Heterosis studies on grain yield and yield attributing traits in Rice (*Oryza sativa* L.)

ABSTRACT:

The research programme was carried out at Agricultural Polytechnic, Polasa, Jagtial during *Kharif*, 2021 and *Rabi*, 2021-22. Eight lines and three testers were employed to generate ~~Twenty~~ twenty four experimental hybrids using line x tester mating design and the resultant hybrids were evaluated in Randomized Block Design.

Key words: Paddy, lines, testers, hybrids, heterosis, heterobeltiosis, standard heterosis

INTRODUCTION:

Rice (*Oryza sativa* L.) is the staple food in majority of the population in the world. India ranks first in the area and second in production. Rice and rice products contribute more towards national economy of the country and accounting for nearly 22% of the world's rice production (Bandumula, 2018)(1).

Rice is cultivated around 167.20 Mha in the world with a production of around 769.60 Mt and with a productivity of 4600 kg ha^{-1} (FAO, 2019)(2). In India, rice is cultivated an area of 45.07 Mha with a production of 122.27 Mt and a productivity of 2713 kg ha^{-1}. In Telangana, it is cultivated in an area of 2.31 Mha with production and productivity levels of 7.70 Mt and 3327 kg ha^{-1} respectively (Directorate of Economics and Statistics, 2021)(3).

MATERIAL AND METHODS

The experimental material consisted of eight lines *viz.,* CMS 23A, CMS 46A, CMS 59A, JMS 11A, JMS 13A, JMS 17A, JMS 18A and CMS 64A and three testers *viz*., JGL 33124, KNM 7787 and RNR 21278 and the resultant 24 experimental hybrids.

Line x Tester mating design was employed (Kempthorne, 1957)(4) to generate 24 hybrids which were evaluated along with their parents and three checks including two varietal checks *viz.,* JGL 18047 (short duration variety) and JGL 24423 (long bold grain type) and one hybrid check *viz.,* 27 P 31 (medium duration) to assess heterosis in the resultant hybrids.

RESULTS AND DISCUSSION

Heterosis is the most important genetic tool for increasing crop yield. Identification of a specific parental combination with greater levels of heterotic effects in F_1 is desirable for commercial heterosis. Heterosis aids in enhancement of production by 30 to 40% for improvement of domesticated crops for various characteristics.

In the present study, heterosis over the mid parent (relative heterosis/average heterosis), over the better parent (heterobeltiosis), and over the standard check (standard heterosis) were estimated in 24 hybrids for nine characters to identify the best parental combinations for getting high degree of useful heterosis and also to characterize parents for the use in future breeding programmes. The performance of hybrids for each character is presented in Table 1, 2 and 3.

Days to 50% flowering

A negative heterotic effect is preferable for earliness. Early maturing hybrids are preferred because they provide higher yields per day and can be used in a variety of cropping strategies. Mid-parent heterosis ranged from -9.70% ~~per cent~~ (JMS 17A x KNM 7787) to 4.11 per cent (JMS 18A x RNR 21278) and 15 hybrids exhibited significantly negative heterosis.

The Better parent heterosis ranged from -15.32 per cent (CMS 59A x KNM 7787) to 2.70 per cent (JMS 18A x RNR 21278). Altogether 21 hybrids exhibited a highly significant negative heterotic effect for this trait.

Standard heterosis over three checks was also estimated and the maximum negative standard heterosis recorded was -6.31 per cent (over JGL 18047), -11.11 per cent (over 27 P 31) and -9.57 per cent (over JGL 24423) in the cross, CMS 64A x RNR 21278. The maximum positive heterosis exploited was 8.11 per cent (over JGL 18047), 2.56 per cent (over 27 P 31) and 4.35 per cent (over JGL 24423) in the crosses, CMS 23A x KNM 7787, CMS 46A x KNM 7787 and JMS 11A x KNM 7787. Significant negative heterosis was observed in 15 hybrids over JGL 18047, 19 hybrids over 27 P 31 and 18 hybrids over JGL 24423.

Table 1. Estimates of heterosis over mid parent for yield and yield attributing traits in the rice hybrids

S.No.	CROSSES	Days to 50% flowering	Plant height (cm)	Panicle length (cm)	No. of productivetillers per plant	No. of filled grains per panicle	No. of unfilled grains per panicle	Spikelet fertility (%)	1000 grain-weight	Grain yieldper plant (g)
1	CMS 23A x RNR 21278	1.23 **	-1.59	-4.02 **	13.33 **	-38.70 **	206.48 **	-31.39 **	-8.31 **	-40.25 **
2	CMS 23A x JGL 33124	1.62 **	1.53	-2.77 **	26.32 **	-17.12 **	201.10 **	-32.49 **	-8.12 **	-24.29 **
3	CMS 23A x KNM 7787	2.86 **	7.86 **	2.78 **	17.78 **	-8.96 **	-8.64	-0.15	26.57 **	39.63 **
4	CMS 46A x RNR 21278	-3.20 **	2.84 **	-1.71	1.18	-64.44 **	219.36 **	-52.80 **	-28.67 **	-68.33 **
5	CMS 46A x JGL 33124	2.63 **	-3.97 **	-8.75 **	17.78 **	-30.65 **	-40.85 **	3.21	25.45 **	30.22 **
6	CMS 46A x KNM 7787	2.13 **	10.06 **	3.49 **	41.1**	6.62 **	-32.04 **	7.21 **	30.57 **	66.30 **
7	CMS 59A x RNR 21278	0.00	-8.91 **	-3.81 **	-13.04 **	-19.96 **	215.13 **	-22.48 **	-24.03 **	-39.86 **
8	CMS 59A x JGL 33124	-4.93 **	-13.43 **	-16.23 **	-9.28 **	-55.69 **	65.34 **	-32.29 **	-35.04 **	-59.86 **
9	CMS 59A x KNM 7787	-8.70 **	-5.45 **	-4.28 **	-2.17	-75.37 **	458.61 **	-75.38 **	-22.82 **	-70.37 **
10	JMS 11A x RNR 21278	-1.80 **	-3.38 **	16.99 **	-1.18	-32.67 **	103.66 **	-21.89 **	12.80 **	-23.06 **
11	JMS 11A x JGL 33124	-9.09 **	-9.85 **	-18.16 **	-22.22 **	-22.06 **	140.45 **	-28.74 **	1.65	-41.94 **

12	JMS 11A x KNM 7787	0.84 *	10.43 **	9.50 **	24.71 **	-21.13 **	84.40 **	-18.17 **	4.71	28.42 **
13	JMS 13A x RNR 21278	-2.73 **	-5.42 **	8.05 **	-1.15	-39.81 **	45.97 **	-17.88 **	-16.49 **	-47.05 **
14	JMS 13A x JGL 33124	-8.30 **	-6.89 **	-10.34 **	-2.17	-96.99 **	186.22 **	-94.86 **	-19.14 **	-94.81 **
15	JMS 13A x KNM 7787	-0.85 *	7.50 **	12.78 **	3.45	-17.49 **	-7.46	-1.66	20.47 **	1.09
16	JMS 17A x RNR 21278	-0.45	-3.61 **	12.24 **	12.94 **	-60.46 **	285.34 **	-54.41 **	24.29 **	-27.82 **
17	JMS 17A x JGL 33124	-6.96 **	-10.01 **	-4.28 **	-7.78 *	-39.34 **	24.46 **	-16.39 **	8.80 **	-32.63 **
18	JMS 17A x KNM 7787	-9.70 **	-8.07 **	1.77	-12.94 **	-60.02 **	45.91 **	-30.20 **	16.47 **	-63.53 **
19	JMS 18A x RNR 21278	4.11 **	-0.48	16.70 **	2.17	-10.89 **	80.19 **	-12.50 **	38.87 **	-5.83 **
20	JMS 18A x JGL 33124	-7.31 **	-10.66 **	-0.61	-7.22 *	-71.61 **	114.34 **	-54.44 **	23.28 **	-56.69 **
21	JMS 18A x KNM 7787	-6.38 **	-0.63	3.0**	-17.39 **	-66.65 **	88.88 **	-43.37 **	-5.78	-66.28 **
22	CMS 64A x RNR 21278	-6.31 **	-3.39 **	-2.74 **	-28.26 **	-53.46 **	377.93 **	-58.42 **	-24.62 **	-64.96 **
23	CMS 64A x JGL 33124	-1.30 **	-3.89 **	-2.02 *	-1.03	-94.89 **	225.49 **	-92.69 **	-26.73 **	-84.46 **
24	CMS 64A x KNM 7787	-5.88 **	5.23 **	11.16 **	-19.57 **	-41.94 **	120.78 **	-33.01 **	-8.30 **	-33.68 **

*Significant at 5 per cent level **Significant at 1 per cent level

Negative heterosis is preferred for days to 50% flowering because it allows hybrids to mature earlier than their parents. These results are in consistent with those reported by Shukla *et al*. (2020)$^{(5)}$ and Meena *et al.* (2021)$^{(6)}$ for exploiting heterosis for earliness.

Plant height (cm)

The mid-parent heterosis for plant height ranged from -13.43 per cent (CMS 59A x JGL 33124) to 10.43 (JMS 11A x KNM 7787) and a total of 14 hybrids exhibited significantly negative heterosis while 6 hybrids exhibited significantly positive heterosis.

Better parent heterosis ranged from -14.81 per cent (CMS 59A x JGL 33124) to 5.65 per cent in the cross, JMS 11A x KNM 7787 and 17 hybrids showed significantly negative heterosis, while five hybrids exhibited significantly positive better parent heterosis.

The lowest standard heterosis recorded was -14.39 per cent (over JGL 18047), -25.09 per cent (over 27 P 31) and -14.03 per cent (over JGL 24423) in the cross, JMS 17A x KNM 7787. The highest standard heterosis recorded was 3.20 per cent (over JGL 18047), -9.70 per cent (over 27 P 31) and 3.64 per cent (over JGL 24423) in the cross, CMS 46A x KNM 7787. Significant negative heterosis was observed in 17 hybrids over JGL 18047, 24 hybrids over 27 P 31 and 16 hybrids over JGL 24423, while three hybrids over JGL 18047 and four hybrids over JGL 24423 recorded significantly positive heterosis. Similar results were reported by Shukla *et al*. (2020)$^{(5)}$ and Vennela *et al.* (2022)$^{(7)}$.

Panicle length (cm)

In general hybrids contain large size panicles, which clearly indicate that they are more efficient in partitioning the assimilates for the developing reproductive parts. Panicle length is one of the important traits that contributes for higher yields in hybrids and hence positive heterotic effect is highly desirable for the trait. The values for mid- parent heterosis ranged from -18.16 per cent (JMS 11A x JGL 33124) to 16.99 per cent

(JMS 11A x RNR 21278). Altogether ten hybrids recorded significantly positive mid- parent heterosis.

Better parent heterosis ranged from -18.32 per cent (JMS 11A x JGL 33124) to 10.83 per cent (JMS 13A x KNM 7787) while only five hybrids exhibited significantly positive better parent heterosis.

The lowest standard heterosis exploited was -12.35 per cent (over JGL 18047), -15.48 per cent (over 27 P 31) and -16.14 per cent (over JGL 24423) in the cross, CMS 64A x RNR 21278. Whereas, the highest standard heterosis exploited was 11.93 percent (over JGL 18047), 7.94 per cent (over 27 P 31) and 7.09 per cent (over JGL 24423) in the cross, JMS 11A x RNR 21278. Significantly positive heterosis was recorded in six hybrids over JGL 18047 and in two hybrids each over 27 P 31 and JGL 24423.

The spikelets attached to the primary and secondary branches would increase proportionally with the increase in panicle length, making a hybrid with a longer panicle and the results are consistent with the earlier findings of Shukla *et al*. (2020)(5).

Number of productive tillers per plant

The number of productive tillers per plant contribute significantly towards grain yield. Hence, positive heterosis for the trait is highly desirable. The mid-parent heterosis for the trait varied from -28.26 per cent (CMS 64A x RNR 21278) to 41.18 per cent (CMS 46A x KNM 7787) and a total of seven crosses exhibited significantly positive mid parent heterosis.

The better parent heterosis ranged from -36.54 per cent (CMS 64A x RNR 21278) to 33.33 per cent (CMS 46A x KNM 7787). The results indicated that four crosses exhibited significantly positive heterosis.

The lowest standard heterosis exploited was -36.54 per cent (over JGL 18047), 34.00 per cent (over 27 P 31) and -40.00 per cent (over JGL 24423) in the cross CMS 64A x RNR 21278 and the highest standard heterosis exploited was 15.38 per cent(over JGL 18047), 20.00 per cent (over 27 P 31) and 9.09 per cent (over JGL 24423) in the crosses, CMS 23A x JGL 33124 and CMS 46A x KNM 7787 respectively. These two crosses also recorded significantly positive heterosis over the three checks. The results are accordance with the findings of Thakor *et al.* (2018)(8).

Table 2. Estimates of heterosis over better parent for yield and yield attributing traits in the rice hybrids

S.No.	CROSSES	Days to 50% flowering	Plant height (cm)	Panicle length (cm)	No. of productive tillers per plant	No. of filled grains per panicle	No. of unfilled grains per panicle	Spikelet fertility (%)	1000 grain-weight (g)	Grain yield per plant (g)
1	CMS 23A x RNR 21278	0.61	-3.75 **	-11.89 **	2.00	-54.13 **	175.61 **	-33.39 **	-29.60 **	-50.85 **
2	CMS 23A x JGL 33124	-1.71 **	-4.17 **	-6.11 **	20.00 **	-42.20 **	96.38 **	-33.93 **	-27.08 **	-38.05 **
3	CMS 23A x KNM 7787	-3.23 **	3.70 **	-1.64	6.00	-35.84 **	-36.42 **	-0.54	0.78	13.54 **
4	CMS 46A x RNR 21278	-4.50 **	2.78 **	-12.88 **	-4.44	-70.74 **	167.96 **	-55.51 **	-45.05 **	-72.82 **
5	CMS 46A x JGL 33124	0.00	-7.36 **	-9.09 **	17.78 **	-47.54 **	-53.80 **	2.28	-0.09	11.13 **
6	CMS 46A x KNM 7787	-3.23 **	3.53 **	-4.55 **	33.33 **	-18.31 **	-41.43 **	4.39 *	4.34 *	40.98 **
7	CMS 59A x RNR 21278	-0.93 *	-10.78 **	-15.30 **	-23.08 **	-38.04 **	139.96 **	-22.62 **	-41.81 **	-47.27 **
8	CMS 59A x JGL 33124	-9.40 **	-14.81 **	-17.16 **	-15.38 **	-68.19 **	-0.85	-35.72 **	-48.58 **	-65.02 **
9	CMS 59A x KNM 7787	-15.32 **	-12.73 **	-12.31 **	-13.46 **	-82.11 **	250.98 **	-76.22 **	-38.71 **	-74.35 **
10	JMS 11A x RNR 21278	-4.39 **	-5.03 **	4.21 **	-6.67	-47.50 **	72.72 **	-27.21 **	2.80	-25.50 **

11	JMS 11A x JGL 33124	-10.26 **	-14.51 **	-18.32 **	-22.22 **	-43.71 **	86.07 **	-30.24 **	-3.33	-43.40 **
12	JMS 11A x KNM 7787	-3.23 **	5.65 **	1.53	17.78 **	-42.37 **	57.20 **	-21.26 **	0.00	26.16 **
13	JMS 13A x RNR 21278	-4.46 **	-6.64 **	1.73	-8.51 *	-44.06 **	8.75	-22.86 **	-26.83 **	-55.11 **
14	JMS 13A x JGL 33124	-10.26 **	-11.33 **	-15.65 **	-4.26	-97.47 **	154.44 **	-94.93 **	-26.22 **	-95.62 **
15	JMS 13A x KNM 7787	-5.65 **	2.42 *	10.82 **	-4.26	-29.52 **	-7.52	-4.60 *	10.37 **	-15.33 **
16	JMS 17A x RNR 21278	-2.65 **	-4.18 **	6.11 **	6.67	-64.72 **	216.60 **	-56.46 **	23.99 **	-31.12 **
17	JMS 17A x JGL 33124	-8.55 **	-13.72 **	-10.31 **	-7.78 *	-50.75 **	-0.88	-16.77 **	3.77	-36.13 **
18	JMS 17A x KNM 7787	-13.71 **	-13.00 **	0.44	-17.78 **	-67.07 **	28.62 **	-31.12 **	10.62 **	-65.68 **
19	JMS 18A x RNR 21278	2.70 **	-0.53	9.44 **	-9.62 **	-12.65 **	39.16 **	-16.19 **	38.20 **	-21.20 **
20	JMS 18A x JGL 33124	-9.69 **	-13.82 **	-6.11 **	-13.46 **	-74.97 **	82.19 **	-54.79 **	18.40 **	-63.96 **
21	JMS 18A x KNM 7787	-11.29 **	-6.52 **	0.86	-26.92 **	-70.12 **	79.53 **	-43.94 **	-9.89 **	-72.12 **
22	CMS 64A x RNR 21278	-8.77 **	-5.35 **	-8.97 **	-36.54 **	-64.46 **	292.00 **	-61.85 **	-38.46 **	-68.75 **
23	CMS 64A x JGL 33124	-2.56 **	-9.15 **	-7.25 **	-7.69 *	-96.37 **	159.64 **	-92.96 **	-37.95 **	-86.23 **
24	CMS 64A x KNM 7787	-9.68 **	1.00	8.55 **	-28.85 **	-58.34 **	94.98 **	-36.57 **	-22.05 **	-41.61 **

*Significant at 5 per cent level **Significant at 1 per cent level

Table 3. Estimates of heterosis over checks for yield and yield attributing traits in rice hybrids

S.No.	CROSSES	Days to 50% flowering			Plant height			Panicle length		
		Checks	Checks	Checks	Checks	Checks	Checks	Checks	Checks	Checks
		JGL 18047	27 P 31	JGL 24423	JGL 18047	27 P 31	JGL 18047	JGL 18047	27 P 31	JGL 18047
1	CMS 23A x RNR 21278	-0.90 *	-5.98 **	-4.35 **	-4.16 **	-16.14 **	-3.75 **	-11.52 **	-14.68 **	-15.35 **
2	CMS 23A x JGL 33124	3.60 **	-1.71 **	0.00	2.77 **	-10.07 **	3.21 **	1.23	-2.38 *	-3.15 **
3	CMS 23A x KNM 7787	8.11 **	2.56 **	4.35 **	-1.28	-13.62 **	-0.86	-1.23	-4.76 **	-5.51 **
4	CMS 46A x RNR 21278	-4.50 **	-9.40 **	-7.83 **	2.45 **	-10.35 **	2.89 **	-5.35 **	-8.73 **	-9.45 **
5	CMS 46A x JGL 33124	5.41 **	0.00	1.74 **	-0.64	-13.06 **	-0.21	-1.23	-4.76 **	-5.51 **
6	CMS 46A x KNM 7787	8.11 **	2.56 **	4.35 **	3.20 **	-9.70 **	3.64 **	3.70 **	0.00	-0.79
7	CMS 59A x RNR 21278	-3.60 **	-8.55 **	-6.96 **	-7.36 **	-18.94 **	-6.96 **	-6.58 **	-9.92 **	-10.63 **
8	CMS 59A x JGL 33124	-4.50 **	-9.40 **	-7.83 **	-8.64 **	-20.06 **	-8.24 **	-8.64 **	-11.90 **	-12.60 **
9	CMS 59A x KNM 7787	-5.41 **	-10.26**	-8.70 **	-9.38 **	-20.71 **	-8.99 **	-3.29 **	-6.75 **	-7.48 **
10	JMS 11A x RNR 21278	-1.80 **	-6.84 **	-5.22 **	-5.44 **	-17.26 **	-5.03 **	11.93 **	7.94 **	7.09 **

11	JMS 11A x JGL 33124	-5.41 **	-10.26**	-8.70 **	-8.32 **	-19.78 **	-7.92 **	-11.93 **	-15.08 **	-15.75 **
12	JMS 11A x KNM 7787	8.11 **	2.56 **	4.35 **	1.60	-11.10 **	2.03 *	9.05 **	5.16 **	4.33 **
13	JMS 13A x RNR 21278	-3.60 **	-8.55**	-6.96 **	-7.04 **	-18.66 **	-6.64 **	-3.29 **	-6.75 **	-7.48 **
14	JMS 13A x JGL 33124	-5.41 **	-10.2**	-8.70 **	-4.90 **	-16.79 **	-4.50 **	-9.05 **	-12.30 **	-12.99 **
15	JMS 13A x KNM 7787	5.41 **	0.00	1.74 **	-0.64	-13.06 **	-0.21	5.35 **	1.59	0.79
16	JMS 17A x RNR 21278	-0.90 *	-5.98 **	-4.35 **	-4.58 **	-16.51**	-4.18 **	0.00	-3.57**	-4.33 **
17	JMS 17A x JGL 33124	-3.60 **	-8.55 **	-6.96 **	-7.46 **	-19.03 **	-7.07 **	-3.29 **	-6.75**	-7.48 **
18	JMS 17A x KNM 7787	-3.60 **	-8.55 **	-6.96 **	-14.39 **	-25.09 **	-14.03 **	-5.35 **	-8.73**	-9.45 **
19	JMS 18A x RNR 21278	2.70 **	-2.56 **	-0.87 *	-0.85	-13.25 **	-0.43	4.94 **	1.19	0.39
20	JMS 18A x JGL 33124	-4.80 **	-9.69 **	-8.12 **	-7.57 **	-19.12 **	-7.17 **	1.23	-2.38 *	-3.15 **
21	JMS 18A x KNM 7787	-0.90 *	-5.98 **	-4.35 **	-6.82 **	-18.47 **	-6.42 **	-3.29 **	-6.75**	-7.48 **
22	CMS 64A x RNR 21278	-6.31 **	-11.11**	-9.57 **	-5.76 **	-17.54 **	-5.35 **	-12.35 **	-15.48**	-16.14 **
23	CMS 64A x JGL 33124	2.70 **	-2.56 **	-0.87 *	-2.56 **	-14.74 **	-2.14 *	0.00	-3.57 **	-4.33 **
24	CMS 64A x KNM 7787	0.90 *	-4.27 **	-2.61 **	-3.52 **	-15.58 **	-3.10 **	4.53 **	0.79	0.00

*Significant at 5 per cent level **Significant at 1 per cent level

Table 3. (cont.).

S.No.	CROSSES	No. of productive tillers per plant			No. of filled grains per panicle			No. of unfilled grains per panicle		
		Checks	Checks	Checks	Checks	Checks	Checks	Checks	Checks	Checks
		JGL 18047	27 P 31	JGL 24423	JGL 18047	27 P 31	JGL 18047	JGL 18047	27 P 31	JGL 18047
1	CMS 23A x RNR 21278	-1.92	2.00	-7.27 *	-15.66 **	-25.14 **	-35.39 **	753.33**	37.67 **	101.56**
2	CMS 23A x JGL 33124	15.38 **	20.00 **	9.09 **	33.70 **	18.68 **	2.42	1494.83**	157.30**	276.71**
3	CMS 23A x KNM 7787	1.92	6.00	-3.64	43.04 **	26.97 **	9.58 **	301.16**	-35.28 **	-5.24
4	CMS 46A x RNR 21278	-17.31 **	-14.00**	-21.82 **	-46.20 **	-52.25 **	-58.79 **	1123.44**	97.38 **	188.98**
5	CMS 46A x JGL 33124	1.92	6.00	-3.64	21.36 **	7.72 **	-7.03 **	275.20**	-39.47 **	-11.38
6	CMS 46A x KNM 7787	15.38 **	20.00 **	9.09 **	82.12 **	61.66 **	39.52 **	269.51**	-40.39 **	-12.72
7	CMS 59A x RNR 21278	-23.08 **	-20.00**	-27.27 **	13.92 **	1.12	-12.73 **	642.95**	19.86	75.49 **
8	CMS 59A x JGL 33124	-15.38 **	-12.00**	-20.00 **	-26.42 **	-34.69 **	-43.64 **	705.21**	29.91 **	90.20 **
9	CMS 59A x KNM 7787	-13.46 **	-10.00**	-18.18 **	-60.13 **	-64.61 **	-69.45 **	2114.42**	257.26**	423.06**
10	JMS 11A x RNR 21278	-19.23 **	-16.00**	-23.64 **	-3.48	-14.33 **	-26.06 **	668.23**	23.94 *	81.46 **
11	JMS 11A x JGL 33124	-32.69 **	-30.00**	-36.36 **	30.22 **	15.59 **	-0.24	1411.10**	143.79**	256.93**
12	JMS 11A x KNM 7787	1.92	6.00	-3.64	28.48 **	14.04 **	-1.58	891.83**	60.02 **	134.28**
13	JMS 13A x RNR 21278	-17.31 **	-14.00**	-21.82 **	2.85	-8.71 **	-21.21 **	587.06**	10.85	62.29 **
14	JMS 13A x JGL 33124	-13.46 **	-10.00**	-18.18 **	-94.15 **	-94.80 **	-95.52 **	1966.31**	233.37**	388.08**
15	JMS 13A x KNM 7787	-13.46 **	-10.00**	-18.18 **	57.12 **	39.47 **	20.36 **	484.25 **	-5.74	38.01 *

16	JMS 17A x RNR 21278	-7.69 *	-4.00	-12.73 **	-35.13 **	-42.42 **	-50.30 **	1424.00 **	145.87 **	259.98 **
17	JMS 17A x JGL 33124	-20.19 **	-17.00 **	-24.55 **	13.92 **	1.12	-12.73 **	704.93 **	29.86 **	90.13 **
18	JMS 17A x KNM 7787	-28.85 **	-26.0**	-32.73 **	-26.58 **	-34.83 **	-43.76 **	711.50 **	30.92 **	91.68 **
19	JMS 18A x RNR 21278	-9.62 **	-6.00	-14.55 **	60.60 **	42.56 **	23.03 **	691.11 **	27.63 **	86.86 **
20	JMS 18A x JGL 33124	-13.46 **	-10.00 **	-18.18 **	-42.09 **	-48.60 **	-55.64 **	1379.57 **	138.70 **	249.48 **
21	JMS 18A x KNM 7787	-26.92 **	-24.00 **	-30.91 **	-33.39 **	-40.87 **	-48.97 **	1032.69 **	82.74 **	167.55 **
22	CMS 64A x RNR 21278	-36.54 **	-34.00 **	-40.00 **	-34.65 **	-41.99 **	-49.94 **	1795.27 **	205.77 **	347.68 **
23	CMS 64A x JGL 33124	-7.69 *	-4.00	-12.73 **	-91.61 **	-92.56 **	-93.58 **	2008.53 **	240.18 **	398.05 **
24	CMS 64A x KNM 7787	-28.85 **	-26.00 **	-32.73 **	-7.12 *	-17.56 **	-28.85 **	1130.21 **	98.47 **	190.58 **

*Significant at 5 per cent level **Significant at 1 per cent level

Table 3. (cont.).

S.No.	CROSSES	Spikelet fertility			1000 grain-weight			Grain yield per plant		
		Checks	Checks	Checks	Checks	Checks	Checks	Checks	Checks	Checks
		JGL 18047	**27 P 31**	**JGL 24423**	**JGL 18047**	**27 P 31**	**JGL 18047**	**JGL 18047**	**27 P 31**	**JGL 18047**
1	CMS 23A x RNR 21278	-36.02 **	-18.25 **	-27.16 **	-32.70 **	-33.90 **	-34.44 **	-48.87 **	-52.06 **	-55.23 **
2	CMS 23A x JGL 33124	-40.23 **	-23.63 **	-31.95 **	-30.29 **	-31.54 **	-32.09 **	-35.56 **	-39.58 **	-43.57 **
3	CMS 23A x KNM 7787	-10.03 **	14.96 **	2.43	-3.65	-5.38 **	-6.14 **	18.10 **	10.73 **	3.42 **
4	CMS 46A x RNR 21278	-57.26 **	-45.40 **	-51.35 **	-47.97 **	-48.90 **	-49.31 **	-74.54 **	-76.13 **	-77.71 **
5	CMS 46A x JGL 33124	-11.42 **	13.18 **	0.85	-5.39 **	-7.09 **	-7.84 **	4.08 **	-2.41 *	-8.85 **
6	CMS 46A x KNM 7787	-6.30 **	19.72 **	6.67 **	-1.20	-2.97	-3.76	32.04 **	23.80 **	15.63 **
7	CMS 59A x RNR 21278	-25.41 **	-4.70 *	-15.08 **	-43.98 **	-44.99 **	-45.43 **	-53.03 **	-55.96 **	-58.87 **
8	CMS 59A x JGL 33124	-38.04 **	-20.84 **	-29.47 **	-50.50 **	-51.39 **	-51.78 **	-68.84 **	-70.78 **	-72.71 **
9	CMS 59A x KNM 7787	-77.08 **	-70.72 **	-73.91 **	-41.00 **	-42.05 **	-42.52 **	-77.15 **	-78.57 **	-79.99 **
10	JMS 11A x RNR 21278	-30.08 **	-10.66 **	-20.40 **	-36.02 **	-37.16 **	-37.67 **	-50.00 **	-53.12 **	-56.21 **
11	JMS 11A x JGL 33124	-39.58 **	-22.80 **	-31.21 **	-39.83 **	-40.91 **	-41.39 **	-62.54 **	-64.87 **	-67.19 **
12	JMS 11A x KNM 7787	-29.33 **	-9.70 **	-19.54 **	-37.76 **	-38.88 **	-39.37 **	-17.82 **	-22.94 **	-28.03 **
13	JMS 13A x RNR 21278	-25.90 **	-5.33 *	-15.64 **	-50.21 **	-51.10 **	-51.50 **	-56.69 **	-59.39 **	-62.07 **
14	JMS 13A x JGL 33124	-95.61 **	-94.39 **	-95.00 **	-49.79 **	-50.69 **	-51.09 **	-95.77 **	-96.04 **	-96.30 **

15	JMS 13A x KNM 7787	-14.37 **	9.41 **	-2.51	-24.90 **	-26.24 **	-26.84 **	-18.31 **	-23.41 **	-28.46 **
16	JMS 17A x RNR 21278	-58.18 **	-46.57 **	-52.39 **	-36.51 **	-37.65 **	-38.16 **	-49.12 **	-52.29 **	-55.44 **
17	JMS 17A x JGL 33124	-27.25 **	-7.04 **	-17.17 **	-41.74 **	-42.79 **	-43.25 **	-52.82 **	-55.76 **	-58.68 **
18	JMS 17A x KNM 7787	-38.17 **	-21.00**	-29.61 **	-37.34 **	-38.47 **	-38.97 **	-74.65 **	-76.23 **	-77.80 **
19	JMS 18A x RNR 21278	-19.50 **	2.86	-8.35 **	-28.55 **	-29.83 **	-30.40 **	-21.48 **	-26.38 **	-31.24 **
20	JMS 18A x JGL 33124	-60.24 **	-49.20**	-54.73 **	-33.53 **	-34.72 **	-35.25 **	-64.08 **	-66.33 **	-68.55 **
21	JMS 18A x KNM 7787	-49.69 **	-35.71**	-42.72 **	-48.96 **	-49.88 **	-50.28 **	-72.22 **	-73.95 **	-75.67 **
22	CMS 64A x RNR 21278	-63.35 **	-53.17**	-58.28 **	-50.21 **	-51.10 **	-51.50 **	-73.24 **	-74.91 **	-76.56 **
23	CMS 64A x JGL 33124	-93.90 **	-92.21 **	-93.06 **	-49.79 **	-50.69 **	-51.09 **	-88.20 **	-88.94 **	-89.67 **
24	CMS 64A x KNM 7787	-43.07 **	-27.25 **	-35.18 **	-36.93 **	-38.06 **	-38.56 **	-50.00 **	-53.12 **	-56.21 **

*Significant at 5 per cent level **Significant at 1 per cent level

Number of filled grains per panicle

Higher number of filled grains per panicle generally results in higher plant yields. Since the number of filled grains have direct impact on seed yield, heterotic effect in positive direction for the trait is desirable. The mid-parent heterosis ranged from -96.99 per cent (JMS 13A x JGL 33124) to 6.62 per cent (CMS 46A x KNM 7787) and only one cross exhibited significantly positive heterosis.

The better parent heterosis ranged from -97.47 per cent (JMS 13A x JGL 33124) to -12.65 per cent (JMS 18A x RNR 21278) and none of the crosses showed significantly positive heterosis.

The lowest standard heterosis exploited was -94.15 per cent (over JGL 18047), -94.80 (over 27 P 31) and -95.52 (over JGL 24423) in the cross, JMS 13A x JGL 33124. The highest standard heterosis exploited was 82.12 per cent (over JGL 18047), 61.66 per cent (over 27 P31) and 39.52 per cent (over JGL 24423) in the cross, CMS 46A x KNM 7787. A total of 10 hybrids (over JGL 18047), 8 hybrids (over 27 P 31) and 4 hybrids (over JGL 24423) exhibited significantly positive heterosis. The findings are in concurrence with the earlier reports of Throat *et al.* (2017)(9).

Number of unfilled grains per panicle

A significant negative heterotic effect is desirable for this trait. The mid-parent heterosis for number of unfilled grains per panicle ranged from -40.85 per cent (CMS 46A x JGL 33124) to 458.61 per cent (CMS 59A x KNM 7787) and only two crosses exhibited significantly negative heterosis.

Better parent heterosis ranged from -53.80 per cent (CMS 46A x JGL 33124) to 292.00 per cent (CMS 64A x RNR 21278) and three crosses have shown significant negative heterosis. The lowest standard heterosis exploited was 269.51 per cent (over JGL 18047), -40.39 per cent (over 27 P 31) and -12.72 (over JGL 24423) in the cross, CMS 46A x KNM 7787. The highest standard heterosis exploited was 2114.42 per cent (over JGL 18047), 257.26 per cent (over 27 P 31) and 423.06 per cent (over JGL 24423) in the cross CMS 59A x KNM 7787. None of the crosses exhibited significantly negative heterosis over the checks, JGL 18047 and JGL 24423 and three crosses exhibitedsignificantly negative heterosis over the other check, 27 P 31. Similar findings were also reported by Throat *et al.* (2017) (9) and Ramesh *et al*.(2018)(10).

Spikelet fertility (%)

A significantly positive heterotic effect is desirable for this trait. The mid-parent heterosis ranged from -94.86 per cent (JMS 13A x JGL 33124) to 7.21 per cent (CMS 46A x KNM 7787) and only one cross exhibited significantly positive heterosis.

Better parent heterosis ranged from -94.93 per cent (JMS 13A x JGL 33124) to 4.39 per cent (CMS 46A x KNM 7787) and only one cross exhibited significantly positive heterosis.

The lowest standard heterosis exploited was -95.61 per cent (over JGL 18047),-94.31 per cent (over 27 P 31) and -95.00 per cent (over JGL 24423) in the cross, JMS 13A x JGL 33124. The highest standard heterosis exploited was -6.30 per cent (over JGL 18047), 19.72 per cent (over 27 P 31) and 6.67 per cent (over JGL 24423) in the cross, CMS 46A x KNM 7787. Significantly positive heterosis was not recorded in any of the 24 crosses over JGL 18047; 4 crosses exhibited significant positive heterosis over 27 P 31 and only one cross exhibited significantly positive heterosis over JGL 24423.The findings are consistent with the earlier findings of Thorat *et al.* (2017)(9).

1000 grain weight (g)

The trait, 1000 grain weight is an important yield determinant to obtain the final yield because bold grained varieties perform well over other types and hence, positive heterotic effect for this trait is desirable. The mid-parent heterosis for 1000 grain weightranged from -35.04 per cent (CMS 59A x JGL 33124) to 38.87 per cent (JMS 18A x RNR 21278). Ten crosses exhibited significantly positive heterosis.

Better parent heterosis ranged from -48.58 per cent (CMS 59A x JGL 33124) to 38.20 per cent (JMS 18A x RNR 21278) and six crosses exhibited significantly positive heterosis.The lowest standard heterosis exploited was -50.50 per cent (over JGL 18047),-51.39 per cent (over 27 P 31) and -51.78 per cent (over JGL 24423) in the cross, CMS 59A x JGL 33124. The highest standard heterosis exploited was -1.20 per cent (over JGL 18047), -2.97 per cent (over 27 P 31) and -3.76 per cent (over JGL 24423) in the cross CMS 46A x KNM 7787. None of the crosses showed significantly positive heterosis over the three checks. These results are in agreement with the findings of Thorat *et al.* (2017)(9).

Grain yield per plant (g)

Mid-parent heterosis ranged from -94.81 per cent (JMS 13A x JGL 33124) to 66.30 per cent (CMS 46A x KNM 7787). Better parent heterosis varied from -95.62 per cent (JMS 13A x JGL 33124) to 40.98 per cent (CMS 46A x KNM 7787).

Four hybrids *i.e.,* CMS 46A x KNM 7787 (66.30), CMS23A x KNM 7787(39.63), CMS 46A x JGL 33124 (30.22) and JMS 11A x KNM 7787 (28.42) showed significantly positive heterosis over mid parent and four hybrids *viz.,* CMS46A x KNM7787(40.98), JMS 11A x KNM 7787 (26.16), CMS23A x KNM 7787 (13.54) and CMS 46A x JGL 33124 (11.13) exhibited significantly positive heterosis over the betterparent.

The lowest standard heterosis exploited was -95.77 per cent (over JGL 18047), -96.04 per cent (over 27 P 31) and -96.30 (over JGL 24423) in the cross, JMS 13A x JGL 33124. The highest standard heterosis exploited was 32.04 per cent (over JGL 18047), 23.80 (over 27 P 31) and 15.63 (over JGL 24423) in the cross CMS 46A x KNM 7787. Significantly positive heterosis was recorded in three crosses *viz.,* CMS 46A x KNM 7787 (32.04), CMS 23A x KNM 7787 (18.10) and CMS 46A x JGL 33124 (4.08) over the check, JGL 18047 while two crosses *viz.,* CMS 46A x KNM 7787 (23.80) and CMS 23A x KNM 7787 (10.73) exhibited significantly positive heterosis over the check, 27 P 31 and two crosses CMS 46A x KNM 7787 (15.63) and CMS 23A x KNM 7787 (3.42) showed significantly positive heterosis over check, JGL 24423.These results are in accordance with the earlier findings of Thakor *et al.* (2018)(9) and Gupta *et al*, (2024)(11).

CONCLUSION

In broad sense, presence of significant heterosis, heterobeltiosis and standard heterosis for grain yield per plant and other associated traits confirms the presence of greater genetic diversity among the lines, testers and crosses as well as the unidirectional distribution of allelic constitution contributing to desirable heterosis in the present material. Heterotic studies indicated that most of the traits exhibited heterotic effects in the desirable direction for yield and yield attributing traits for the material under study. Crosses with good heterotic expression in F_1 may be explored further in future generations to select superior transgressive segregrants. For each attribute, the standard heterosis, relative heterosis and heterobeltiosis for top crosses are provided in Table 4.

Table 4. Standard heterosis, heterobeltiosis and relative heterosis for top crosses for each trait in rice.

S. No.	Character/Cross	Standard heterosis			Heterobeltiosis	Relative heterosis
		OVER JGL 18047	OVER R27 P 31	OVER JGL 24423		
1.	**Days to 50 % flowering**					
1	CMS 64A x RNR 21278	-6.31**	-11.11**	-9.57**	-8.77**	-6.31**
2	CMS 59A x KNM 7787	-5.41**	-10.26**	-8.70**	-15.32**	-8.70**
3	JMS 11A x JGL 33124	-5.41**	-10.26**	-8.70**	-10.26**	-9.09**
4	JMS 13A x JGL 33124	-5.41**	-10.26**	-8.70**	-10.26**	-8.30**
5	JMS 18A x JGL 33124	-4.80**	-9.69**	-8.12**	-9.69**	-7.31**
2.	**Plant height**					
1	JMS 17A x KNM 7787	-14.39**	-25.09**	-14.03**	-13.00**	-8.07**
2	CMS 59A x KNM 7787	-9.38**	-20.71**	-8.99**	-12.73**	-5.45**
3	CMS 59A x JGL 33124	-8.64**	-20.06**	-8.24**	-14.81**	-13.43**
4	JMS 11A x JGL 33124	-8.32**	-19.78**	-7.92**	-14.51**	-9.85**
5	JMS 18A x JGL 33124	-7.57**	-19.12**	-7.17**	-13.82**	-10.66**
3.	**Panicle length**					
1	JMS 11A x RNR 21278	11.93**	7.94**	7.09**	4.21**	16.99**
2	JMS 11A x KNM 7787	9.05**	5.16**	4.33**	1.53	9.50**
3	JMS 13A x KNM 7787	5.35**	1.59	0.79	10.83**	12.78**
4	JMS 18A x RNR 21278	4.94**	1.19	0.39	9.44**	16.70**
5	CMS 64A x KNM 7787	4.53**	0.79	0.00	8.55**	11.16**
4.	**Number of productive tillers per plant**					
1	CMS 46A x KNM 7787	15.38**	20.00**	9.09**	33.33**	41.12**
2	CMS 23A x JGL 33124	15.38**	20.00**	9.09**	20.00**	26.32**
3	CMS 23A x KNM 7787	1.92	6.00	-3.64	6.00	17.78**
4	CMS 46A x JGL 33124	1.92	6.00	-3.64	17.78**	17.78**
5	JMS 11A x KNM 7787	1.92	6.00	-3.64	17.78**	24.71**
5.	**Number of filled grains per panicle**					
1	CMS 46A x KNM 7787	82.12**	61.66**	39.52**	-18.31**	6.62**
2	JMS 18A x RNR 21278	60.60**	42.56**	23.03**	-12.65**	-10.89**
3	JMS 13A x KNM 7787	57.12**	39.47**	20.36**	-29.52**	-17.49**
4	CMS 23A x KNM 7787	43.04**	29.67**	9.58**	-35.84**	-8.96**
5	CMS 23A x JGL 33124	33.70**	18.68**	2.42	-42.20**	-17.12**
6.	**Number of unfilled grains per panicle**					
1	CMS 46A x KNM 7787	269.51**	-40.39**	-12.72	-41.43**	-32.04**
2	CMS 46A x JGL 33124	275.20**	-39.47**	-11.38	-53.80**	-40.85**
3	CMS 23A x KNM 7787	301.16**	-35.28**	-5.24	-36.42**	-8.64
4	JMS 13A x KNM 7787	484.25**	-5.74	38.01*	-7.52	-7.46
5	JMS 13A x RNR 21278	587.06**	10.85	62.29**	8.75**	45.97**

7.	**Spikelet fertility (%)**					
1	CMS 46A x KNM 7787	-6.30**	19.72**	6.67**	4.39*	7.21**
2	CMS 23A x KNM 7787	-10.03**	14.96**	2.43	-0.54	-0.15
3	CMS 46A x JGL 33124	-11.42**	13.18**	0.85	2.28	3.21
4	JMS 13A x KNM 7787	-14.37**	9.41**	-2.51	-4.60*	-1.66
5	JMS 18A x RNR 21278	-19.50**	2.86	-8.35**	-16.19**	-12.50**
8.	**1000 grain weight**					
1	CMS 46A x KNM 7787	-1.20	-2.97	-3.76	4.34*	30.57**
2	CMS 23A x KNM 7787	-3.65	-5.38**	-6.14**	0.78	26.57**
3	CMS 46A x JGL 33124	-5.39**	-7.09**	-7.84**	-0.09	25.45**
4	JMS 13A x KNM 7787	-24.90**	-26.24**	-26.84**	-10.37**	20.47**
5	JMS 18A x RNR 21278	-28.55**	-29.83**	-30.40**	-38.20**	38.87**
9.	**Grain yield per plant**					
1	CMS 46A x KNM 7787	32.04**	23.80**	15.63**	40.98**	66.30**
2	CMS 23A x KNM 7787	18.10**	10.73**	3.42**	13.54**	39.63**
3	CMS 46A x JGL 33124	4.08**	-2.41*	-8.85**	11.13**	30.22**
4	JMS 11A x KNM 7787	-17.82**	-22.94**	-28.03**	26.16**	28.42**
5	JMS 13A x KNM 7787	-18.31**	-23.41**	-28.46**	-15.33**	1.09

*Significant at 5 per cent level **Significant at 1 per cent level

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