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Exploring Heterosis in *Kharif* Sorghum Landraces (*Sorghum bicolor* (L.) Moench) for Yield and its Associated Traits

N. Pugahendhi[1]*, B. Sunil Kumar[2], Karnam Venkatesh[3] and P. Rajendrakumar[4]

[1,2]Department of Genetics and Plant Breeding, Annamalai University (Tamil Nadu), India
[3]Genetics & Plant Breeding, ICAR-Indian Institute of Millets Research (IIMR), Hyderabad, India
[4]Biotechnology, ICAR-Indian Institute of Millets Research (IIMR), Hyderabad, India

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ABSTRACT

The extent of heterosis was evaluated through Line x Tester analysis for twenty-seven hybrids, derived from 9 kharif landrace lines and 3 grain sorghum variety testers. Heterosis levels varied across all traits examined for each cross. Significantly high standard heterosis values were observed for grain yield per plant, panicle width, panicle length of primary branches, plant height, and number of leaves, while the remaining traits displayed moderate to low levels of heterosis. The highest positive heterosis for grain yield over the better parent was recorded at 44.17 percent. This enhancement in grain yield could be attributed to the heterosis exhibited in its constituent traits, particularly panicle width and panicle length of primary branches. Among the crosses, namely, EG 54XCSV 15 and ERN 26XCSV 15, exhibited high *per se* performance,high positive and statistically significant standard heterosis, as well as heterobeltiosis, alongwith high *sca* effects and involved at least one good combiner parent. Consequently, these specific crosses hold the potential for commercial exploitation in heterosis breeding programs.

Key words: Kharif *sorghum landraces, Heterobeltiosis, Standard heterosis, Grain yield*

Introduction

Sorghum bicolor (L.) Moench (2n = 2x = 20) is a significant cereal grain. It ranks sixth in both grain production and cultivated area, following wheat, maize, rice, and barley. Globally, it was grown on 40.07 million hectares, producing 62.20 million metric tons (Agricultural Statistics at a Glance 2022, Department of Agriculture, Cooperation, and Farmers Welfare). The grains are energy-rich, per 100 g providing 349 kcal, along with 10.4g of protein and 72.6g of carbohydrates. Additionally, they contain 1.2g of crude fiber and are a source of essential minerals such as 42 mg of calcium and 8.0mg of iron (Nutritive value of Indian food, NIN, ICMR, 2018). India's landraces, in particular, exhibit higher levels of both genetic and phenotypic variability (Elangovan *et al*., 2012; Vara Prasad and Sridhar, 2019). These indigenous populations serve as crucial sources of diversity that plant breeders can harness to develop improved cultivars with enhanced yields. However, the current yield potential of landraces is insufficient to attract farmers due to their low productivity. Therefore, to achieve a significant leap in yield, the exploitation of hybrid vigor and heterosis breeding is gaining prominence.

([1]Research Scholar, [2]Associate Professor, [3]Senior Scientist, [4]Principal Scientist)

This necessitates the recombination of genes through controlled crosses and systematic study of the heterotic effect in F1 progeny. Therefore, the present study aims to estimate the magnitude of heterosis analysis for yield and its component traits in kharif sorghum landraces.

Materials and Methods

The experimental material comprised 39 entries, including 9 kharif landrace females (EG 2, EG 35, EA 10, EG 1, E 158, SEA 14, EG 54, GGUB 61, ERN 26) and 3 male parent grain sorghum varieties (CSV 20, CSV 15, CSV 27), along with their resulting 27 crosses, obtained through a line x tester mating design. These entries were sown in a randomized block design with three replications at ICAR-Indian Institute of Millets Research, Hyderabad, during the Kharif season of 2022. Observations were recorded for twelve traits*viz*., days to 50 percent flowering, plant height (cm), number of leaves, leaf length (cm), leaf width (cm), panicle length (cm), panicle width (cm), panicle length of primary branches (cm), stem diameter (cm), days to maturity, hundred seed weight (g), and grain yield per plant (g). The mean values were subjected to line x-tester analysis. Heterosis computation followed the procedures outlined by Turner (1955) and Hayes *et al*. (1953)

Result and Discussion

The analysis of variance revealed significant differences among parents and F1 hybrids for all the traits. The hybrids exhibited significantly superior performance compared to their respective parents. Notably, substantial heterosis was observed across most of the traits studied. The varying levels of average heterosis and heterobeltiosis in the hybrids can be attributed to the genetic diversity of the parents utilized in the hybrid generation. This highlights the presence of vigor and the successful development of hybrids. The range of heterosis, heterobeltiosis, and economic heterosis along with several significant crosses for twelve characters are presented in Tables 1a and 1b. In this current investigation, negative direction heterosis is considered favorable for both days to 50% flowering and days to maturity, while for the remaining traits, significant positive direction heterosis is deemed desirable.

In heterosis breeding, seed yield heterosis and its components are helpful. By completely using the variance owing to additive and non-additive gene activities, heterosis can be maximized since they determine yield and component expression.

Significant heterosis for grain yield per plant was observed in 14 crosses over the mid parent and in 10 crosses over the better parent. Among these crosses, ERN 26XCSV 15 demonstrated the highest magnitude of relative heterosis and heterobeltiosis for grain yield per plant (58.79% and 44.17%, respectively). Heterosis levels ranged from -22.83% (E 158XCSV 15) to 58.79% (ERN 26XCSV 15) over the mid parent, and from -40.47% (E 158XCSV 15) to 44.17% (ERN 26XCSV 15) over the better parent (Table 1b). In terms of standard heterosis, the cross ERN 26XCSV 15 exhibited the highest positive and statistically significant value. Similar findings regarding grain yield were reported by Khadi *et al.*, (2018); Tiwari *et al*. (2019), and Ambika *et al*. (2021).

The other components contributing to grain yield, such as panicle length, also displayed a notable percentage of heterosis, ranging from -43.14% (EA 10XCSV 27) to 40.71% (EG 1XCSV 15) over the mid parent, and from -44.33% (EA 10XCSV 27) to 22.98% (EG 1XCSV 15) over the better parent. Notably, EG 1XCSV 15 recorded the highest percentage of standard heterosis at 22.98%.

Regarding panicle width, the magnitude of heterosis ranged from -48.15% (GGUB 613 XCSV 20) to 62.82% (EG 35XCSV 27) over the mid-parent, and from -50.7% (GGUB 61XCSV 20) to 51.19% (EG 35XCSV 27) over the better parent. In terms of standard heterosis, three hybrids, namely EG 35XCSV 27 (71.62%), EG 54XCSV 15 (51.35%), and SEA 14XCSV 15 (45.95%) demonstrated positive significant superiority.

For the panicle length of primary branches, five hybrids exhibited significant positive heterosis over the mid parent, while two hybrids displayed it over the better parent. The cross EG 35XCSV 27 exhibited the highest significant positive heterosis over both the better parent (62.82%) and the mid-parent (51.19%).

In the case of 100 seed weight, heterosis ranged from -13.51% to 27.96% over the mid parent, and from -27.74% to 8.85% over the better parent. Significant heterosis over the mid parent was observed in seven hybrids, whereas five hybrids exhibited significant heterosis over the better parent. The cross GGUB 61XCSV 15 displayed the maximum heterosis of 27.96% and 8.85% over the mid-parent and better-parent, respectively.

Table 1a. Estimation of relative heterosis (RH), heterobeltiosis (HB), and standard heterosis (SH) for yield and yield associated traits

S. No.	Hybrids	Days to 50%Flowering			Plant height (cm)			Number of leaves			Leaf Length (cm)			Leaf width (cm)			Panicle length (cm)		
		RH	HB	SH	RH	HB	SH	RH	HB	SH	RH	HB	SH	RH	HB	SH	RH	HB	SH
1	EG 2XCSV 20	-0.59	-4.17 *	0.4	62 **	55.02 **	59.46 **	-1.61	-5.67	36.57 **	2.25	-2.7	4.49	20.21 **	16.49 **	48.68 **	3.06	-3.8	-1.94
2	EG 2XCSV 15	-1.41	-2.78	-2.78	12.85 **	9.46 **	9.46 **	12.2 **	-5.15	37.31 **	1.82	0.3	0.3	24.55 **	14.29 **	36.84 **	7.06 **	0.83	0.83
3	EG 2XCSV27	-0.8	-2.37	-1.98	60.05 **	48.04 **	63.73 **	-12.53 **	-19.07 **	17.16 **	-10.41 **	-18.02 **	-4.19	-5.76 *	-10 **	18.42 **	-9.32 **	-17.48 **	-11.08 **
4	EG 35XCSV 20	-11.55 **	-15.91 **	-11.9 **	6.89 **	-2.26	0.54	6.76	-15.73 **	11.94 *	-9.18 **	-19.14 **	-13.17 **	-7.69 **	-13.4 **	10.53 **	-16.48 **	-30.43 **	-29.09 **
5	EG 35XCSV 15	0.11	-2.78	-2.78	10.89 **	2.72	2.72	46.84 **	29.85 **	29.85 **	33.56 **	22.75 **	22.75 **	36.65 **	29.41 **	44.74 **	-6.93 **	-21.88 **	-21.88 **
6	EG 35XCSV27	-6.31 **	-9.09 **	-8.73 **	2.61	-9.15 **	0.48	0.78	-18.15 **	0.78	1.35	-12.98 **	1.7	-10.27 **	-17 **	9.21 **	-25.55 **	-39.33 **	-34.63 **
7	EA 10XCSV 20	2.09	-7.58 **	-3.17	8.35 **	-5.01 **	29.7 **	10.06 **	4.49	38.81 **	7.45 **	2.71	20.96 **	3.26	-5.93 **	46.05 **	-13.18 **	-17.24 **	-6.93 **
8	EA 10XCSV 15	-5.58 **	-12.7 **	-12.7 **	3.96 *	-9.95 **	22.96 **	10.99 **	1.97	21.75 **	2.84	-4.92 *	11.98 **	5.15 *	-13.56 **	34.21 **	-3.52	-8.87 **	2.49
9	EA 10XCSV27	3.64 *	-4.35 *	-3.97 *	-13.15 **	-21.4 **	7.31 **	10.15 **	8.48 *	33.58 **	-4.38 *	-4.75 *	12.18 **	-11.93 **	-18.64 **	26.32 **	-43.14 **	-44.33 **	-37.4 **
10	EG 1XCSV 20	5.77 **	4.17 *	9.13 **	27.79 **	25.1 **	34.33 **	-15.73 **	-15.73 **	11.94 *	5.39 **	4.46	12.18 **	-4.76 *	-7.32 **	25 **	22.57 **	6.25 *	8.31 **
11	EG 1XCSV 15	-10.24 **	-10.94 **	-9.52 **	21.02 **	16.86 **	25.48 **	10.26 **	-3.37	28.36 **	-8.11 **	-10.5 **	-5.59 *	-24.93 **	-34.63 **	-11.84 **	40.71 **	22.98 **	22.98 **
12	EG 1XCSV27	-0.2	-0.78	0.79	10.74 **	9.12 **	20.69 **	-12.54 **	-15.73 **	11.94 *	-8.08 **	-12.55 **	2.2	3.41	2.15	37.76 **	-5.92 *	-20.31 **	-14.13 **
13	E 158XCSV 20	1.48	-9.09 **	-4.76 *	-29.36 **	-35.57 **	-19.58 **	-3.7	-19.66 **	6.72	-20.21 **	-22.4 **	-16.67 **	-38.64 **	-44.33 **	-28.95 **	-32.72 **	-34.62 **	-29.36 **
14	E 158XCSV 15	-11.5 **	-19.05 **	-19.05 **	-17.12 **	-25.35 **	-6.84 **	19.37 **	12.69 **	12.69 **	-4.11	-4.82 *	-3.39	47.1 **	44.3 **	50 **	-24.63 **	-27.44 **	-21.61 **
15	E 158XCSV27	-5.63 **	-13.83 **	-13.49 **	-16.26 **	-21.02 **	-1.43	-16.2 **	-27.88 **	-11.19 *	-11.06 **	-16.91 **	-2.89	26.26 **	13 **	48.68 **	-37.61 **	-37.69 **	-32.69 **
16	SEA 14XCSV 20	-0.19	-2.27	2.38	-10.52 **	-15.38 **	-12.96 **	8.64 **	7.73 *	45.52 **	-7.41 **	-9.39 **	-2.69	-2.39	-8.93 **	34.21 **	-0.87	-22.28 **	-20.78 **
17	SEA 14XCSV 15	4.55 **	4.35 *	4.76 *	-8.91 **	-12.69 **	-12.69 **	9.84 **	-4.42	29.1 **	-4.04	-5.34 *	-2.69	9.57 **	-8.04 **	35.53 **	26.32 **	-0.28	-0.28
18	SEA 14XCSV27	3.16	3.16	3.57	-0.19	-8.72 **	0.96	-14.45 **	-18.23 **	10.45 *	-25.22 **	-29.72 **	-17.86 **	-16.04 **	-20.54 **	17.11 **	2.01	-21.59 **	-15.51 **
19	EG 54XCSV 20	-11.2 **	-11.36 **	-7.14 **	3.32	-3.37	-0.6	-2.25	-2.25	29.85 **	0.59	-4.28	2.79	17.39 **	11.34 **	42.11 **	3.44	0.77	8.31 **
20	EG 54XCSV 15	-21.17 **	-22.81 **	-19.44 **	-6.49 **	-11.37 **	-11.37 **	23.08 **	7.87 *	43.28 **	22.59 **	20.76 **	20.76 **	14.11 **	6.9 *	22.37 **	13.48 **	9.54 **	17.73 **
21	EG 54XCSV27	-13.95 **	-15.59 **	-11.9 **	7.41 **	-2.81	7.49 **	-6.12	-9.55 **	20.15 **	-16.01 **	-23.14 **	-10.18 **	16.58 **	9 **	43.42 **	-25.87 **	-25.96 **	-20.22 **
22	GGUB 61XCSV 20	-2.16	-5.68 **	-1.19	2.88	1.7	7.07 **	4.79	4.49	38.81 **	-15.01 **	-23.7 **	-18.06 **	17.71 **	6.19 *	35.53 **	-25.96 **	-37.23 **	-36.01 **
23	GGUB 61XCSV 15	-6.64 **	-7.94 **	-7.94 **	6.12 **	3.46	8.93 **	10.61 **	-2.82	28.36 **	-1.72	-8.88 **	-8.88 **	11.69 **	10.26 **	13.16 **	-11.51 **	-24.38 **	-24.38 **
24	GGUB 61XCSV27	-1.2	-2.77	-2.38	-0.19	-2.59	7.73 **	-9.36 **	-12.43 **	15.67 **	5.67 **	-8.54 **	6.89 **	8.99 **	-3	27.63 **	-19.69 **	-33.42 **	-28.25 **
25	ERN 26XCSV 20	4.31 *	-3.79 *	0.79	-33.99 **	-46.17 **	-44.63 **	12.78 **	-15.73 **	11.94 *	-16.2 **	-16.59 **	-10.43 **	-0.55	-7.22 **	18.42 **	-15.85 **	-18.48 **	-16.9 **
26	ERN 26XCSV 15	-8.63 **	-13.89 **	-13.89 **	-34.9 **	-46.33 **	-46.33 **	67.57 **	38.81 **	38.81 **	-19.54 **	-21.95 **	-16.97 **	31.25 **	25 **	38.16 **	14.73 **	12.19 **	12.19 **
27	ERN 26XCSV27	-5.46 **	-11.07 **	-10.71 **	-30.74 **	-45.05 **	-39.22 **	17.87 **	-9.64 *	11.27 *	-17.75 **	-21.43 **	-8.18 **	21.74 **	12 **	47.37 **	-8.45 **	-13.62 **	-6.93 **
	Min	-21.17	-22.81	-19.44	-34.9	-46.33	-46.33	-16.2	-27.88	-11.19	-25.22	-29.72	-18.06	-38.64	-44.33	-28.95	-43.14	-44.33	-37.4
	Max	5.77	4.35	9.13	62	55.02	63.73	67.57	38.81	45.52	33.56	22.75	22.75	47.1	44.3	50	40.71	22.98	22.98
	No.of significant crosses	12	18	14	12	6	13	14	6	24	5	2	7	15	12	24	6	4	5

Table 1b. Estimation of relative heterosis (RH), heterobeltiosis (HB), and standard heterosis (SH) for yield and yield associated traits

S. No.	Hybrids	Panicle width (cm)			Panicle length of primary branches (cm)			Stem diameter (cm)			Days to maturity			Hundred seed weight (g)			Grain yield per plant (g)		
		RH	HB	SH	RH	HB	SH	RH	HB	SH	RH	HB	SH	RH	HB	SH	RH	HB	SH
1	EG 2XCSV 20	31.91 **	30.99 **	25.68 **	-4.76 *	-19.49 **	-15.18 **	17.71 **	-5.57 *	51.34 **	3.71*	-2.08	7.71**	-11.63 **	-27.74 **	-28.54 **	19.76 **	6.06	-11.55 **
2	EG 2XCSV 15	4.17	1.35	1.35	-16.28 **	-27.68 **	-27.68 **	-12.52 **	-28.97 **	13.84 **	-6.65**	-7.71**	-7.71**	-11.14 **	-27.65 **	-27.65 **	0.84	-17.15 **	-17.15 **
3	EG 2XCSV27	35.21 **	33.33 **	29.73 **	-21.88 **	-36.64 **	-25.89 **	3.8	2.79	64.73 **	1.80	-3.17	4.86**	-13.51 **	-27.2 **	-33.08 **	16.82 **	-0.47	-9.06 **
4	EG 35XCSV 20	-14.84 **	-21.43 **	-10.81	3.66	-16.1 **	-11.61 **	17.02 **	6.91	3.57	6.18**	-1.82	8.00**	4.45 *	-0.34	-1.44	23.58 **	3.5	-13.68 **
5	EG 35XCSV 15	22.78 **	15.48 **	31.08 **	-28.65 **	-41.07 **	-41.07 **	60.84 **	44.87 **	44.87 **	1.62	-1.71	-1.71	4.31 *	-1.01	-1.01	15.63 **	-9.64 **	-9.64 **
6	EG 35XCSV27	62.82 **	51.19 **	71.62 **	0.01	-22.14 **	-8.93 **	12.89 **	-14.77 **	33.93 **	6.23**	-1.06	7.14**	-3.35	-4.45 *	-12.17 **	23.56 **	-0.16	-8.78 **
7	EA 10XCSV 20	-2.82	-2.82	-6.76	-13.25 **	-13.56 **	-8.93 **	11.75 **	-11.75 **	47.54 **	9.63**	0.52	10.57**	-4.87 *	-19.24 **	-20.13 **	3.9	-3.7	-19.69 **
8	EA 10XCSV 15	10.34 *	8.11	8.11	-4.87 **	-6.96 **	-2.68	17.13 **	-6.41 **	56.47 **	-9.09**	12.86**	-12.86**	17.28 **	-0.88	-0.88	24.99 **	6.99 *	6.99 *
9	EA 10XCSV27	-25.87 **	-26.39 **	-28.38 **	-46 **	-48.85 **	-40.18 **	1.17	-1.87	64.06 **	-3.43*	-10.82**	-3.43	19.86 **	4.93 *	-3.54	12.88 **	0.41	-8.26 **
10	EG 1XCSV 20	-1.96	-8.54	1.35	-8.72 **	-24.58 **	-20.54 **	19.58 **	-4.17	54.02 **	-2.11	-3.64*	6.00**	9.84 **	6.15 **	4.98 *	28.31 **	28.2 **	7.1 *
11	EG 1XCSV 15	32.05 **	25.61 **	39.19 **	40.74 **	18.75 **	18.75 **	29.97 **	5.42 *	69.42 **	0.69	-2.41	4.00*	11.51 **	7.19 **	7.19 **	46.46 **	34.41 **	34.41 **
12	EG 1XCSV27	2.6	-3.66	6.76	-0.96	-21.37 **	-8.04 **	-7.3 **	-8.33 **	47.32 **	-1.06	-1.85	6.29**	1.74	1.56	-6.31 **	33.16 **	27.46 **	16.45 **
13	E 158XCSV 20	-17.24 **	-18.92 **	-18.92 **	-1.52	-10.96 **	16.07 **	13.72 **	-6.53 *	40.62 **	4.98**	-9.61**	-0.57	1.32	-18.68 **	-19.58 **	-9.33 **	-25.16 **	-37.59 **
14	E 158XCSV 15	-1.35	-1.35	-1.35	8.53 **	-4.11 **	25 **	4.1	-13.35 **	30.36 **	2.23	-8.29**	-8.29**	5.61 **	-15.6 **	-15.6 **	-22.83 **	-40.47 **	-40.47 **
15	E 158XCSV27	-9.59	-10.81	-10.81	-7.58 **	-12.33 **	14.29 **	6.68 **	4.4	64.06 **	14.46*	-0.79	7.43**	1.75	-16 **	-22.79 **	-11.04 **	-29.1 **	-35.22 **
16	SEA 14XCSV 20	18.84 **	15.49 *	10.81	-12.77 **	-30.51 **	-26.79 **	-1.03	-10.59 **	7.37	-2.14	-5.19**	4.29*	2.1	0.78	-0.33	10.78 **	9.03 **	-9.06 **
17	SEA 14XCSV 15	53.19 **	45.95 **	45.95 **	-27.47 **	-41.07 **	-41.07 **	52.13 **	39.41 **	67.41 **	5.77**	4.16*	7.43**	7.27 **	5.31 **	5.31 **	21.18 **	9.53 **	9.53 **
18	SEA 14XCSV27	15.11 **	11.11	8.11	-25.37 **	-42.75 **	-33.04 **	-8.21 **	-19.03 **	27.23 **	3.51*	1.06	9.43**	-10.93 **	-12.97 **	-16.15 **	7.4 *	1.17	-7.56 **
19	EG 54XCSV 20	7.45	-13.68 **	36.49 **	-14.66 **	-16.1 **	-11.61 **	10.66 **	-4.52	27.46 **	5.39**	1.56	11.71**	6.59 **	4.92 *	3.76	4.21	-0.38	-8.89 **
20	EG 54XCSV 15	17.28 **	-4.27	51.35 **	-3.54 *	-4.39 *	-2.68	48.76 **	30.1 **	73.66 **	6.08**	5.04**	7.14**	10.51 **	8.19 **	8.19 **	45.36 **	39.15 **	39.15 **
21	EG 54XCSV27	-22.75 **	-37.61 **	-1.35	-25.71 **	-30.53 **	-18.75 **	16.13 **	7.39 **	68.75 **	4.08**	1.06	9.43**	3.01	0.92	-3.32	-10.37 **	-10.42 **	-18.07 **
22	GGUB 61XCSV 20	-48.15 **	-50.7 **	-52.7 **	-26.09 **	-42.37 **	-39.29 **	11.71 **	8.21 *	11.83 **	-3.96*	-8.57**	0.57	14.4 **	-2.24	-3.32	-9.59 **	-22.19 **	-35.1 **
23	GGUB 61XCSV 15	-4.35	-10.81	-10.81	-29.21 **	-43.75 **	-43.75 **	41.6 **	39.31 **	43.97 **	2.58	2.29	2.29	27.96 **	8.85 **	8.85 **	-19.03 **	-35.16 **	-35.16 **
24	GGUB 61XCSV27	-11.76 *	-16.67 **	-18.92 **	-27.92 **	-45.8 **	-36.61 **	-19.79 **	-33.52 **	4.46	3.16*	-1.06	7.14**	15.49 **	1.81	-6.42 **	-17.55 **	-31.63 **	-37.53 **
25	ERN 26XCSV 20	5.8	2.82	-1.35	10.34 **	-18.64 **	-14.29 **	5.02	1.73	5.13	4.60**	-5.45**	4.00*	-8.58 **	-14.21 **	-15.15 **	26.47 **	25.1 **	4.33
26	ERN 26XCSV 15	43.26 **	36.49 **	36.49 **	40.48 **	5.36 **	5.36 **	49.51 **	47.08 **	52.01 **	-2.27	-7.71**	-7.71**	-2.13	-8.63 **	-8.63 **	58.79 **	44.17 **	44.17 **
27	ERN 26XCSV27	-2.16	-5.56	-8.11	8.02 **	-22.9 **	-9.82 **	15.68 **	-4.12	50.67 **	6.09**	-3.43*	4.57*	-4.4 *	-7.1 **	-14.6 **	27.99 **	21.14 **	10.68 **
	Min	-48.15	-50.7	-52.7	-46	-48.85	-43.75	-19.79	-33.52	3.57	-9.09	-10.82	-12.86	-13.51	-27.74	-33.08	-22.83	-40.47	-40.47
	Max	62.82	51.19	71.62	40.74	18.75	25	60.84	47.08	73.66	14.46	12.86	11.71	27.96	8.85	8.85	58.79	44.17	44.17
	No. of significant crosses	10	8	9	5	2	5	18	8	23	4	10	4	13	7	5	14	10	6

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The heterosis observed for grain yield is a consequence of simultaneous heterosis in multiple yield components Khadi *et al*. (2018) and More *et al*. (2016). Heterosis for grain yield and its contributing traits *viz*., panicle length, panicle width, panicle length of primary branches, and 100 seed weight was also observed by Premalatha *et al*. (2006); Boratkar *et al*., (2015); More *et al.* (2016) and Totre *et al.,* (2020).

The negative heterosis for days to 50 percent flowering and days to maturity is of interest to the breeder as it indicates earliness. Heterosis for days to 50 percent flowering was significant in 12 and 18 crosses over mid-parent and better-parent, respectively. The magnitude of heterosis varied from -21.17 (EG 54XCSV 15) to 5.77 percent (EG 1XCSV 20) over mid-parent, and from -22.81 (EG 54XCSV 15) to 4.35 percent (SEA 14XCSV 15) over the better parent. Regarding standard heterosis, 14 crosses showed negative significant heterosis. The heterosis ranged from -19.44 (EG 54XCSV 15) to 9.13 (EG 1XCSV 20) percent. This indicates that there is a possibility for breeding sorghum for earliness. Negative heterosis for days to 50 percent flowering was also reported by Umakanth *et al.* (2006) and Tiwari *et al*. (2019).

For days to maturity, four crosses recorded significant negative heterosis over mid-parent, indicating the standard heterosis. The highest negative heterosis over mid-parent was recorded by cross EA 10XCSV27 (-3.43). Ten crosses recorded negative heterosis over better parent, which indicates the presence of heterobeltiosis in hybrids. The highest significant negative heterosis over better parent was recorded by cross ERN 26XCSV27 (-3.43). The highest economic heterosis was recorded by cross ERN 26XCSV 15 (-7.71) and E 158XCSV 15 (-8.29). These results are in conformity with Tiwari *et al*. (2019). Desirable heterosis for plant height, number of leaves, leaf length, leaf width, and stem diameter were also found to be cumulative effects contributing towards their high yield potential.

For plant height, out of 12 hybrids, all the crosses showed significant positive heterosis over mid-parent and 6 crosses over the better parent. The percent heterosis for plant height ranged from -34.9 (ERN 26XCSV 15) to 62 percent (EG 2XCSV 20) over mid-parent, and from -46.33 (ERN 26XCSV 15) to 55.02 percent (EG 2XCSV 20) over better parent in the desired direction. The value of standard heterosis ranged from -46.33 (ERN 26XCSV 15) to 63.73 (EG 2XCSV27) percent. Thirteen crosses showed negative standard heterosis. Positive heterosis for plant height was also reported by Ambhika*et al.* (2021).

Among the 27 hybrids, the heterosis was observed from -27.88 (E 158XCSV27) to 38.81 percent (ERN 26XCSV 15) for the number of leaves; from -29.72 (SEA 14XCSV27) to 22.75 percent (EG 35XCSV 15) for leaf length; from -44.3 percent (E 158XCSV 20) to 44.3 percent (E 158XCSV 15) for leaf width; and from -33.52 percent (GGUB 61XCSV27) to 47.08 percent (ERN 26XCSV 15) for stem diameter. The crosses ERN 26XCSV 15, EG 35XCSV 15, E 158XCSV 15, and ERN 26XCSV 15 showed high heterosis over mid-parent and better parent for the number of leaves, leaf length, leaf width, and stem diameter.

The high productivity of hybrids is the result of hybrid vigor or heterosis. Among the 27 hybrids, the top two crosses, *viz*., EG 54XCSV 15 and ERN 26XCSV 15, exhibited all three types of heterosis for grain yield and its contributing traits. Hence, these crosses could be commercially exploited to boost grain yield after thorough testing in different environments. These hybrids were exploited to obtain better transgressive segregants for different traits. Top of Form

Conclusion

In conclusion, the results from the heterosis studies suggest that there was observed expression of relative heterosis, heterobeltosis, and standard heterosis in various crosses for a majority of the traits, both in desirable and negative directions. The manifestation of heterosis for the end product, specifically yield, is observed as the cumulative impact of heterosis for each component trait. The comprehensive examination of the above crossings has revealed a significant observation: a majority of the crosses that had a favourable and statistically significant heterosis effect on yield also displayed the same effect on a majority of the component traits. The current investigation on heterosis has provided clear evidence that the heterotic response for yield and its components was observed exclusively in specific cross combinations, highlighting the prominent influence of non-fixable interallelic interactions. These crosses exhibit an opportunity for further evaluation and commercial use of heterosis and can be readily utilized through traditional breeding methods in the future.

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