 Grain Weight

The 1000 grain weight is serves as an indicator of grain yield as it is an important character contributing to yield. In the present investigation, most of the hybrids recorded positive heterosis over mid parent and better parent. Among 48 hybrids, 15 crosses exhibited significant positive average heterosis, most of the crosses recorded significant positive heterobeltiosis and standard checks. The cross 2010-10A x RSR 986 (29.22%) exhibited maximum positive average heterosis followed by the cross 2010-10A x RSR 955 (27.03%) and 2010-10AxRSR 987 (20.09%). Weight heterobeltiosis ranged from -12.55 to 41.66 per cent. Most of the crosses recorded significant positive heterobeltiosis. The crosses 2010-10AxRSR955 (41.66%) followed by 2010-10AxRSR 986 (35.36%) exhibited maximum significant positive heterobeltiosis (Table 3). Standard heterosis over check CSH-15R ranged from -13.20 to 22.30 per cent. The cross 104 A X RSR 955 (22.30%) recorded maximum standard heterosis followed by the cross 2010-10AxRSR955 (20.39%). Significant better parent heterosis for 1000 grain weight was reported by Premalatha et al. [14] and Mahdy et al. [17].

3.5 Harvest Index

Average heterosis for harvest index ranged from -19.29 to 61.34 per cent. Out 48 crosses 19 crosses exhibited significant positive average heterosis, the cross 2010-24AxRSR 986 (61.34%) exhibited maximum positive average heterosis followed by the cross 2010-24AxRSR 986 (60.10%) and 104A X RSR 1019 (43.95%). Heterobeltiosis ranged from -15.47 to 111.19 per cent. Most of the crosses recorded significant positive heterobeltiosis. The crosses 185 A x RSR 1012 (111.19%) followed by 185AXRSR1027 (93.61%) and 2010-24AxRSR 986 (86.22%) exhibited maximum significant positive heterobeltiosis (Table 3). Standard heterosis over check CSH-15R ranged from 12.55 to 56.67 per cent. The cross 104A X RSR 1019 (56.67%) recorded maximum standard heterosis followed by the cross 2010-24AxRSR1012 (52.18%) and 185 A x RSR 1012 (51.24%). Similar results observed by Swarnalata Kaul et al., [18] for positive significant harvest index.

Table 1. Analysis of variance for seven characters in R*abi* Sorghum

Sources	D F	Days to 50% flowering	Days to physio. maturity	Plant height (cm)	1000 grain wt (g)	Harvest index (%)	Dry fodde. yield/ plant(g)	Grain yield/ plant(g)
Replication	1	0.25	1.81	3.78	13.28	2.41	0.01	0.20
Treatments	63	87.87**	82.61**	1548.62**	10.95**	51.03**	819.62**	349.40**

Table 2. Mean performance of parents, hybrids and standard check for eleven characters in *rabi* sorghum

Sr. No.	Name of parents/ crosses	Days to 50% flowering	Days to physiolo. Maturity	Plant height (cm)	1000 grain wt. (g)	Harvest index (%)	Dry fodder yield/ plant(g)	Grain yield/ plant (g)
				Female (Lines)				
1	185A	73.8	114.1	119.1	25.9	20.5	75.5	21.5
2	RMS2010-10A	80.0	120.2	112.3	21.9	33.9	47.0	22.2
3	RMS2010-24A	75.3	115.3	122.3	25.2	28.0	40.7	27.2
4	104A	70.0	109.5	147.3	28.0	34.9	44.5	30.3
	Lines mean	**74.8**	**114.8**	**125.3**	**25.27**	**29.33**	**51.93**	**25.3**
				Male (Testers)				
5	RSR 950	88.5	124.9	121.0	29.3	34.0	49.5	46.2
6	RSR1012	88.4	128.2	176.5	25.1	33.6	47.5	50.2
7	RSR1013	87.1	127.2	146.3	27.7	31.2	41.0	33.2
8	RSR984	88.6	128.6	126.9	30.8	30.1	42.5	34.6
9	RSR1014	88.1	128.1	170.5	27.3	38.8	44.2	48.3
10	RSR1019	86.1	126.2	191.6	28.6	27.4	88.0	43.7
11	RSR986	63.7	104.1	132.8	24.1	21.4	70.0	26.9
12	RSR987	89.0	129.0	187.9	22.7	29.5	97.3	47.7
13	RSR1020	88.3	128.3	175.6	25.6	34.1	96.3	64.1
14	RSR1027	89.0	129.1	200.6	26.1	40.3	36.5	51.6
15	RSR1003	87.6	127.7	221.8	24.8	40.0	59.4	72.2
16	RSR955	89.1	129.1	189.2	27.1	36.2	80.0	49.9
	Testers mean	**86.1**	**125.9**	**170.1**	**26.6**	**33.05**	**62.7**	**47.4**
				Hybrids				
17	185 A x RSR 950	72.7	113.2	118.9	23.3	29.4	62.5	24.5
18	185 A x RSR 1012	71.1	111.6	178.2	24.3	43.3	50.0	52.5
19	185 A X RSR 1013	72.9	113.5	166.7	22.8	36.8	36.5	35.8
20	185 A X RSR 984	65.9	107.6	154.9	22.9	32.2	36.5	30.0
21	185 A X RSR 1014	74.1	114.6	155.0	22.7	26.4	43.5	31.5
22	185AXRSR1019	73.6	113.6	194.9	24.5	33.7	94.0	54.5

Sr. No.	Name of parents/ crosses	Days to 50% flowering	Days to physiolo. Maturity	Plant height (cm)	1000 grain wt. (g)	Harvest index (%)	Dry fodder yield/ plant(g)	Grain yield/ plant (g)
23	185AXRSR 986	64.5	105.0	180.1	27.2	26.9	103.5	37.5
24	185AXRSR987	74.3	114.7	121.5	22.8	30.9	41.5	28.0
25	185AXRSR1020	74.7	115.5	132.4	24.0	32.8	61.0	46.5
26	185AXRSR1027	74.2	114.6	162.8	24.9	39.4	59.5	43.0
27	185AXRSR1003	74.3	114.9	147.4	25.8	26.4	82.5	31.5
28	185AXRSR 955	69.9	110.6	165.7	23.4	31.4	80.5	40.5
29	2010-10AxRSR 950	72.6	112.9	155.5	23.9	36.1	52.5	39.5
30	2010-10AxRSR1012	74.6	114.9	206.5	25.7	34.6	80.5	54.5
31	2010-10AxRSR1013	75.1	115.2	182.9	28.0	40.5	77.5	66.9
32	2010-10AxRSR 984	77.7	117.9	200.4	27.7	36.7	86.5	58.5
33	2010-10AxRSR1014	77.0	117.5	169.5	24.5	42.2	53.5	63.5
34	2010-10AxRSR1019	79.1	119.2	187.4	26.5	33.7	66.0	48.5
35	2010-10AxRSR 986	67.8	108.6	175.7	29.8	30.7	55.5	35.0
36	2010-10AxRSR 987	74.9	115.8	168.4	26.9	38.3	55.5	55.5
37	2010-10AxRSR1020	75.2	115.6	131.8	23.6	36.9	49.0	45.5
38	2010-10AxRSR1027	79.3	119.6	173.4	27.9	34.3	75.5	49.0
39	2010-10AxRSR1003	79.0	119.4	185.5	24.9	37.4	49.5	44.5
40	2010-10AxRSR955	73.9	114.4	182.8	31.2	35.8	78.5	69.0
41	2010-24AxRSR950	81.2	121.7	140.4	22.6	33.6	41.5	37.3
42	2010-24AxRSR1012	76.5	116.6	171.2	26.6	43.6	49.4	60.0
43	2010-24AxRSR1013	80.5	121.1	160.2	22.5	41.5	35.0	41.0
44	2010-24AxRSR984	82.5	122.9	136.9	24.5	33.0	45.5	37.5
45	2010-24AxRSR1014	76.8	117.2	155.8	28.9	34.5	59.5	55.5
46	2010-24AxRSR1019	81.5	121.8	192.3	25.5	36.3	67.5	47.0
47	2010-24AxRSR 986	67.1	107.5	156.9	29.6	39.9	43.0	42.5
48	2010-24AxRSR 987	82.4	123.0	122.0	26.9	35.6	58.5	44.5
49	2010-24AxRSR1020	82.0	122.5	142.5	22.8	36.6	59.0	51.5
50	2010-24AxRSR1027	82.2	122.0	111.3	24.7	31.9	37.5	32.5
51	2010-24AxRSR1003	81.6	122.9	142.0	28.2	27.5	83.0	34.0
52	2010-24AxRSR 955	81.9	122.1	155.6	24.6	27.8	86.5	38.5
53	104A x RSR 950	76.2	116.4	149.5	26.2	28.8	100.5	48.5
54	104A x RSR 1012	70.5	110.5	200.6	25.7	36.2	94.0	76.5
55	104A X RSR 1013	70.0	110.1	160.4	26.4	28.2	96.0	42.5
56	104A X RSR 984	74.5	114.7	198.0	30.0	36.0	81.5	58.5
57	104A X RSR 1014	75.6	116.0	190.6	26.7	31.0	102.5	60.0
58	104A X RSR 1019	75.9	116.1	214.0	28.6	44.9	79.5	71.0
59	104A X RSR 986	80.0	120.2	158.6	27.0	33.5	32.0	30.7

Sr. No.	Name of parents/ crosses	Days to 50% flowering	Days to physiolo. Maturity	Plant height (cm)	1000 grain wt. (g)	Harvest index (%)	Dry fodder yield/ plant(g)	Grain yield/ plant (g)
60	104A X RSR 987	75.3	115.3	194.7	23.4	33.1	64.1	44.2
61	104A X RSR 1020	75.3	115.6	164.1	27.7	37.2	40.5	31.1
62	104 A X RSR 1027	74.7	114.7	172.9	26.4	32.7	63.5	33.5
63	104 A X RSR 1003	74.8	175.2	207.4	24.6	39.9	70.5	70.0
64	104 A X RSR 955	66.0	106.3	195.0	31.6	37.7	54.5	55.5
65	**CSH 15R (Ch)**	**66.0**	**106.4**	**170.7**	**25.9**	**28.6**	**61.5**	**41.0**
	Hybrid mean HM)	**75.3**	**116.9**	**166.5**	**25.9**	**34.75**	**64.09**	**46.5**
	SE ±	3.39	3.44	2.82	0.71	1.72	4.29	3.26
	CD at 5%	6.82	6.92	5.68	1.42	3.46	8.63	6.55
	CD at 1%	9.10	9.24	7.59	1.90	4.61	11.52	8.75

Table 3. Estimates of Heterosis (%) over mid-parent (MP), better-parent (BP) and standard check (H_3) for different characters

Sr. No	Crosses	Days to 50% flowering			Days to physiological Maturity			Plant height		
		1			2			3		
		MP (H_1)	BP (H_2)	Check (H_3)	MP (H_1)	BP (H_2)	Check (H_3)	MP (H_1)	BP (H_2)	Check (H_3)
1	185 A x RSR 950	-10.41**	-1.49	10.15*	-5.27*	-0.79	6.39*	-0.96	-0.17	-30.35**
2	185 A x RSR 1012	-12.35**	-3.66	7.73	-7.88**	-2.19	4.89	20.57**	49.62**	4.39**
3	185 A X RSR 1013	-9.38**	-1.22	10.45*	-5.93*	-0.53	6.67*	25.62**	39.97**	-2.34
4	185 A X RSR 984	-18.84**	-10.70*	-0.15	-11.33**	-5.70	1.13	25.93**	30.06**	-9.26**
5	185 A X RSR 1014	-8.46*	0.41	12.27*	-5.37*	0.44	7.71*	7.04**	30.14**	-9.20**
6	185AXRSR1019	-7.94*	-0.27	11.52*	-5.45*	-0.44	6.77*	25.46**	63.64**	14.18**
7	185AXRSR 986	-6.18	1.26	-2.27	-3.76	0.86	-1.32	43.16**	51.22**	5.51**
8	185AXRSR987	-8.72*	0.68	12.58*	-5.64*	0.53	7.80*	-20.85**	2.02	-28.82**
9	185AXRSR1020	-7.83*	1.22	13.18**	-4.87*	1.05	8.36**	-10.15**	11.17**	-22.44**
10	185AXRSR1027	-8.85*	0.54	12.42*	-5.76*	0.44	7.71*	1.85	36.69**	-4.63**
11	185AXRSR1003	-7.93*	0.68	12.58*	-4.96*	0.70	7.99*	-13.52**	23.76**	-13.65**
12	185AXRSR 955	-14.18**	-5.28	5.91	-9.05**	-3.07	3.95	7.49**	39.13**	-2.93
13	2010-10AxRSR 950	-13.83**	-9.25*	10.00*	-7.87**	-6.07*	6.11	33.30**	38.47**	-8.90**
14	2010-10AxRSR1012	-11.43**	-6.75	13.03*	-7.49**	-4.41	7.99*	43.01**	83.88**	20.97**
15	2010-10AxRSR1013	-10.11**	-6.13	13.79**	-6.87**	-4.16	8.27*	41.45**	62.87**	7.15**
16	2010-10AxRSR 984	-7.83*	-2.87	17.73**	-5.23*	-1.91	10.81**	67.56**	78.45**	17.40**
17	2010-10AxRSR1014	-8.38	-3.74	16.67**	-5.36*	-2.25	10.43**	19.87**	50.93**	-0.70
18	2010-10AxRSR1019	-4.76	-1.13	19.85**	-3.25	-0.83	12.03**	23.33**	66.87**	9.78**
19	2010-10AxRSR 986	-5.64	6.44	2.73	-3.17	4.32	2.07	43.55**	56.46**	2.93
20	2010-10AxRSR 987	-11.36**	-6.37	13.48**	-7.06**	-3.66	8.83**	12.19**	49.96**	-1.35
21	2010-10AxRSR1020	-10.64**	-6.00	13.94**	-6.96**	-3.83	8.65**	-8.44**	17.36**	-22.79**
22	2010-10AxRSR1027	-6.15	-0.88	20.15**	-4.05	-0.50	12.41**	10.83**	54.41**	1.58
23	2010-10AxRSR1003	-5.73	-1.25	19.70**	-3.67	-0.67	12.22**	11.04**	65.18**	8.67**
24	2010-10AxRSR955	-12.60**	-7.62	11.97*	-8.22**	-4.83	7.52*	21.26**	62.78**	7.09**
25	2010-24AxRSR950	-0.85	7.84	23.03**	1.33	5.55	14.38**	15.41**	16.03**	-17.75**
26	2010-24AxRSR1012	-6.56	1.59	15.91**	-4.23	1.13	9.59**	14.59**	39.98**	0.29
27	2010-24AxRSR1013	-0.86	6.91	21.97**	-0.12	5.03	13.82**	19.29**	30.99**	-6.15**

Sr. No	Crosses	Days to 50% flowering			Days to physiological Maturity			Plant height		
		1			2			3		
		MP (H_1)	BP (H_2)	Check (H_3)	MP (H_1)	BP (H_2)	Check (H_3)	MP (H_1)	BP (H_2)	Check (H_3)
28	2010-24AxRSR984	0.67	9.56*	25.00**	0.78	6.59*	15.51**	9.87**	11.94**	-19.80**
29	2010-24AxRSR1014	-6.00	1.99	16.36**	-3.70	1.65	10.12**	6.42**	27.39**	-8.73**
30	2010-24AxRSR1019	0.99	8.23	23.48**	0.87	5.64	14.47**	22.52**	57.24**	12.65**
31	2010-24AxRSR 986	-3.45	5.34	1.67	-2.01	3.27	1.03	23.16**	28.29**	-8.08**
32	2010-24AxRSR 987	0.30	9.34*	24.85**	0.70	6.68*	15.60**	-21.34**	-0.25	-28.53**
33	2010-24AxRSR1020	0.24	8.90*	24.24**	0.57	6.24*	15.13**	-4.33**	16.52**	-16.52**
34	2010-24AxRSR1027	0.06	9.16*	24.55**	-0.16	5.81*	14.66**	-31.06**	-8.99**	-34.80**
35	2010-24AxRSR1003	0.18	8.37	23.64**	1.15	6.59*	15.51**	-17.47**	16.11**	-16.81**
36	2010-24AxRSR 955	-0.36	8.76*	24.09**	-0.08	5.90*	14.76**	-0.10	27.23**	-8.85**
37	104A x RSR 950	-3.85	8.86*	15.45**	-0.68	6.30*	9.40**	11.28**	23.55**	-12.42**
38	104A x RSR 1012	-11.01**	0.71	6.82	-7.03**	0.91	3.85	23.75**	35.82**	17.52**
39	104A X RSR 1013	-10.88**	0.00	6.06	-6.97**	0.55	3.48	9.12**	9.64**	-6.03**
40	104A X RSR 984	-6.05	6.43	12.88*	-3.65	4.75	7.80*	44.21**	56.03**	15.99**
41	104A X RSR 1014	-4.36	8.00	14.55**	-2.36	5.94	9.02**	19.80**	29.05**	11.66**
42	104A X RSR 1019	-2.75	8.43	15.00**	-1.48	6.03	9.12**	26.14**	44.89**	25.37**
43	104A X RSR 986	19.67**	25.59**	21.21**	12.55**	15.47**	12.97**	13.20**	19.70**	-7.09**
44	104A X RSR 987	-5.28	7.57	14.09**	-3.31	5.30	8.36*	16.03**	31.82**	14.06**
45	104A X RSR 1020	-4.86	7.57	14.09**	-2.78	5.57	8.65**	1.52	11.10**	-3.87*
46	104 A X RSR 1027	-6.04	6.71	13.18**	-3.86	4.75	7.80*	-0.72	17.06**	1.29
47	104 A X RSR 1003	-5.08	6.86	13.33**	-2.87	5.21	8.27*	12.26**	40.42**	21.50**
48	104 A X RSR 955	-17.03**	-5.71	0.00	-10.90**	-2.92	-0.09	15.76**	32.02**	14.24**
	Range	**-18.84 to 19.67**	**-10.70 to 25.59**	**10.00 to 25.00**	**-4.87 to 12.55**	**-6.07 to 15.47**	**6.39 to 15.60**	**-31.06 to 67.56**	**-8.99 to 78.45**	**-34.80 to 25.37**
	SE ±	2.79	3.22	3.22	2.85	3.29	3.29	2.27	2.62	2.62
	CD at 5%	5.61	6.48	6.48	5.73	6.62	6.62	4.57	5.27	5.27
	CD at 1%	7.49	8.64	8.64	7.65	8.84	8.84	6.09	7.04	7.04

Table 3. Continue

Sr. No.	Crosses	1000 Grain weight			Harvest Index			DM/Plant			Grain yield/plant		
		4			5			6			7		
		MP (H1)	BP (H2)	Check(H3)	MP (H1)	BP (H2)	Check(H)	MP(H1)	BP (H2)	Check(H3)	MP (H1)	BP (H2)	Check(H3)
1	185 A x RSR 950	-15.66**	-10.34**	-9.99**	7.77	43.30**	2.62	0.00	26.26**	1.63	-27.62**	13.95	-40.24**
2	185 A x RSR 1012	-4.63	-3.02	-5.82*	60.10**	111.19**	51.24**	-18.70**	5.26	-18.70**	46.44**	144.19**	28.05**
3	185 A X RSR 1013	-14.76**	-11.97**	-11.63**	42.51**	79.67**	28.67**	-37.34**	-10.98	-40.65**	30.90**	66.51**	-12.68
4	185 A X RSR 984	-19.06**	-11.57**	-11.23**	15.96**	57.17**	12.55*	-38.14**	-14.12	-40.65**	6.95	39.53**	-26.83**
5	185 A X RSR 1014	-14.65**	-12.55**	-12.21**	-11.12*	28.57**	-7.93	-27.32**	-1.58	-29.27**	-9.74	46.51**	-23.17**
6	185AXRSR1019	-10.32**	-5.72*	-5.35	40.58**	64.33**	17.69**	14.98**	24.50**	52.85**	67.18**	153.49**	32.93**
7	185AXRSR 986	8.41**	12.51**	5.00	28.12**	30.91**	-6.25	42.27**	47.86**	68.29**	54.96**	74.42**	-8.54
8	185AXRSR987	-6.51*	0.09	-11.96**	23.31**	50.49**	7.77	-51.97**	-45.03**	-32.52**	-19.08*	30.23*	-31.71**
9	185AXRSR1020	-6.99**	-6.40*	-7.23*	20.26**	60.00**	14.58*	-28.99**	-19.21**	-0.81	8.64	116.28**	13.41
10	185AXRSR1027	-4.08	-3.79	-3.42	30.69**	93.61**	38.65**	6.25	63.01**	-3.25	17.65*	100.00**	4.88
11	185AXRSR1003	1.39	3.73	-0.46	-12.82*	28.64**	-7.87	22.31**	38.89**	34.15**	-32.76**	46.51**	23.17**
12	185AXRSR 955	-4.22	-2.23	-1.86	10.67	52.88**	9.48	3.54	6.62	30.89**	13.45	88.37**	-1.22
13	2010-10AxRSR 950	-6.41*	9.05**	-7.32*	6.36	6.53	26.19**	8.81	11.70	-14.63*	15.50*	77.93**	-3.66
14	2010-10AxRSR1012	9.17**	16.96**	-0.60	2.55	3.05	20.90**	70.37**	71.28**	30.89**	50.55**	145.50**	32.93**
15	2010-10AxRSR1013	12.92**	27.51**	8.37**	24.50**	29.93**	41.57*	76.14**	89.02**	26.02**	141.52**	201.35**	63.17**
16	2010-10AxRSR 984	5.08*	26.08**	7.15*	6.48	8.30	28.28**	93.30**	103.53**	40.65**	105.99**	163.51**	42.68**
17	2010-10AxRSR1014	-0.54	11.37**	-5.35	15.94**	24.32**	47.26**	17.32*	21.04**	-13.01	80.14**	186.04**	54.88**
18	2010-10AxRSR1019	4.76	20.60**	2.49	9.69	22.65**	17.51**	-2.22	40.43**	7.32	47.19**	118.47**	18.29*
19	2010-10AxRSR 986	29.22**	35.56**	15.21**	10.99	43.45**	7.21	-5.13	18.09*	-9.76	42.57**	57.66**	-14.63
20	2010-10AxRSR 987	20.09**	22.19**	3.85	20.82**	29.76**	33.89**	-23.08**	18.09*	-9.76	58.80**	150.00**	35.37**
21	2010-	-0.87	7.37*	-8.75**	8.57	8.80	28.88**	-31.61**	4.26	-20.33**	5.45	104.95**	10.98

Sr. No.	Crosses	1000 Grain weight			Harvest Index			DM/Plant			Grain yield/plant		
		4			5			6			7		
		MP (H1)	BP (H2)	Check(H3)	MP (H1)	BP (H2)	Check(H)	MP(H1)	BP (H2)	Check(H3)	MP (H1)	BP (H2)	Check(H3)
	10AxRSR1020												
22	2010-10AxRSR1027	16.15**	27.08**	8.00**	-7.34	1.31	20.01**	80.84**	106.85**	22.76**	32.79**	120.72**	19.51*
23	2010-10AxRSR1003	6.77*	13.67**	-3.40	1.10	10.18	30.52**	-6.95	5.23	-19.51**	-5.72	100.45**	8.54
24	2010-10AxRSR955	27.03**	41.66**	20.39**	2.05	5.41	24.86**	23.62**	67.02**	27.64**	91.40**	210.81**	68.29**
25	2010-24AxRSR950	-17.11**	-10.44**	-12.77**	8.47	20.14**	17.48**	-7.98	1.97	-32.52**	1.63	37.13**	-9.02
26	2010-24AxRSR1012	5.88*	6.03*	2.98	41.50**	55.63**	52.18**	12.02	21.38**	-19.67**	55.04**	120.59**	46.34*
27	2010-24AxRSR1013	-15.04**	-10.87**	-13.20**	40.31**	48.33**	45.04**	-14.32	-14.00	-43.09**	35.76**	50.74***	0.00
28	2010-24AxRSR984	-12.36**	-2.66	-5.20	4.56	17.78**	15.17*	9.37	11.79	-26.02**	21.36**	37.87**	-8.54
29	2010-24AxRSR1014	10.06**	14.54**	11.56**	3.28	23.25**	20.51**	40.16**	46.19**	-3.25	47.02**	104.04**	35.37**
30	2010-24AxRSR1019	-5.29*	1.17	-1.47	31.08**	32.43**	26.89**	4.90	65.85**	9.76	32.58**	72.79**	14.63
31	2010-24AxRSR 986	20.08**	22.69**	14.51**	61.34**	86.22**	39.18**	-22.31**	5.65	-30.08**	57.12**	57.99**	3.66
32	2010-24AxRSR 987	12.55**	18.59**	4.31	23.67**	27.08**	24.27**	-15.22**	43.73**	-4.88	18.83*	63.60**	8.54
33	2010-24AxRSR1020	-10.16**	-9.37**	-11.73**	17.95**	30.71**	27.81**	-13.87**	44.96**	-4.07	12.81*	89.34**	25.61**
34	2010-24AxRSR1027	-3.82	-2.04	-4.60	-6.50	13.96*	11.44	-2.85	2.74	-39.02**	-17.51*	19.49	-20.73
35	2010-24AxRSR1003	12.91**	13.75**	9.16**	-19.29**	-1.98	-4.16	65.83**	103.93**	34.96**	-31.59**	25.00*	-17.07*
36	2010-24AxRSR 955	-5.90*	-2.44	-4.99	-13.33**	-0.71	-2.92	43.33**	112.53**	40.65**	-0.13	41.54**	-6.10
37	104A x RSR 950	-8.68**	-6.70*	1.10	-16.54**	-15.47**	0.44	113.83**	125.84**	63.41**	26.80**	60.07*	18.29*
38	104A x RSR 1012	-3.39	2.21	-0.73	5.87	7.92	26.61**	104.35**	111.24**	52.85**	90.06**	152.48**	86.59**
39	104A X RSR 1013	-5.41*	-4.79	1.84	-14.62**	-9.57	-1.47	124.56**	134.15**	56.10**	37.01**	43.56**	6.10

Sr. No.	Crosses	1000 Grain weight			Harvest Index			DM/Plant			Grain yield/plant		
		4			5			6			7		
		MP (H1)	**BP (H2)**	**Check(H3)**	**MP (H1)**	**BP (H2)**	**Check(H)**	**MP(H1)**	**BP (H2)**	**Check(H3)**	**MP (H1)**	**BP (H2)**	**Check(H3)**
40	104A X RSR 984	2.19	7.19**	16.15**	3.32	3.60	26.24**	87.36**	91.76**	32.52**	80.28**	93.07**	42.68**
41	104A X RSR 1014	-3.30	-1.91	3.32	-15.80**	-11.06*	8.38	131.12**	131.90**	66.67**	52.67**	98.02**	46.34**
42	104A X RSR 1019	0.81	1.89	10.42**	43.95**	63.52**	56.67**	20.00**	78.65**	29.27**	91.89**	134.32**	73.17**
43	104A X RSR 986	3.51	11.84**	4.39	18.85**	56.32**	16.83**	-44.10**	-28.09**	-47.97**	7.34	14.13	-25.12**
44	104A X RSR 987	-7.83**	2.86	-9.53**	2.79	12.10	15.66*	-9.59	44.04**	4.23	13.33	45.87**	7.80
45	104A X RSR 1020	3.05	7.86**	6.90*	7.84	9.16	29.84**	-42.47**	-8.99	-34.15**	-21.40**	22.44*	-9.51
46	104 A X RSR 1027	-2.46	1.11	2.11	-12.87**	-6.17	14.33*	56.79**	73.97**	3.25	-18.19**	10.56	-18.29*
47	104 A X RSR 1003	-6.77**	-0.75	-4.75	6.58	14.40**	39.40**	35.71**	58.43**	14.63*	36.59**	131.02**	70.73**
48	104 A X RSR 955	14.87**	19.97**	22.30**	6.19	8.09	31.72**	-12.45*	22.47*	-11.38	38.40**	83.17**	35.37**
	Range	**-19.06 to 29.22**	**-12.55 to 41.66**	**-13.20 to 22.30**	**-19.29 to 61.34**	**-15.47 to 111.19**	**12.55 to 56.67**	**-51.97 to 131.12**	**-45.03 to 134.15**	**-47.97 to 68.29**	**-32.76 to 141.52**	**22.44 to 210.81**	**-40.24 to 86.59**
	SE ±	0.62	0.71	0.71	1.55	1.79	1.79	3.52	4.06	4.06	2.63	3.04	3.04
	CD at 5%	1.24	1.43	1.43	3.11	3.59	3.59	7.08	8.17	8.17	5.30	6.11	6.11
	CD at 1%	1.65	1.91	1.91	4.15	4.80	4.80	9.44	10.91	10.91	7.07	8.16	8.16

** , ** = Significant at 5% and 1% respectively, CD= critical difference, SE= standard error*

3.6 Dry Fodder per Plant

The heterosis in positive direction (Significant) was considered to be desirable for this trait. Average heterosis for Dry fodder per plant ranged from -51.97 to 131.12 per cent. Out 48 crosses 20 crosses exhibited significant positive average heterosis, the cross 104A X RSR 1014 (131.12%) exhibited maximum positive average heterosis followed by the cross 104A X RSR 1013 (124.56%), 104A x RSR 950 (113.83%) and 104A x RSR 1012 (104.34%). Heterobeltiosis ranged from -45.03 to 134.15 per cent. Most of the crosses recorded significant positive heterobeltiosis. The crosses 104A X RSR 1013 (134.15%) followed by 104A x RSR 950 (125.84%) and 2010-24AxRSR 955 (112.53%), 104A x RSR 1012 (111.24%) and 2010-24A x RSR 1003 (103.93%) exhibited maximum significant positive heterobeltiosis (Table 3). Standard heterosis over check CSH-15R ranged from -47.97 to 68.29 per cent. The cross 185AXRSR 986 (68.29%) recorded maximum standard heterosis followed by the cross 104A X RSR 1014 (66.67%) and 104A x RSR 950 (63.41%). The significant parent heterosis for dry fodder per plant was reported by Prakash et al. [19].

3.7 Grain Yield/ Plant Yield

Average heterosis for grain yield per plant ranged from -32.76 to 141.52 per cent. Out 48 crosses 31 crosses exhibited significant positive average heterosis, the cross 2010-10A x RSR 1013 (141.52%) exhibited maximum positive average heterosis followed by the cross 2010-10AxRSR 984 (105.99%), 2010-10AxRSR955 (91.40%) and 104A x RSR 1012 (90.06%). Heterobeltiosis ranged from 22.44 to 210.81 per cent. Most of the crosses recorded significant positive heterobeltiosis. The crosses 2010-10A x RSR 955 (210.81%) followed by 2010-10A x RSR 1013 (201.35%) and 2010-10A x RSR 1014 (186.04%) exhibited maximum significant positive heterobeltiosis (Table 3). Standard heterosis over check CSH-15R ranged from -40.24 to 86.59 per cent. The cross 104A x RSR 1012 (86.59%) recorded maximum standard heterosis followed by the cross 104A X RSR 1019 (73.17%) and 104 A X RSR 1003 (70.73%). Significant positive heterosis for grain yield per plant was reported by Hovny [20] and Kenga et al. [13]. Both mid parent and better parent positive heterosis were reported by Sharma et al., [21] and Premalatha et al. [14]. All three types of heterosis namely, average heterosis, heterobeltiosis and standard heterosis for this trait was reported by Esha [22]. Standard heterosis for grain yield was reported by Makanda et al. [23].

The degree of heterosis varied considerably for grain yield per plant and its attributes. The highest percentage of average heterosis was observed for grain yield per plant followed by dry fodder per plant, plant height, harvest index, 1000 grain weight. The negative heterosis was observed for days to 50 per cent flowering and days to physiological maturity in the grain for most of the hybrids. The observed highest heterosis for grain yield per plant was due to expression of heterosis in component characters like dry fodder per plant, plant height, harvest index, 1000 grain weight. The highest per cent of heterobeltiosis was documented for grain yield per plant followed by dry fodder per plant, plant height, harvest index, 1000 grain weight. The highest percentage of standard heterosis was observed for dry fodder per plant, plant height, harvest index, 1000 grain weight, whereas negative standard heterosis was observed for characters like dry fodder per plant, plant height, harvest index, 1000 grain weight in the grain suggesting that for these characters checks performed better than the crosses in the present study.

4. CONCLUSION

The exploitation of hybrid vigour is an appropriate alternative for making further breakthrough in sorghum yield. A higher yield over high yielding check varieties and wider adaptability has been instrumental in rapid spread of hybrid sorghum in India. It was observed that estimates of degree of dominance were more than unity for grain yield and yield components except length of primary branch, which indicates over dominance, is the cause of heterosis. Commercial exploitation of heterosis in sorghum today is profitable proposition. It is obviously important that the crosses are compared with released hybrids rather than merely comparing with their mid or better parent. So in the present study the performance of the experimental crosses were compared with that of the most popular released hybrid, CSH 15 R in order to estimate the magnitude of standard heterosis so that the crosses with high heterotic potential could be isolated for further evaluation and commercial cultivation.

Significant positive heterosis over mid and better parents has been observed for grain yield and yield components in majority of the crosses. High level of heterosis was noticed for grain yield per plant followed by dry fodder per plant, plant height, harvest index, 1000 grain weight. The hybrid 104A x RSR 1012 exhibited significant positive heterosis for grain yield per plant over standard check CSH 15R and was also good specific combiner. Most of the hybrids exhibited significant positive heterosis over standard check for grain yield, dry fodder per plant, plant height, harvest index, 1000 grain weight. The hybrids *viz.,* RMS 2010-10A x RSR 984, 2010-10A x RSR 986, 185A x RSR 986 and RMS 2010-10A x RSR 1012 were tall and high yielding compared to parents. The hybrids, most of the crosses like RMS 2010-10A x RSR 1013, 104A x RSR 1019 and 104A x RSR 1012 were superior than the standard check with regards to grain yield per plant.

It can be concluded that in the present investigation, the hybrid RMS 2010-10A x RSR 1013 was the best experimental hybrid identified based on the overall performance, the desirable *sca* effects, high heterosis and with other important attributes, followed by RMS 2010-10A x RSR 1012, 104A x RSR 1012, 104A x RSR 1003, RMS 2010-10A x RSR 955, 185A x RSR 1027, 185A x RSR 1020, RMS 2010-24A x RSR 1019, RMS, 185A x RSR 986, RMS 2010-24A x RSR 1020 and RMS 2010-24A x RSR 986.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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