Plant Archives Vol. 25, No. 1, 2025 pp. 1978-1986 e-ISSN:2581-6063 (online), ISSN:0972-5210

Plant Archives

Journal homepage: http://www.plantarchives.org

DOI Url : https://doi.org/10.51470/PLANTARCHIVES.2025.v25.no.1.286

IDENTIFICATION OF HETEROTIC CROSS COMBINATIONS FOR GRAIN YIELD AND HEAD RICE RECOVERY IN RICE (*ORYZA SATIVA* L.) HYBRIDS

M. Maneesha[1*], V. Gouri Shankar[1], B. Srinivas[2] and Y. Hari[3]

[1]Agricultural College, Polasa, Jagtial - 505 529, PJTAU, Telangana, India.
[2]Regional Agricultural Research Station, Polasa, Jagtial - 505 529, PJTAU, Telangana, India.
[3]Regional Agricultural Research Station, Warangal - 506 007, PJTAU, Telangana, India.
*Corresponding author E-mail : maneeshamuppani0861@gmail.com

(Date of Receiving-12-01-2025; Date of Acceptance-13-03-2025)

ABSTRACT

This study aimed to assess the extent of heterotic effects over mid, better and standard parent for grain yield, head rice recovery and various other quantitative and qualitative traits. Analysis of variance indicated significant difference among the genotypes for various traits. Estimates of relative heterosis, heterobeltiosis and standard heterosis were calculated. CMS 64A × SN 2397, CMS 64A × BV 166, RMS 2A × BV 166, CMS 52A × SN 223 and CMS 64A × SN 232 recorded high standard heterosis over two checks for grain yield. For the trait, head rice recovery JMS 18A × SN 2397, CMS 52A × SN 223, JMS 18A × SN 232 and RMS 2A × SN 2397 these hybrids recorded high standard heterosis. The hybrid CMS 52A × SN 223 is heterotic hybrid for both grain yield and head rice recovery. This hybrid could be exploited commercially after critical evaluation for its superiority and stability across the locations over years.

Key words : Relative heterosis, Heterobeltiosis, Grain yield, Head rice recovery, Rice (*Oryza sativa* L.).

Introduction

For more than half of the world's population, rice is the main diet source. It contributes significantly to dietary energy, supplying about 43% of the caloric intake and accounts for 20-25% of agricultural income. Globally rice is cultivated in around 165 million hectares with a production of 508.9 million tonnes. In India, rice is cultivated in 478.32 lakh hectares with production of 1357.55 lakh tonnes and productivity of 2838 kg/ha. (INDIASTAT, 2022-23). The utilization of heterosis has been a remarkable advancement in plant breeding, with hybrid rice technology representing a practical approach to enhance future rice yields. Hybrids can produce 15-20% more than the top improved or high-yielding varieties (Yuan, 1994). The phenomenon of heterosis in rice was first documented by Jones in 1926, who noted that certain F_1 hybrids exhibited more culms and higher yields than their parental lines. In India with limited resources like land, water, labour and other inputs, rice productivity needs to be increased without disturbing the environment. Hybrid rice technology is the pragmatic approach to increase rice production of 15 to 20 per cent than the pure line varieties by exploiting hybrid vigour.

Evaluating the nature and extent of heterosis for various characteristics is essential for identifying promising hybrid combinations, which can be utilized to create breeding materials for isolating transgressive segregants aimed at producing high-yielding pure line varieties/hybrids.

Materials and Methods

Heterosis studies were conducted on twenty-four rice hybrids developed by crossing four diverse Wild Abortive (WA) CMS lines *i.e.*, CMS 64A, CMS 52A, JMS 18A and RMS 2A with six elite testers with proven high head rice recovery *i.e.*, SN 233, SN 232, SN 223, SN 2397, SN 1326 and BV 166 in a L × T mating design during *kharif* 2023. Ten parental lines, 24 hybrids and two control checks Shabnam and KPH 473 were evaluated using a randomized block design replicated twice with a spacing of 20 × 15 cm at the Regional Agricultural Research Station (RARS), Polasa, Jagtial, during the *rabi* 2023-24. Data was collected for various traits, including days to 50 % flowering, plant height (cm), panicle length (cm), number of productive tillers per plant, grains per panicle, 1000 grain weight (g), grain yield per plant (g), hulling percentage, milling percentage, head rice recovery percentage, kernel length (mm), kernel breadth (mm) and kernel L/B ratio. The collected data was analyzed for heterosis, heterobeltiosis and standard heterosis.

Results and Discussion

Significant variances among the genotypes for each trait under investigation were found using analysis of variance. This suggests that the material being studied had wider range of variability for the genotypes.

Higher grain yield is the main objective for almost all the breeding programm. Heterosis for seed yield in positive direction is desirable. In the current study, out of 24 hybrids, significant and positive heterosis had shown by 17 hybrids over mid parent, 15 hybrids over better parent, nine hybrids over Shabnam and five hybrids over KPH 473. Relative heterosis ranged from 12.02% (JMS 18A × BV 166) to 69.68 % (CMS 64A × SN 2397 and CMS 64A × BV 166) over mid parent, heterobeltiosis ranged from -10.22% (JMS 18A × SN 223) to 68.92% (CMS 64A × BV 166). Whereas the cross CMS 64A × SN 2397 had the highest standard heterosis exploited was 41.97% over Shabnam and 25.69% over KPH 473. Among the 24 hybrids examined five hybrids namely, CMS 64A × SN 2397, CMS 64A × BV 166, RMS 2A × BV 166, CMS 52A × SN 223 and CMS 64A × SN 232 recorded high and significant heterosis for all three types of heterosis. These outcomes are similar with the findings of Salah *et al*. (2020), Meena *et al*. (2021), Devi *et al*. (2022), Mohan *et al*. (2022) and Deepika *et al*. (2023).

Top five hybrids with significant positive standard heterosis over Shabnam and KPH 473 with good *per se* performance were CMS 64A × SN 2397 (41.97%, 25.69%, 38.90g), CMS 64A × BV 166 (36.86%, 21.16%, 37.50g), RMS 2A × BV 166 (33.21%, 17.93%, 36.50g), CMS 52A × SN 223 (31.02%, 15.99%, 35.90g) and CMS 64A × SN 232 (28.47%, 13.73%, 35.20g) as shown in Table 2.

Head rice recovery is most important trait which needs a specific attention in the case of hybrids for this study. The relative heterosis for head rice recovery varied from -66.12% (CMS 52A × SN 1326) to 29.61% (CMS 52A × SN 223). Out of 24 hybrids, two hybrids CMS 52A × SN 223 (29.61%) and JMS 18A × SN 2397 (9.25%) showed significant positive heterosis over mid parent. Heterobeltiosis for this trait varied from -71.30% (CMS 52A × SN 1326) to 11.54% (CMS 52A × SN 223). Among the 24 hybrids, one cross CMS 52A × SN 223 (11.54) exhibited significant positive heterosis over better parent. These outcomes are aligned with the conclusions of Singh *et al*. (2019), Begum *et al*. (2020), Devi *et al*. (2022) and Ramakrishna *et al*. (2023).

Present study revealed, eight hybrids with significant positive heterosis over the check Shabnam for the trait head rice recovery and most of them recorded good mean values. The hybrids with significant positive heterosis over Shabnam and good head rice recovery identified were JMS 18A × SN 2397 (67.57%, 62.00%), CMS 52A × SN 223 (56.76%, 58.00 %), JMS 18A × SN 232 (48.65%, 55.00 %), RMS 2A × SN 2397 (48.65%, 55.00 %), CMS 64A × SN 2397 (47.30%, 54.50 %), CMS 64A × SN 223 (40.54%, 52.00 %), CMS 64A × BV 166 (39.19%, 51.50%), CMS 52A × SN 232 (24.32%, 46.00 %).

Thirteen hybrids exhibited significant positive heterosis for head rice recovery over KPH 473. Most of these recorded good mean values for this trait. The hybrids namely, JMS 18A × SN 2397 (117.54%, 62.00%), CMS 52A × SN 223 (103.51%, 58.00 %), JMS 18A × SN 232 (92.98%, 55.00 %), RMS 2A × SN 2397 (92.98%, 55.00 %), CMS 64A × SN 2397 (91.23%, 54.50%), CMS 64A × SN 223 (82.46%, 52.00%), CMS 64A × BV 166 (80.70%, 51.50 %), CMS 52A × SN 232 (61.40%, 46.00%) and RMS 2A × SN 223 (42.11%, 40.50 %) showed significant positive heterosis along with good head rice recovery over KPH 473. Therefore, these hybrids could be evaluated further during *rabi* situation to identify most stable heterotic hybrids to give high head rice in *rabi* season.

The hybrid CMS 52A × SN 223 is heterotic hybrid for both grain yield and head rice recovery.

Negative heterosis is preferable for days to 50% flowering to develop hybrids with early duration. For this trait 19 hybrids each over mid parent and Shabnam, 20 hybrids each over better parent and KPH 473 showed significant negative heterosis in desirable direction. Similar results have also been observed (Kushal *et al*., 2023; and Ramakrishna *et al*., 2023) suggesting the potential for exploiting heterosis for earliness.

For plant height, negative value of heterosis is desirable. Among 24 hybrids, seven hybrids over mid parent, 10 hybrids over the better parent, 19 crosses over Shabnam and 15 crosses over KPH an *et al*. (2022) and Deepika *et al*. (2023) emphasized the importance of significant 473 were significantly better and the range was -14.09% (JMS 18A × SN 1326) to 18.56% (CMS 52A × SN 223) for mid parental heterosis, -15.68% (CMS

52A × SN 2397) to 5.11% (CMS 64A × SN 232) for heterobeltiosis. The highest standard heterosis exploited was -6.26% (over Shabnam) in the cross CMS 52A × SN 233 and -3.90% (over KPH 473) in the cross CMS 64A × SN 2397. Manivel negative heterosis for plant height to develop dwarf plant types.

Panicle length is the important component of grain yield as it bears the sink in rice. More is the length of the panicle it likely to give more no. of grains per panicle, resulting in higher productivity. For the character panicle length, relative heterosis ranged from -8.09% (JMS 18A × SN 233) to 15.35% (CMS 52A × SN 1326). Among the 24 hybrids, nine showed significant positive heterosis over mid parent. Better parent heterosis varied from -9.34% (JMS 18A × SN 233 and JMS 18A × SN 223) to 12.10% (CMS 52A × SN 1326). Out of 24 hybrids, three had significantly positive heterosis over the better parent. None of the crosses exhibited significant positive standard heterosis over Shabnam and over KPH 473.

Panicle length is a key attribute associated with higher yields, as supported by the findings of Devi *et al.* (2022) and Mohamed *et al.* (2022).

Number of productive tillers per plant is known to directly contribute towards grain yield. In case of productive tillers per plant relative heterosis ranged from -22.34% (CMS 64A × BV 166) to 10.86% (CMS 64A × SN 2397), heterobeltiosis ranged from -22.94% (RMS 2A × SN 232) to -10.39% (JMS 18A × SN 232). The hybrid, CMS 64A × SN 2397 showed significant heterosis for relative heterosis and over the check KPH 473 and the hybrids, CMS 52A × BV 166, CMS 64A × SN 223 and CMS 52A × SN 233 showed highly significant standard heterosis indicating that these hybrids will have potential to give high production and productivity due to recording higher effective tillers. The results align with the findings of Devi *et al.* (2022), Deepika *et al.* (2023) and Kushal *et al.* (2023).

Number of filled grains per panicle is very important trait, which has direct effect on yield, out of 24 hybrids the estimates of relative heterosis, heterobeltiosis and standard heterosis were significant and positive, eight hybrids showed over mid parent, five hybrids over better parent, four hybrids over Shabnam and one hybrid over KPH 473. The relative heterosis for this trait ranged from -30.49% (CMS 52A × BV 166) to 111.97% (CMS 52A × SN 223), heterobeltiosis from -41.14% (CMS 52A × BV 166) to 86.83% (CMS 52A × SN 223). The cross RMS 2A × BV 166 had the highest standard heterosis exploited was 42.22% (over Shabnam) and 25.98% (over KPH 473). Similar kind of heterotic pattern was noted by Thakor *et al.* (2018), Sari *et al.* (2019), Kushal *et al.* (2023) and Ramakrishna *et al.* (2023).

For 1000 grain weight heterosis in positive direction is desirable. Magnitude of heterosis showed significant positive heterosis, 12 hybrids showed over mid parent and three hybrids over better parent. None of the crosses over KPH 473 and over Shabnam revealed significant positive standard heterosis. These results align with Singh *et al.* (2020), Azad *et al.* (2022) and Kushal *et al.* (2023).

Kernel length is one of the determining factors in fixing market price and rice with more grain/kernel length fetches more price. Among 24 hybrids, significant and positive heterosis exhibited by ten hybrids over mid parent, five hybrids over better parent and four hybrids over Shabnam, while none of the crosses over KPH 473 exhibited significant positive standard. Relative heterosis ranged from -14.55% (CMS 52A × SN 223) to 22.55% (CMS 64A × SN 2397), heterobeltiosis ranged from -20.53% (CMS 52A × SN 2397) to 17.31% (CMS 64A × SN 2397). Similar findings were reported by Babu *et al.* (2020), Meena *et al.* (2021), Devi *et al.* (2022) and Kushal *et al.* (2023).

For kernel breadth, relative heterosis ranged from -13.75% (RMS 2A × SN 223) to 12.71% (CMS 64A × SN 2397) and better parental values ranged from -21.81% (RMS 2A × SN 223) to 11.95% (CMS 64A × SN 2397). Out of 24 hybrids, 17 hybrids over mid parent and 2 hybrids over better parent exhibited significant and positive heterosis. None of the crosses showed significant positive standard heterosis over Shabnam and over KPH 473. Meena *et al.* (2021), Devi *et al.* (2022) and Kushal *et al.* (2023) reported similar results for this trait.

Kernal length/breadth ratio before cooking is one of the important physical traits determining the quality of the grain. A higher value of kernel length/breadth ratio before cooking is desirable as the slender grain having length/breadth ratio of 3.0 and above will fetch high premium price in the market and present study revealed both positive and negative values depending upon the cross combinations. Out of 24 hybrids, significant and positive heterosis displayed by four hybrids each over mid parent and better parent, twelve hybrids over Shabnam and nine hybrids over KPH 473. The highest standard heterosis recorded was 21.11% (over Shabnam) and 16.40% (over KPH 473) in the cross CMS 64A × SN 223. The hybrids, RMS 2A × SN 223, RMS 2A × SN 2397 and CMS 64A × SN 223 recorded significant positive heterosis for three types of heterosis *i.e.,* average heterosis, heterobeltiosis and standard heterosis in which RMS 2A × SN 223 exhibited highly significant heterosis. Similar findings have

Table 1 : Estimates of heterosis over mid parent, better parent and standard checks for grain yield, yield contributing and quality traits in rice.

S. no.	Crosses	Days to 50 % flowering				Plant height			
		H	HB	SH		H	HB	SH	
				Check 1	Check 2			Check 1	Check 2
				Shabnam	KPH 473			Shabnam	KPH 473
1	CMS 52A × SN 233	-4.46**	-8.53**	-12.27**	-11.87**	15.21**	2.20	-6.26**	-2.11
2	CMS 52A × SN 232	-6.67**	-10.85**	-14.09**	-13.70**	8.58**	-4.63*	-10.51**	-6.54**
3	CMS 52A × SN 223	-4.93**	-9.39**	-12.27**	-11.87**	18.56**	3.85*	-1.92	2.43
4	CMS 52A × SN 2397	-11.57**	-20.08**	-13.18**	-12.79**	-6.53**	-15.68**	-25.56 **	-22.26**
5	CMS 52A × SN 1326	-9.63**	-13.68**	-16.82**	-16.44**	8.77**	-1.72	-13.54**	-9.70**
6	CMS 52A × BV 166	-9.05**	-11.71**	-17.73**	-17.35**	0.86	-11.62**	-16.62 **	-12.92**
7	CMS 64A × SN 233	-2.84**	-2.84**	-6.82**	-6.39**	9.16**	1.76	-6.67**	-2.53
8	CMS 64A × SN 232	-4.49**	-4.72**	-8.18**	-7.76**	13.94**	5.11**	-1.36	3.01
9	CMS 64A × SN 223	-8.02**	-12.13**	-11.36**	-10.96**	-4.77**	-12.41**	-17.27**	-13.61**
10	CMS 64A × SN 2397	-6.67	-12.68**	-4.55**	-4.11**	9.83**	4.23*	-7.98**	-3.90*
11	CMS 64A × SN 1326	-4.96**	-5.19**	-8.64**	-8.22**	5.68**	0.46	-11.62**	-7.70**
12	CMS 64A × BV 166	3.85**	5.37**	-1.82	-1.37	5.06**	-3.32	-8.79**	-4.75*
13	JMS 18A × SN 233	-9.18**	-10.90	-14.55**	-14.16**	-4.88**	-7.71**	-15.35**	-11.60**
14	JMS 18A × SN 232	-9.88**	-11.79	-15.00**	-14.61**	-7.68**	-11.41**	-16.87**	-13.19**
15	JMS 18A × SN 223	-10.58**	-12.68**	-15.45**	-15.07**	0.17	-4.17*	-9.49**	-5.49**
16	JMS 18A × SN 2397	-6.33**	-13.39**	-5.91	-5.48**	-8.22**	-9.27**	-19.90**	-16.35**
17	JMS 18A × SN 1326	-13.73**	-15.57**	-18.64**	-18.26**	-14.09**	-14.93**	-25.15**	-21.84**
18	JMS 18A × BV 166	-12.25**	-12.68**	-18.64**	-18.26**	-8.05**	-11.99**	-16.97**	-13.29**
19	RMS 2A × SN 233	-1.13	-5.22**	-0.91	-0.46	-1.84	-3.31	-8.59**	-4.54*
20	RMS 2A × SN 232	-3.17**	-6.96**	-2.73*	-2.28*	2.84	2.46	-3.13	1.16
21	RMS 2A × SN 223	-1.13	-4.78**	-0.45	0.00	4.01*	3.95*	-1.72	2.64
22	RMS 2A × SN 2397	0.64	-1.26	7.27**	7.76**	1.55	-1.82	-7.17**	-3.06
23	RMS 2A × SN 1326	-6.33**	-10.00**	-5.91**	-5.48**	1.27	-2.24	-7.58**	-3.48
24	RMS 2A × BV 166	-5.29**	-10.43**	-6.36**	-5.94 **	2.67	2.56	-3.03	1.27

S. no.	Crosses	Panicle length				Number of productive tillers per plant			
		H	HB	SH		H	HB	SH	
				Check 1	Check 2			Check 1	Check 2
				Shabnam	KPH 473			Shabnam	KPH 473
1	CMS 52A × SN 233	7.44*	4.00	-4.06	-1.52	1.35	-4.26	-1.32	11.94*
2	CMS 52A × SN 232	10.50**	8.68*	-2.95	-0.38	5.19	3.72	-2.19	10.95
3	CMS 52A × SN 223	10.21**	9.75*	-4.43	-1.89	3.92	1.44	-7.02	5.47
4	CMS 52A × SN 2397	-6.28	-8.20*	-17.34**	-15.15**	2.33	-0.45	-3.51	9.45
5	CMS 52A × SN 1326	15.35**	12.10**	2.58	5.30	-3.64	-8.23	-7.02	5.47
6	CMS 52A × BV 166	-2.36	-2.15	-15.87**	-13.64**	6.36	1.30	2.63	16.42**
7	CMS 64A × SN 233	5.35	4.31	-1.85**	0.76	-17.42**	-18.30**	-15.79**	-4.48
8	CMS 64A × SN 232	7.04*	4.31	-1.85	0.76	-5.62	-8.70	-7.89	4.48
9	CMS 64A × SN 223	7.13*	3.14	-2.95	-0.38	8.62	1.30	2.19	15.92**
10	CMS 64A × SN 2397	9.42**	7.06	0.74	3.41	10.86*	8.70	9.65	24.38**
11	CMS 64A × SN 1326	4.17	2.75	-3.32	-0.76	-18.00**	-18.18**	-17.11**	-5.97
12	CMS 64A × BV 166	7.38*	2.75	-3.32	-0.76	-22.34**	-22.51**	-21.49**	-10.95

Table 1 continued...

Table 1 continued...

13	JMS 18A × SN 233	-8.09*	-9.34 *	-14.02**	-11.74**	-7.19	-13.42 *	-12.28*	-0.50
14	JMS 18A × SN 232	-6.21	-8.95*	-13.65**	-11.36**	0.73	-10.39*	-9.21	2.99
15	JMS 18A × SN 223	-5.48	-9.34*	-14.02**	-11.74**	9.87	-6.06	-4.82	7.96
16	JMS 18A × SN 2397	-2.99	-5.45	-10.33**	-7.95*	5.04	-5.19	-3.95	8.96
17	JMS 18A × SN 1326	-7.72*	-9.34*	-14.02**	-11.74**	3.98	-3.90	-2.63	10.45
18	JMS 18A × BV 166	2.86	-1.95	-7.01*	-4.55	-8.20	-15.15**	-14.04**	-2.49
19	RMS 2A × SN 233	-4.62	-8.15*	-8.49*	-6.06	-9.60*	-16.45**	-15.35**	-3.98
20	RMS 2A × SN 232	4.3	-1.11	-1.48	1.14	-12.53*	-22.94**	-21.93**	-11.44
21	RMS 2A × SN 223	3.16	-3.33	-3.69	-1.14	5.37	-10.82*	-9.65	2.49
22	RMS 2A × SN 2397	2.72	-2.22	-2.58	0.00	-3.63	-13.85**	-12.72*	-1.00
23	RMS 2A × SN 1326	0.39	-3.70	-4.06	-1.52	-8.27	-16.02**	-14.91**	-3.48
24	RMS 2A × BV 166	9.34**	1.85	1.48	4.17	-3.55	-11.69*	-10.53*	1.49

S. no.	Crosses	Number of filled grains per panicle				1000 grain weight			
		H	HB	SH		H	HB	SH	
				Check 1	Check 2			Check 1	Check 2
				Shabnam	KPH 473			Shabnam	KPH 473
1	CMS 52A × SN 233	70.94**	54.52**	-3.51**	-14.53	-6.79*	-11.03**	-24.11**	-29.60**
2	CMS 52A × SN 232	104.30**	72.12**	26.76*	12.28	-23.04**	-24.21**	-35.35**	-40.02**
3	CMS 52A × SN 223	111.97**	86.83**	23.56**	9.45	-14.06**	-20.42**	-32.12**	-37.02**
4	CMS 52A × SN 2397	-18.53	-37.56**	-40.89**	-47.64**	1.48	-23.12**	-34.43**	-39.16**
5	CMS 52A × SN 1326	27.12	23.26	-37.82**	-44.92**	1.31	-2.40	-16.75**	-22.77**
6	CMS 52A × BV 166	-30.49*	-41.14**	-57.20**	-62.09**	-0.31	-14.34**	-26.94**	-32.21**
7	CMS 64A × SN 233	39.40*	31.32	-18.00	-27.36**	13.58**	12.45**	-12.82**	-19.12**
8	CMS 64A × SN 232	17.28	2.60	-24.44*	-33.07**	9.82**	5.35	-12.86**	-19.15**
9	CMS 64A × SN 223	57.07**	44.09**	-4.71	-15.59	7.48*	5.15	-20.11**	-25.88**
10	CMS 64A × SN 2397	18.74	-6.01	-11.02	-21.18*	26.45**	-0.22	-24.19**	-29.66**
11	CMS 64A × SN 1326	9.79	2.01	-43.69**	-50.12**	12.74**	10.55**	-12.62**	-18.93**
12	CMS 64A × BV 166	86.24**	6.81**	19.11	5.51	-20.70	-28.36**	-45.57**	-49.50**
13	JMS 18A × SN 233	-11.11	-28.76**	-26.22*	-34.65**	6.09	-17.35**	-35.92**	-40.55**
14	JMS 18A × SN 232	-3.19	-17.17	-14.22	-24.02*	8.93*	-17.04**	-31.38**	-36.34**
15	JMS 18A × SN 223	-5.08	-22.23*	-19.47	-28.66**	2.64	-18.13**	-40.50**	-44.80**
16	JMS 18A × SN 2397	-28.34**	-31.42**	-28.98**	-37.09**	20.52**	19.61**	-47.45**	-51.25**
17	JMS 18A × SN 1326	-12.54	-36.27**	-34.00**	-41.54**	16.01**	-10.25**	-29.06**	-34.18**
18	JMS 18A × BV 166	2.27	-12.96	-9.87	-20.16*	26.63**	8.01	-33.80*	-38.58**
19	RMS 2A × SN 233	4.10	-23.86**	2.71	-9.02	1.34	-17.16**	-35.77**	-40.41**
20	RMS 2A × SN 232	4.09	-19.54*	8.53	-3.86	4.40	-16.73**	-31.13**	-36.10**
21	RMS 2A × SN 223	18.73*	-11.53	19.33	5.71	0.83	-15.44*	-38.54**	-42.98**
22	RMS 2A × SN 2397	6.83	9.09	22.62*	8.62	12.30*	6.26	-47.69**	-51.47**
23	RMS 2A × SN 1326	5.63	-28.63**	-3.73	-14.72	11.94**	-9.17*	-28.21**	-33.40**
24	RMS 2A × BV 166	37.02**	5.44	42.22**	25.98**	10.45*	-0.42	-38.97**	-43.38**

S. no.	Crosses	Grain yield per plant				Kernel length			
		H	HB	SH		H	HB	SH	
				Check 1	Check 2			Check 1	Check 2
				Shabnam	KPH 473			Shabnam	KPH 473
1	CMS 52A × SN 233	15.74**	4.62	-0.73	-12.12**	0.23	-3.68**	2.27*	-3.61**
2	CMS 52A × SN 232	25.37**	13.51**	7.30	-5.01	-0.11	-4.05**	1.88*	-3.98**

Table 1 continued...

Table 1 continued...

3	CMS 52A × SN 223	48.35**	41.18**	31.02**	15.99**	-14.55**	-18.32**	-13.28**	-18.26**
4	CMS 52A × SN 2397	-2.24	-7.63	-20.44**	-29.56**	-9.40**	-20.53**	-15.63**	-20.47**
5	CMS 52A × SN 1326	44.78**	31.02**	13.87**	0.81	-5.30**	-10.01**	-4.45**	-9.94**
6	CMS 52A × BV 166	4.42	2.05	-18.07**	-27.46**	-5.70**	-17.14**	-12.03**	-17.08**
7	CMS 64A × SN 233	32.78**	23.08**	16.79**	3.39	8.85**	3.11**	0.94	-4.86**
8	CMS 64A × SN 232	46.36**	35.91**	28.47**	13.73**	6.87**	1.28	-0.94	-6.63**
9	CMS 64A × SN 223	18.55**	7.30	7.30	-5.01**	12.80**	7.43**	3.98**	-1.99*
10	CMS 64A × SN 2397	69.68**	64.83**	41.97**	25.69**	22.55**	17.31**	2.73**	-3.17**
11	CMS 64A × SN 1326	26.86**	26.58**	2.55	-9.21**	6.01**	1.55	-2.89**	-8.47**
12	CMS 64A × BV 166	69.68**	68.92**	36.86**	21.16**	-9.49**	-13.20**	-23.98**	-28.35**
13	JMS 18A × SN 233	17.26**	8.46**	2.92	-8.89*	-1.56	-11.89**	-13.75**	-18.70
14	JMS 18A × SN 232	19.17**	10.42*	4.38	-7.59*	-0.54	-10.94*	-12.89**	-17.89**
15	JMS 18A × SN 223	-0.61	-10.22*	-10.22*	-20.52**	1.84*	-8.39**	-11.33**	-16.42**
16	JMS 18A × SN 2397	-7.22	-10.17*	-22.63**	-31.50**	2.53*	0.78	-19.30**	-23.93**
17	JMS 18A × SN 1326	32.58**	32.58**	6.93	-5.33	4.16**	-5.80**	-9.92*	-15.10**
18	JMS 18A × BV 166	12.02*	11.76*	-9.85*	-20.19**	5.10**	3.11**	-17.11**	-21.87**
19	RMS 2A × SN 233	-0.20	-4.62	-9.49*	-19.87**	-4.25**	-15.48**	-17.27**	-22.02**
20	RMS 2A × SN 232	33.87**	28.19**	21.17**	7.27	-2.67**	-14.06**	-15.94**	-20.77**
21	RMS 2A × SN 223	-0.98	-7.66	-7.66	-18.26**	-1.91	-12.99**	-15.78**	-20.62**
22	RMS 2A × SN 2397	0.63	0.42	-13.14**	-23.10**	17.94**	14.15**	-8.59**	-13.84**
23	RMS 2A × SN 1326	32.75**	28.27**	10.95*	-1.78	-2.52**	-13.07**	-16.88**	-21.65**
24	RMS 2A × BV 166	59.74**	54.01**	33.21**	17.93**	0.60	-2.82*	-21.88**	-26.36**

S. no.	Crosses	Kernel breadth				Kernel L/B ratio			
		H	HB	SH		H	HB	SH	
				Check 1	Check 2			Check 1	Check 2
				Shabnam	KPH 473			Shabnam	KPH 473
1	CMS 52A × SN 233	5.79**	0.28	-7.05**	-8.95**	-5.83**	-14.04**	10.03**	5.76**
2	CMS 52A × SN 232	3.29*	-1.43	-9.92**	-11.76**	-3.69*	-11.58**	13.17**	8.78**
3	CMS 52A × SN 223	4.62**	-0.57	-8.36**	-10.23**	-18.82**	-26.08**	-5.39**	-9.06**
4	CMS 52A × SN 2397	7.04**	2.83	-14.62**	-16.37**	-15.06**	-22.81**	-1.20**	-5.04*
5	CMS 52A × SN 1326	-1.98	-10.82**	-9.66**	-11.51**	-4.85**	-17.31**	5.84**	1.73
6	CMS 52A × BV 166	3.78*	0.00	-10.44**	-12.28**	-9.83**	-23.27**	-1.80	-5.61**
7	CMS 64A × SN 233	8.70**	-1.41	-8.62**	-10.49**	-0.40	-4.90*	10.48**	6.19**
8	CMS 64A × SN 232	9.55**	0.00	-8.62**	-10.49**	-2.75	-6.57**	8.53**	4.32*
9	CMS 64A × SN 223	2.49	-6.80**	-14.10**	-15.86**	9.47**	4.25*	21.11**	16.40**
10	CMS 64A × SN 2397	12.71**	11.95**	-14.36**	-16.11**	8.75**	3.35	20.06**	15.40**
11	CMS 64A × SN 1326	4.58**	-8.76**	-7.57**	-9.46**	-0.07	-9.41**	5.24**	1.15
12	CMS 64A × BV 166	2.22	-5.83**	-15.67**	-17.39**	-12.35**	-22.29**	-9.73	-13.24**
13	JMS 18A × SN 233	8.74**	-3.66**	-10.70**	-12.53**	-9.59**	-10.65**	-3.29	-7.05**
14	JMS 18A × SN 232	0.96	-10.00**	-17.75**	-19.44**	-1.53	-2.07	5.99**	1.87
15	JMS 18A × SN 223	7.81**	-4.25**	-11.75**	-13.55**	-5.68**	-7.05**	0.60	-3.31
16	JMS 18A × SN 2397	0.88	-2.39	-25.33**	-26.85**	1.83	0.14**	8.38**	4.17*
17	JMS 18A × SN 1326	0.91	-13.92**	-12.79**	-14.58**	1.92	-4.56**	3.29	-0.72
18	JMS 18A × BV 166	4.70**	-5.83**	-15.67**	-17.39**	-0.68	-9.13**	-1.65	-5.47*
19	RMS 2A × SN 233	11.21**	0.56	-6.79**	-8.70**	-13.75**	-16.01**	-11.23**	-14.68**

Table 1 continued...

Table 1 continued...

20	RMS 2A × SN 232	10.52**	0.57	-8.09**	-9.97**	-11.56**	-14.41**	-8.38**	-11.94**
21	RMS 2A × SN 223	-13.75**	-21.81**	-27.94**	-29.41**	14.08**	11.40**	17.07**	12.52**
22	RMS 2A × SN 2397	3.45*	2.39	-21.67**	-23.27**	14.04**	11.59**	16.77**	12.23**
23	RMS 2A × SN 1326	9.33**	-4.90**	-3.66*	-5.63**	-11.23**	-13.75**	-13.62**	-16.98**
24	RMS 2A × BV 166	12.70**	3.50*	-7.31**	-9.21**	-11.11**	-15.70**	-15.57**	-18.85**

S. no.	Crosses	Hulling				Milling			
		H	HB	SH		H	HB	SH	
				Check 1	Check 2			Check 1	Check 2
				Shabnam	KPH 473			Shabnam	KPH 473
1	CMS 52A × SN 233	-0.32	-0.63	-1.26	-1.26	-1.50	-2.96	-4.38	0.00
2	CMS 52A × SN 232	1.90	1.26	1.26	1.26	6.72**	4.38	4.38	9.16**
3	CMS 52A × SN 223	0.66	-2.55	-3.77	-3.77	6.20**	4.58	0.00	4.58
4	CMS 52A × SN 2397	4.89*	2.55	1.26	1.26	2.96	0.00	1.46	6.11*
5	CMS 52A × SN 1326	-0.63	-1.86	-0.63	-0.63	-1.44	-6.80**	0.00	4.58
6	CMS 52A × BV 166	0.63	0.00	0.00	0.00	5.22*	2.92	2.92	7.63**
7	CMS 64A × SN 233	-0.95	-1.26	-1.26	-1.26	-4.96*	-8.84**	-2.19	2.29
8	CMS 64A × SN 232	1.26	1.26	1.26	1.26	4.23*	0.68	8.03**	12.98**
9	CMS 64A × SN 223	3.27	-0.63	-0.63	-0.63	5.84**	-1.36	5.84*	10.69**
10	CMS 64A × SN 2397	1.62	-1.26	-1.26	-1.26	0.00	-2.72	4.38	9.16**
11	CMS 64A × SN 1326	-3.13	-3.73	-2.52	-2.52	-21.09**	-21.09**	-15.33**	-11.45**
12	CMS 64A × BV 166	-1.26	-1.26	-1.26	-1.26	-6.34**	-9.52**	-2.92	1.53
13	JMS 18A × SN 233	-2.47	-4.82*	-0.63	-0.63	1.49	0.74	-0.73	3.82
14	JMS 18A × SN 232	0.31	-1.81	2.52	2.52	7.41**	5.84*	5.84*	10.69**
15	JMS 18A × SN 223	0.32	-5.42*	-1.26	-1.26	8.46 **	6.02*	2.92	7.63**
16	JMS 18A × SN 2397	5.70**	0.60	5.03*	5.03*	4.41*	2.16	3.65	8.40**
17	JMS 18A × SN 1326	-0.31	-1.81	2.52	2.52	1.43	-3.40	3.65	8.40**
18	JMS 18A × BV 166	-3.38	-5.42*	-1.26	-1.26	0.00	-1.46	-1.46	3.05
19	RMS 2A × SN 233	2.22	1.90	1.26	1.26	2.24	1.48	0.00	4.58
20	RMS 2A × SN 232	-1.90	-2.52	-2.52	-2.52	1.48	0.00	0.00	4.58
21	RMS 2A × SN 223	5.92**	2.55	1.26	1.26	5.38*	3.01	0.00	4.58
22	RMS 2A × SN 2397	7.49**	5.10*	3.77	3.77	8.09**	5.76*	7.30**	12.21**
23	RMS 2A × SN 1326	-3.77	-4.97*	-3.77	-3.77	-3.57	-8.16 **	-1.46	3.05**
24	RMS 2A × BV 166	-0.63	-1.26*	-1.26	-1.26	1.48	0.00	0.00	4.58

S. no.	Crosses	Head rice recovery			
		H	HB	SH	
				Check 1	Check 2
				Shabnam	KPH 473
1	CMS 52A × SN 233	-46.39**	-56.30**	-29.73**	-8.77**
2	CMS 52A × SN 232	-0.54	-16.36**	24.32**	61.40**
3	CMS 52A × SN 223	29.61**	11.54**	56.76**	103.51**
4	CMS5 2A × SN 2397	-41.29**	-53.17**	-20.27**	3.51
5	CMS 52A × SN 1326	-66.12**	-71.30**	-58.11**	-45.61**
6	CMS 52A × BV 166	-36.96**	-46.79**	-21.62**	1.75
7	CMS 64A × SN 233	-33.95**	-40.34**	-4.05	24.56**

Table 1 continued...

Table 1 continued...

8	CMS 64A × SN 232	-40.78**	-44.55**	-17.57**	7.02
9	CMS 64A × SN 223	4.00	0.00	40.54**	82.46**
10	CMS 64A × SN 2397	-1.80	-13.49**	47.30**	91.23**
11	CMS 64A × SN 1326	-50.00**	-52.78**	-31.08**	-10.53**
12	CMS 64A × BV 166	0.49	-5.50**	39.19**	80.70**
13	JMS 18A × SN 233	-30.00**	-35.29**	4.05	35.09**
14	JMS 18A × SN 232	4.27	0.00	48.65**	92.98**
15	JMS 18A × SN 223	-28.78**	-29.81**	-1.35	28.07**
16	JMS 18A × SN 2397	9.25**	-1.59	67.57**	117.54**
17	JMS 18A × SN 1326	-62.68**	-63.89**	-47.30**	-31.58**
18	JMS 18A × BV 166	-28.57**	-31.19**	1.35	31.58**
19	RMS 2A × SN 233	-64.44**	-66.39**	-45.95**	-29.82**
20	RMS 2A × SN 232	-40.74**	-41.82**	-13.51*	12.28
21	RMS 2A × SN 223	-22.86	-23.58**	9.46	42.11**
22	RMS 2A × SN 2397	-5.17	-12.70**	48.65**	92.98**
23	RMS 2A × SN 1326	-65.42**	-65.74 **	-50.00**	-35.09 **
24	RMS 2A × BV 166	-41.40**	-42.20**	-14.86**	10.53

Table 2 : Five best heterotic crosses for grain yield/plant and head rice recovery over Shabnam and over KPH 473 with their *per se* performance.

S. no.	Crosses	*Per se* performance (g)	Standard heterosis	
			Over Shabnam	Over KPH 473
1	**Grain yield per plant (g)**			
1	CMS 64A × SN 2397	38.90	41.97**	25.69**
2	CMS 64A × BV 166	37.50	36.86**	21.16**
3	RMS 2A × BV 166	36.50	33.21**	17.93**
4	CMS 52A × SN 223	35.90	31.02**	15.99**
5	CMS 64A × SN 232	35.20	28.47**	13.73**
2	**Head rice recovery (%)**			
1	JMS 18A × SN 2397	62.00	67.57**	117.54**
2	CMS 52A × SN 223	58.00	56.76**	103.51**
3	JMS 18A × SN 232	55.00	48.65**	92.98**
4	RMS 2A × SN 2397	55.00	48.65**	92.98**
5	CMS 64A × SN 2397	54.50	47.30**	91.23**

been reported by Bano and Singh (2018), Begum *et al.* (2020), Yadav *et al.* (2020) and Deepika *et al.* (2023).

For hulling percentage, relative heterosis for this trait varied from 4.89% (CMS 52A × SN 2397) to 7.49% (RMS 2A × SN 2397). Out of 24 hybrids, 4 showed significant positive relative heterosis, only one hybrid RMS 2A × SN 2397 exhibited a significant positive heterosis over better parent and only one hybrid JMS 18A × SN 2397 (5.03%) over Shabnam and over KPH 473, showed significant positive standard heterosis. The results are in accordance with the earlier findings of Devi *et al.* (2017), Gokulakrishnan *et al.* (2018), Meena *et al.* (2021) and Ramakrishna *et al.* (2023).

Milling percentage is also very important quality trait in rice and out of 24 hybrids studied, significant positive heterosis in desired direction exhibited by ten hybrids over mid parent, three hybrids over better parent and four hybrids over Shabnam and 12 hybrids over KPH 473. The hybrids, RMS 2A × SN 2397 and JMS 18A × SN 232 showed significant heterosis over mid parent, better parent and standard heterosis.

The results align with the findings of Begum *et al.* (2020), Meena *et al.* (2021) and Devi *et al.* (2022).

Conclusion

Based on the results, five hybrids namely, CMS 64A × SN 2397, CMS 64A × BV 166, RMS 2A × BV 166, CMS 52A × SN 223 and CMS 64A × SN 232 showed high and significant relative heterosis, heterobeltiosis and standard heterosis for grain yield. Apart from grain yield, these hybrids also found promising for other traits like days to 50 % flowering, plant height, number of filled grains per panicle and kernel length. For the trait, head rice recovery the hybrids JMS 18A × SN 2397, CMS 52A × SN 223, JMS 18A × SN 232, RMS 2A × SN 2397 and CMS 64A × SN 2397 exhibited significant positive standard heterosis, CMS 52A × SN 223 and JMS 18A × SN 2397 exhibited high relative heterosis and CMS 52A × SN 223 was the only hybrid identified with positive and significant heterobeltiosis. The hybrid CMS 52A × SN 223 is heterotic hybrid for both grain yield and head rice recovery. Hence, these were identified as potential hybrids for the traits studied based on their *per se* performance and heterosis estimates. These promising cross combinations can be further used in rice breeding programs by tested in observational/multilocational trial before the commercial exploitation of its heterotic potential.

References

Azad, A.K., Sarker U., Ercisli S., Assouguem A., Ullah R., Almeer R., Sayed A.A. and Peluso I. (2022). Evaluation of combining ability and heterosis of popular restorer and male sterile lines for the development of superior rice hybrids. *Agronomy*, **12(4)**, 965.

Babu, R.P and Sreelakshmi C. (2020). Study on heterosis for yield and quality traits in rice (*Oryza sativa* L.). *ORYZA-An Int. J. Rice*, **57(3)**, 190-198.

Bano, D.A. and Singh S.P. (2018). Heterosis for yield and quality traits in aromatic rice (*Oryza sativa* L.) genotypes. *Curr. J. Appl. Sci. Technol.*, **30(6)**, 1-18.

Begum, S., Reddy V., Srinivas B. and Arunakumari C.H. (2020). Heterosis studies for yield and physical quality traits in hybrid rice (*Oryza sativa* L.). *J. Crop Weed*, **16(1)**, 38-50.

Deepika, K., Manimaran R., Pushpa R., Bama K.S., Umamageswari C. and Suresh R. (2023). Studies on variability and heterosis for yield and nutritional traits in rice (*Oryza sativa* L.). *Elect. J. Plant Breed*., **14(3)**, 1135-1146.

Devi, K.R., Hari Y., Prasad K.R. and Rao P.J.M. (2022). Heterotic evaluation for phonological and quality traits in CMS based rice (*Oryza sativa* L.) hybrids. *The Pharma Innov. J.*, **11(3)**, 1102-1116.

Devi, K.R., Lingaiah N., Parimala K., Venkanna V., Hari Y. and Chandra B.S. (2017). Magnitude of heterosis and gene effects for yield and quality traits in rice (*Oryza sativa* L.). *Elect. J. Plant Breed*., **8(3)**, 799-810.

Gokulakrishnan, J. (2018). Heterosis for yield and yield attributed traits in rice (*Oryza sativa* L.). *Horticult. Biotechnol. Res*., 26-29.

INDIANSTAT (2023). https://www.indiastat.com

Jones, J.W. (1926). Hybrid vigor in rice. *J. American Society*, **18**, 423-428.

Kushal, G., Suresh J., Sreedhar S. and Hari Y. (2023). Study of combining ability in association with heterosis in rice (*Oryza sativa* L.). *Int. J. Environ. Clim. Change*, **13(9)**, 2829-2847.

Manivelan, K., Hepziba S.J., Suresh R., Theradimani M., Renuka R. and Gnanamalar R.P. (2022). Combining ability and heterosis for yield and grain quality characters in rice (*Oryza sativa* L.). *Elect. J. Plant Breed*., **13(2)**, 410-418.

Meena, D., Karnwal M.K., Chaudhary H., Kashyap S. and Sachan N. (2021). Study of heterosis for yield and quality traits in rice (*Oryza sativa* L.) using line × tester mating system. *J. Pharmacog. Phytochem*., **10(2)**, 384-391.

Mohamed, A.E.A., Mazrou Y., Arafat E.S., Gawish O., Kamara M. and Omar A.E.D. (2022). Line × tester analysis for grain yield and yield related traits for some cytoplasmic male sterile and restorer lines of rice. *Fresenius Environ. Bull.*, **31(01)**, 1503-1512.

Mohan, Y.C., Krishna L., Singh T.V., Babu T.K., Varma N.R.G. and Ramana M.V. (2022). Genetic analysis of parental lines and identification of heterotic hybrid combinations in rice (*Oryza sativa* L.). *ORYZA-An Int. J. Rice*, **59(1)**, 1-11.

Ramakrishna, T., Krishna L., Mohan Y.C., Shankar V.G. and Naik D.S. (2023). Heterosis studies for grain yield and yield attributes in rice (*Oryza sativa* L.) hybrids. *Elect. J. Plant Breed*., **14(1)**, 279-295.

Salah, M.H.G., Diaa A.E., Ehab M.R.M. and Mohamed., M.E.M. (2020). Combining ability and heterosis studies for some economic traits in rice (*Oryza sativa* L.). *Res. J. Biotechnol*., **15(1)**, 101-111.

Sari, W.K., Nualsri C., Junsawang N. and Soonsuwon W. (2019). Heterosis studies for yield and agronomic traits in Thai upland rice. *Indian J. Agricult. Res*., **53**, 255-262.

Shull, G.H. (1914). Duplicate genes for capsule form in Bursa pasteris. *Zeitscher Induktive Abstammu Vererbunglehra*, **12**, 97-149.

Singh, N.K., Singh A.K., Misra V. and Mall A.K. (2019). Heterosis breeding in rice (*Oryza sativa* L.) for quantitative traits. *Plant Archives*, **19(1)**, 544-548.

Singh, T.V.J., Raju C.D., Mohan Y.C., Jagadeeshwar R., Balram M. and Krishna L. (2020). Combining ability and heterosis studies for grain yield and its components in rice (*Oryza sativa* L.). *Int. J. Ecol. Environ. Sci*., **2**, 67-75.

Thakor, R.P., Balat J.R., Delvadiya I.R. and Rathva S.R. (2018). Heterosis and heterobeltiosis studies for grain yield and yield attributing traits in rice (*Oryza sativa* L.). *Elect. J. Plant Breed*., **9(4)**, 1286-1294.

Yadav, A.K., Vyas R.P., Yadav V.K. and Kumar V. (2020). Exploitation of heterobeltiosis and economic heterosis for yield and its component traits in rice (*Oryza sativa* L.). *Plant Archives*, **20(2)**, 4555-4563.

Yuan, L.P. (1994). *Increasing yield potential in rice by exploitation of heterosis*. In: Virmani, S.S. (ed). Hybrid rice technology: new developments and future prospects. Los Banos (Philippines): International Rice Research Institute, 1994, 1-6.