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Research Note

Studies on combining ability and gene action for grain yield, head rice recovery and other agronomic traits in rice (*Oryza sativa* L.)

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Abstract
Twenty-four rice hybrids were assessed for grain yield, head rice recovery andother traits alongside their parents to study combiningability.Analysis of variance revealed significant differences among genotypes for every trait examined. It indicated that non-additive gene action was predominant for most of the characters studied except days to50% flowering and 1000 grain weight whichwere controlled by additive gene action. CMS 64B, SN 223 and SN 232 were good general combiners for grain yieldand head rice recovery can be superior parents for hybridization programme. SCA effects showed that the hybrids,CMS52A×SN223,CMS64A×SN2397andCMS64A×BV166 were good specific combiners for grain yield, head rice recovery and other traits like panicle length, number of grains per panicle, , 1000 grain weight, number productive tillers per plant etc . In the future, these hybrids might be tested through multi-environment trials before being used commercially.

Keywords:Combining ability,grain yield, head rice recovery, line×tester

For many Asian nations, rice (*Oryza sativa* L.) is staple food and major source of nutrition. To fulfil the demands of an expanding population the rice production must increase. High temperatures of about 38-42° C and low relative humidity (<40%) is recorded in Telangana in the months of April and May during which the *rabi* rice crop is at grain filling to maturity stage. These conditions result in low head rice recovery percentage of *rabi* rice produce. Selection is an important technique in plant breeding and breeders use this method for improving the architecture of a crop by management of available genetic variability (Kohnaki *et al.,* 2013). Breeding strategies based on selection of hybrids require expected level of heterosis as well as specific combining ability. Combining ability analysis is one of the useful tools available to estimate the combining ability effects and aids in selecting the desirable parents and crosses for the exploitation of heterosis.Additionally, it helps in understanding the nature and extent of gene action in the inheritance of specific traits. The Line × Tester analysis method, proposed by Kempthorne in 1957, is the most commonly used approach for identifying general and specific combiners and to study the nature of gene action governing the inheritance of different characters. Therefore, the present research work was carried out to estimate the nature of gene action and combining ability effects of parents and crosses for grain yield and quality traits in rice based on their mean performance, genetic parameters and heterosis.

The experiment was conducted at Regional Agricultural Research Station, PJTAU, Polasa, Jagtial, Telangana. Six proven high head rice recovery testers (SN 223, SN 232, SN 233, SN 2397, SN 1326 and BV 166) were crossed with four elite CMS lines (CMS 52A, CMS 64A, JMS 18A and RMS 2A) in Line×Tester mating design during *kharif* 2023. The resultant 24 hybrids were assessed in a randomised block design with two replications during *rabi* 2023–24, along with their parents and two standard checks *viz*., Shabnam and KPH 473. Each entry was planted in two rows of three meters length with a spacing of 20 x 15 cm. Observations werer ecorded on 13 traits and the data was analysed as per Kempthorne (1957) for Line x Tester.

The analysis of variance for combining ability (**Table1**) revealed significant variance for all the characters studied for parents and hybrids. For each character, the variance due to hybrids was divided into variance due to lines, testers and lines×testers. Except for grain yield per plant, kernel breadth and hulling per cent, the variances due to lines were significant for all of the characters. Variances due to testers were significant for all traits except panicle length and grain yield per plant. Except for grain yield per plant, the variances due to lines x testers were significant for all characters studied. These findings highlighted the significance of combining ability studies in indicating variability in the materials studied and there is a good opportunity for identifying promising parents and hybrid combinations for improving yield through its components. In the present study, the traits plant height, panicle length, number of productive tillers per plant, number of filled grains per panicle, grain yield per plant, kernel length, kernel breadth, kernel L/B ratio, hulling percentage, milling percentage and head rice recovery displayed higher SCA variance compared to GCA variance. This suggests that non additive gene action plays a dominant

Table 1.Analysis of variance of Line×Tester mating design for grain yield, yield contributing and qualitytraits in rice

Source of Variation	d.f.	Daysto 50% flowering	Plant h eight	Panicle length	No. of productive tillers per plant	No.offilled grains per panicle	1000 grain weight	Grain yield per plant
Replicates	1	0.23	0.21	3.76	0.62	1204.56	0.28	24.60
Treatments	33	119.45**	99.79**	4.51**	1.50**	7241.59**	21.92**	52.20**
Parents	9	85.49**	117.56**	2.71*	1.30**	7625.21**	39.07**	9.17
Parents(Line)	3	122.79**	196.83**	4.44*	1.46**	16575.15**	60.90**	2.46
Parents (Testers)	5	71.33**	17.47**	0.88	0.91*	2452.13**	31.17**	10.17
Parents(LvsT)	1	44.40**	380.20**	6.72*	2.79**	6636.48***	13.06**	24.30
Parents *vs* Crosses	1	645.61**	10.44	8.06**	1.72*	16126.17**	5.13**	435.18**
Crosses	23	109.86**	92.72**	5.06**	1.57**	6705.19**	15.94**	52.39**
Line effect	3	587.79**	311.03*	18.39*	3.23	16585.31*	47.35	118.93
Tester effect	5	81.28*	83.60	0.69	1.40	6317.42	23.42*	26.26
Line x Tester eff.	15	23.79**	58.23**	3.85**	1.29**	4858.42**	7.17**	47.79**
Error	33	1.29	2.76	1.01	0.32	501.50	0.50	7.65
Total	67	59.47	50.51	2.81	0.90	3831.74	11.05	29.84

Source of Variation	d.f.	Kernel length	Kernel breadth	Kernel L/B ratio	Hulling	Milling	Head rice recovery
Replicates	1	0.23	0.02	0.001	11.52	13.23	3.76
Treatments	33	0.66**	0.03**	0.24**	8.48*	20.81**	392.14**
Parents	9	0.95**	0.07**	0.25**	14.33**	20.80**	93.57**
Parents(Line)	3	1.65**	0.01	0.31**	9.12	27.33**	92.83**
Parents (Testers)	5	0.62**	0.04**	0.11**	16.33**	20.80**	33.53**
Parents (LvsT)	1	0.47**	0.36**	0.77**	20.00*	1.20**	396.03**
Parents vs Crosses	1	0.01	0.03*	0.12**	7.85	9.6**	3261.74**
Crosses	23	0.58**	0.02**	0.25**	6.21	21.31**	384.21**
Line Effect	3	1.75*	0.02	0.31	6.24	6.80	263.72
Tester Effect	5	0.64	0.05	0.37	8.77	39.40	1009.35**
Line x Tester Eff.	15	0.33**	0.01**	0.19**	5.35	18.18**	199.96**
Error	33	0.06	0.006	0.004	3.77	4.44	3.49
Total	67	0.36	0.02	0.12	6.20	12.64	194.92

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Table 2. Mean performance of parents,crosses and checks for grain yield, yield contributing and quality traits in rice

S.No		Days to 50% flowering	Plant height(cm)	Panicle length(cm)	Number of productive tillers per Plant	Number of filled grains per panicle	1000 grain weight(g)	Grain yield per plant (g)
	PARENTS:							
	Lines							
1	CMS52B	96.00	70.30	23.40	10.00	113.00	23.11	21.00
2	CMS64B	105.00	78.50	25.50	11.00	124.00	20.59	22.20
3	JMS18B	101.00	85.40	25.70	10.00	233.00	11.72	22.10
4	RMS2B	115.00	93.60	27.00	10.00	303.00	13.34	23.70
	Mean	**104.00**	**81.95**	**25.40**	**10.00**	**193.00**	**17.19**	**22.25**
	Testers							
1	SN233	105.00	90.80	25.00	12.00	140.00	21.01	26.00
2	SN232	106.00	92.90	24.20	11.00	166.00	22.41	25.90
3	SN223	106.00	93.50	23.60	10.00	149.00	19.69	27.40
4	SN2397	119.00	87.40	24.40	11.00	213.00	11.90	23.60
5	SN1326	106.00	87.10	24.80	11.00	107.00	21.42	22.10
6	BV166	102.00	93.40	23.30	11.00	164.00	16.61	22.00
	Mean	**107.00**	**90.85**	**24.21**	**11.00**	**156.00**	**18.84**	**24.50**

S.No		Days to 50% flowering	Plant height (cm)	Panicle length (cm)	No. of productive tillers per plant	No.of filled grains per panicle	1000 grain weight (g)	Grain yield per plant (g)
	Crosses:							
1	CMS52A× SN 233	96.00	92.80	26.00	11.00	217.00	20.56	27.20
2	CMS52A× SN 232	94.00	88.60	26.30	11.00	285.00	17.52	29.40
3	CMS52A× SN 223	96.00	97.10	25.90	11.00	278.00	18.39	35.90
4	CMS52A× SN 2397	95.00	73.70	22.40	11.00	133.00	17.77	21.20
5	CMS52A× SN 1326	91.00	85.60	27.80	11.00	140.00	22.56	31.20
6	CMS52A×BV 166	90.00	82.55	22.80	12.00	96.00	19.80	22.45
7	CMS64A× SN 233	102.00	92.40	26.60	10.00	184.00	23.62	32.00
8	CMS64A× SN 232	101.00	97.65	26.60	10.00	170.00	23.61	35.20
9	CMS64A× SN 223	97.00	81.90	26.30	12.00	214.00	21.65	29.40
10	CMS64A× SN 2397	105.00	91.10	27.30	12.00	200.00	20.54	38.90
11	CMS64A× SN 1326	100.00	87.50	26.20	9.00	127.00	23.68	28.10
12	CMS64A× BV 166	108.00	90.30	26.20	9.00	268.00	14.75	37.50
13	JMS18A× SN233	94.00	83.80	23.30	10.00	166.00	17.36	28.20
14	JMS18A× SN232	93.00	82.30	23.40	10.00	193.00	18.59	28.60
15	JMS18A×SN223	93.00	89.60	23.30	11.00	181.00	16.12	24.60
16	JMS18A× SN2397	103.00	79.30	24.30	11.00	160.00	14.24	21.20
17	JMS18A× SN1326	89.00	74.10	23.30	11.00	148.00	19.22	29.30
18	JMS 18A× BV 166	89.00	82.20	25.20	10.00	203.00	17.94	24.70
19	RMS2A×SN 233	109.00	90.50	24.80	10.00	231.00	17.40	24.80
20	RMS2A× SN 232	107.00	95.90	26.70	9.00	244.00	18.66	33.20
21	RMS 2A× SN223	109.00	97.30	26.10	10.00	268.00	16.65	25.30
22	RMS2A× SN 2397	118.00	91.90	26.40	10.00	276.00	14.17	23.80
23	RMS2A×SN 1326	103.00	91.50	26.00	10.00	217.00	19.45	30.40
24	RMS2A×BV 166	103.00	96.00	27.50	10.00	320.00	16.54	36.50
	Mean	**99.00**	**88.15**	**25.44**	**10.00**	**204.00**	**18.78**	**29.12**
	S.E	0.83	1.19	0.73	0.39	15.80	0.49	2.02
	C.D (5%)	2.41	3.42	2.10	1.14	45.37	1.42	5.81
	C.D (1%)	3.23	4.58	2.82	1.53	60.87	1.90	7.80

Table 2. Continued..

S.No		Kernel length (mm)	Kernel breadth (mm)	Kernel L/B ratio	Hulling(%)	Milling(%)	Head rice recovery(%)
	PARENTS:						
	Lines						
1	CMS52B	6.79	1.59	4.27	78.50	66.50	37.50
2	CMS64B	5.60	1.44	3.88	79.50	73.50	48.00
3	JMS18B	4.95	1.37	3.61	83.00	66.50	50.50
4	RMS2B	4.79	1.43	3.34	78.50	66.50	53.00
	Mean	5.53	1.45	3.77	79.87	68.25	47.25
	Testers						
1	SN233	6.26	1.77	3.53	79.00	67.50	59.50
2	SN232	6.26	1.75	3.57	79.50	68.50	55.00
3	SN223	6.19	1.76	3.51	73.50	63.50	52.00
4	SN2397	5.12	1.46	3.41	75.00	69.50	63.00
5	SN1326	6.12	1.94	3.15	80.50	73.50	54.00
6	BV166	5.14	1.71	3.00	79.50	68.50	54.50
	Mean	5.84	1.73	3.36	77.83	68.50	56.33

S.No		Kernel length (mm)	Kernel breadth mm)	Kernel L/B ratio	Hulling (%)	Milling (%)	Head rice recovery (%)
	CROSSES:						
1	CMS52A× SN 233	6.54	1.78	3.67	78.50	65.50	26.00
2	CMS52A× SN 232	6.52	1.72	3.78	80.50	71.50	46.00
3	CMS 52A× SN 223	5.55	1.75	3.16	76.50	68.50	58.00
4	CMS52A× SN 2397	5.40	1.63	3.30	80.50	69.50	29.50
5	CMS52A× SN 1326	6.11	1.73	3.53	79.00	68.50	15.50
6	CMS52A×BV 166	5.63	1.71	3.28	79.50	70.50	29.00
7	CMS64A× SN 233	6.46	1.75	3.69	78.50	67.00	35.50
8	CMS64A× SN 232	6.34	1.75	3.62	80.50	74.00	30.50
9	CMS64A× SN 223	6.65	1.64	4.04	79.00	72.50	52.00
10	CMS64A× SN 2397	6.57	1.64	4.01	78.50	71.50	54.50
11	CMS64A× SN 1326	6.21	1.77	3.51	77.50	58.00	25.50
12	CMS64A×BV 166	4.86	1.61	3.01	78.50	66.50	51.50
13	JMS18A× SN233	5.52	1.71	3.23	79.00	68.00	38.50
14	JMS18A× SN232	5.57	1.57	3.54	81.50	72.50	55.00
15	JMS18A× SN223	5.67	1.69	3.36	78.50	70.50	36.50
16	JMS18A× SN2397	5.16	1.43	3.62	83.50	71.00	62.00
17	JMS18A× SN1326	5.76	1.67	3.45	81.50	71.00	19.50
18	JMS 18A× BV 166	5.30	1.61	3.28	78.50	67.50	37.50
19	RMS2A× SN 233	5.29	1.78	2.96	80.50	68.50	20.00
20	RMS2A× SN 232	5.38	1.76	3.06	77.50	68.50	32.00
21	RMS 2A× SN223	5.39	1.38	3.91	80.50	68.50	40.50
22	RMS2A× SN 2397	5.85	1.50	3.90	82.50	73.50	55.00
23	RMS2A× SN 1326	5.32	1.84	2.88	76.50	67.50	18.50
24	RMS2A×BV 166	5.00	1.77	2.82	78.50	68.50	31.50
	Mean	**5.75**	**1.67**	**3.44**	**79.39**	**69.12**	**37.50**
	S.E	0.16	0.05	0.04	1.88	1.48	1.30
	C.D (5%)	0.48	0.15	0.13	3.97	4.25	3.74
	C.D(1%)	0.65	0.20	0.18	5.33	5.71	5.03

role in the inheritance of these traits. Hybrid vigor, in later or advanced generations can be achieved through breeding and selection processes. This is possible because these processes increase the variation in non-additive gene actions for all traits. This will be essential for enhancing these attributes. Findings of Naik *et al*., 2021, Soni *et al*., 2021, Ramakrishna *et al*., 2022, Maring *et al*., 2023 and Arunkumar and Narayanan 2024 support the present results of non additive gene action predominant for majority of traits .

The GCA variances were greater than the SCA variances for days to 50 %flowering (Ibrahim *et al*., 2024) and for 1000 grain weight (Kushal *et al*., 2023) showing that additive gene action predominance and reliance should be placed on mass selection and progeny selection in self pollinated species like rice for improvement of the above traits. Among lines, CMS 64B (4.36), CMS 52B (2.16) and in testers BV 166 (2.12), SN 223 (1.98) and SN232(1.94) showed significant and positive *gca* effect for grain yield per plant (**Table 3**). For the trait, head rice recovery the lines, CMS64B(4.08),JMS18B (4.00) and in testers SN 2397 (12.75), SN 223 (9.25) and SN 232 (3.37) had significant and positive *gca* effects. The parents CMS64B, SN223 and SN 232 showed significant positive *gca* effects for both grain yield and head rice recovery. Among the lines CMS 64B had considerable *gca* impact in the desirable direction for crucial traits, such as panicle length, number of productive tillers per plant,1000 grain weight, number of filled grains perpanicle, kernel length and kernel L/B ratio.CMS52B was the most effective general combiner among the lines for important traits such as days to 50 % flowering, plant height, panicle length, number of filled grains per panicle, 1000 grain weight, kernel length and kernel breadth. With respect to days to 50 % flowering, the lines CMS 52B and JMS 18B as well as the testers SN 1326 and BV 166 recorded significant negative *gca* effect. This suggests that these parents are good combiners for the generation of early hybrids. The study revealed that SN 223, SN 2397 and BV 166 were the most efficient combiners in terms of number of productive tillers per plant indicating a significant positive *gca* effect.

The parents RMS 2B, CMS 52B, CMS 64B, SN 223, SN 232 and BV 166 were found to be good general combiners for number of filled grains per panicle. Test weight is another crucial characteristic that influences rice production. The male parents SN 233, SN 232 and SN 1326 as well as lines CMS 64B and CMS 52B proved to be good general combiners for this trait. In the current study, it is clearly observed in certain cases the lines and testers with good mean performance were not good general combiners and *vice versa* and hence, the effectiveness of choice of parents based on mean performance alone may not be effective in hybridisation programmes.

The *sca* effects showed that among 24 hybrids, CMS52A × SN 223(8.26) CMS64A×SN2397 (8.11),RMS2A×BV166 (5.40) and CMS64A × BV 166 (3.81) had significant and positive effect for grain yield perplant. (**Table 3**). These results align with the earlier studies conducted by Maring *et al*. (2023), Nivedha *et al.* (2024) and Singh (2023). For the trait, head rice recovery significant positive *sca* effect was exhibited by seven hybrids *viz*., CMS52A×SN223 (14.75), JMS18A×SN232 (10.12), CMS64A× BV166(10.04),CMS52A×SN232(8.62),JMS18A×SN233(4.50) ,CMS64A×SN2397(3.12) and RMS2A×SN2397(2.94) respectively. These results are similar to findings of Islam *et al*. (2022), Ramakrishna *et al*. (2022) and Vennela *et al*. (2023). The hybrids, CMS52A×SN223,

Table 3. Estimates of GCA and SCA and proportionate gene action in rice for the characters under study

S.No	Character	Sourceofvariation			Nature of Gene Action
		σ^2gca	σ^2sca	Variance ratio (σ^2gca/ σ^2sca)	
1	Days to 50% flowering	33.32	11.25	2.96	Additive
2	Plant height (cm)	19.45	27.73	0.70	NonAdditive
3	Panicle length (cm)	0.85	1.42	0.59	NonAdditive
4	Number of productive tillers per plant	0.19	0.48	0.39	NonAdditive
5	Number of filled grains perpanicle	1094.98	2178.45	0.50	NonAdditive
6	1000 grain weight (g)	3.48	3.33	1.04	Additive
7	Grain yield per plant (g)	6.58	20.50	0.32	NonAdditive
8	Kernel length (mm)	0.11	0.16	0.68	NonAdditive
9	Kernel breadth (mm)	0.003	0.008	0.37	NonAdditive
10	Kernel L/Bratio	0.03	0.09	0.33	NonAdditive
11	Hulling (%)	0.46	1.24	0.38	NonAdditive
12	Milling (%)	2.04	7.78	0.26	NonAdditive
13	Headrice recovery (%)	63.30	98.22	0.64	NonAdditive

CMS64A×SN2397 and CMS64A×BV166 proved to be effective specific combiners for head rice recovery as well as grain yield. Significant negative *sca* effect for days to 50 % flowering was showed by CMS 64A × SN223(-4.35), RMS2A×BV166 (-3.39),CMS64A×SN2397(-3.22), JMS18A× BV 166 (-2.39) and CMS 52A × BV 166 (-1.72) and can be considered as highly desirable for earliness. The results obtained align with Mohan *et al*.(2022) and Kushal *et al*.(2023). The cross CMS64A×SN223(-11.56) recorded negative *sca* effect for plant height followed byCMS52A×SN2397(-8.87),RMS2A×SN233(-5.07),CMS52A × BV 166 (-3.78) and JMS 18A × SN 232 (-2.54) which is desirable. The results are consistent with Kumar *et al*. (2021) and Azad *et al*. (2022). The hybrids CMS 64A × BV 166 (1.51) and CMS 52A × SN 223 (1.48) were found to be good specific combiners for panicle length. Similar findings were reported by Maring *et al*. (2023) and Nivedha *et al*. (2024).

Two hybrids,CMS64A × SN2397(1.40) and CMS52A × SN223(0.85) were identified as good specific combiners for increasing the number of productive tillers per plant. These out comes are in consonance with the findings of Nagamani *et al*.(2022)and Ramakrishna *et al*. (2022).

Table 4. Estimates of *gca* for lines and testers for grain yield and yield contributing traitsin rice

S.No	Source	Days to 50% flowering	Plant height	Panicle length	Number of productive tillers per plant	Number of filled grains per panicle	1000 grain weight	Grain yield per plant
	PARENTS:							
	Lines							
1	CMS52B	-5.52**	-1.42**	0.80**	0.30	13.45*	0.64**	2.16**
2	CMS64B	2.72**	1.99**	1.00**	0.36*	13.37*	2.52**	4.36**
3	JMS18B	-5.85**	-6.26**	-1.64**	-0.004	-54.26**	-1.53**	-3.55**
4	RMS2B	8.64**	5.70**	-0.20	-0.66**	27.43**	-1.63**	-2.97**
	Testers							
1	SN233	0.81	2.34**	-0.65	-0.57**	-5.36	0.94**	-1.16
2	SN232	-0.68	2.68**	-0.75**	-0.50**	18.06*	0.81**	1.94**
3	SN223	-0.56	3.32**	0.81**	0.64**	30.48**	-1.28*	1.98**
4	SN2397	5.81**	-4.15**	0.75**	0.65**	-12.81	-2.10**	-0.15
5	SN1326	-3.43**	-2.61**	-0.95**	-0.76**	-47.11**	1.04**	-1.10
6	BV166	-1.93**	-1.57**	0.79**	0.54**	16.73*	-3.62**	2.12*
	CD 95%GCA(Line)	0.68	0.99	0.60	0.33	13.37	0.42	1.55
	CD 95%GCA(Tester)	0.83	1.21	0.73	0.41	16.37	0.52	1.90

S.No	Source	Kernel length	Kernel L/B ratio	Hulling	Milling	Head rice recovery
	PARENTS:					
	Lines					
1	CMS52B	0.20**	0.11	-0.31	-0.12	-3.50**
2	CMS64B	0.43**	0.20**	-0.64	-0.87	4.08**
3	JMS18B	-0.25**	-0.03	1.02	0.95	4.00**
4	RMS2B	-0.38**	-0.18**	-0.06	0.04	-4.58**
	Testers					
1	SN233	0.20**	-0.05*	-0.27	-1.87*	-7.50**
2	SN232	0.19**	0.05*	0.60	2.50**	3.37**
3	SN223	0.06	0.17**	-0.77	0.87	9.25**
4	SN2397	-0.007	0.26**	1.85*	2.25**	12.75**
5	SN1326	0.09	-0.09**	-0.77	-2.87**	-17.75**
6	BV166	-0.55	-0.34**	-0.64	-0.87	-0.12
	CD 95%GCA(Line)	0.14	0.04	1.16	1.25	1.11
	CD 95%GCA(Tester)	0.18	0.05	1.42	1.54	1.36

Table 4.Estimates of *sca* for grain yield and yield contributing traits in rice

S.No	Crosses	Day to 50% flowering	Plant height	Panicle length	Number of productive tillers per plant	Number of filled grains per panicle	1000 grain weight	Grain yield per plant
1	CMS52A×SN233	1.52	4.35**	1.07	0.52	30.87	0.17	0.31
2	CMS52A×SN232	1.02	-1.08	0.79	0.32	74.55**	-2.72**	-1.04
3	CMS52A×SN223	2.89**	7.05**	1.48**	0.85*	55.92**	-0.46	8.26**
4	CMS52A×SN2397	-4.47	-8.87**	-2.45**	-0.70	-45.77*	0.43	-3.46
5	CMS52A×SN1326	0.77	2.35	1.02	-0.21	-4.57*	0.68	2.61
6	CMS52A×BV166	-1.72*	-3.78**	-2.37**	0.48	-112.02**	1.89**	-6.67**
7	CMS64A×SN233	-0.72	0.53	0.33	-0.52	-4.10	1.36*	-0.41
8	CMS64A×SN232	-0.72	4.54**	-0.23	0.27	-42.02*	1.49**	-0.76
9	CMS64A×SN223	-4.35**	-11.56**	-0.87	0.80	-10.05	0.34	-3.76
10	CMS64A×SN2397	-3.22**	5.10**	1.11	1.40**	33.75**	1.33*	8.11**
11	CMS64A×SN1326	1.52	0.83	-0.71	-0.75	-20.15	-0.45	-6.01**
12	CMS64A×BV166	7.52**	0.54	1.51**	-1.20**	57.29**	-5.03**	3.81**
13	JMS 18A×SN233	-0.64	0.19	-0.22	-0.52	-3.85	-0.83	3.20
14	JMS 18A×SN232	0.35	-2.54*	-0.70	0.06	-0.27	0.53	0.05
15	JMS 18A×SN223	-0.27	4.39**	-0.76	-0.74	-24.50	-0.92	-1.14
16	JMS18A×SN2397	3.85**	1.56	-0.68	-0.55	-2.60	-0.90	-2.17
17	JMS18A×SN1326	-0.89	-4.30	-1.19	0.37	20.39	-0.46	2.60
18	JMS18A×BV166	-2.39**	0.70	0.84	-0.42	10.84	2.22**	-2.53
19	RMS2A×SN233	-0.14**	-5.07**	-1.86**	0.18	-22.92	0.51	-3.09
20	RMS2A×SN232	-0.64	-0.91	0.14	-0.66	-33.24*	0.70	1.75
21	RMS2A×SN223	1.72*	0.12	-0.10	0.11	-21.37	0.08	-3.34
22	RMS2A×SN2397	3.85**	2.20	0.49	-0.48	22.47	-0.87	-2.47
23	RMS2A×SN1326	-1.39	1.12	-0.62	0.15	4.39	-0.52	0.80
24	RMS2A×BV166	-3.39**	2.53*	1.27	0.05	37.02*	0.45	5.40**
	CD 95%SCA	1.66	2.43	1.47	0.83	32.75	1.04	3.80

S.No	Crosses	Kernel length	Kernel breadth	Kernel L/ Bratio	Hulling	Milling	Headrice recovery
1	CMS52A×SN233	0.38*	-0.02	0.27**	-0.31	-1.62	-0.50
2	CMS52A×SN232	0.36*	-0.02	0.26**	0.81	0.001	8.62**
3	CMS52A×SN223	-0.47*	0.09	-0.47**	-1.81	-1.37	14.75**
4	CMS52A×SN2397	-0.55**	0.03	-0.41**	-0.43	-1.75	-17.25**
5	CMS52A×SN1326	0.05	-0.07	0.17**	0.68	2.37	-0.75
6	CMS52A×BV166	0.22	-0.01	0.16**	1.06	2.37	-4.87**
7	CMS64A×SN233	0.07	-0.02	0.09	0.02	0.62	1.41
8	CMS64A×SN232	-0.04	0.02	-0.08	1.10	3.25*	-14.45**
9	CMS64A×SN223	0.40*	0.009	0.22**	1.02	3.37*	1.16
10	CMS64A×SN2397	0.39*	0.07	0.09	2.99*	1.00	3.12**
11	CMS64A×SN1326	-0.06	-0.002	-0.03	-0.47	-7.37**	1.66
12	CMS64A×BV166	-0.76**	-0.08	-0.29**	0.39	-0.87	10.04**
13	JMS 18A×SN233	-0.18	0.01	-0.13*	-1.14	-0.20	4.50**
14	JMS 18A×SN232	-0.12	-0.06	0.06	0.47	-0.08	10.12**
15	JMS 18A×SN223	0.11	0.13**	-0.22**	-1.14	-0.45	-14.25**
16	JMS18A×SN2397	-0.32	-0.05	-0.05	1.22	-1.33	7.75
17	JMS 18A×SN1326	0.16	-0.02	0.13*	-1.00	3.79*	-4.25**
18	JMS18A×BV166	0.35	-0.03	0.21**	-1.27	-1.70	-3.87**
19	RMS2A×SN233	-0.27	0.03	-0.23**	1.43	1.20	-5.41**
20	RMS2A×SN232	-0.19	0.06	-0.25**	-2.43	-3.16*	-4.29**
21	RMS2A×SN223	-0.04	-0.23**	0.47**	1.93	-1.54	-1.66
22	RMS2A×SN2397	0.48*	-0.04	0.38**	1.31	2.08	2.94*
23	RMS2A×SN1326	-0.15	0.09	-0.27**	-2.06	1.20	-6.76**
24	RMS2A×BV166	0.18	0.09	-0.09	-0.18	0.20	-1.29
	CD 95%SCA	0.36	0.11	0.10	2.84	3.08	2.73

Among 24 hybrids, five hybrids *viz*., CMS 52A × SN 232 (74.55),CMS64A×BV166(57.29),CMS52A×SN223(55 .92),RMS2A×BV166 (37.02) and CMS64A × SN 2397 (33.75) were found to be effective specific combiners for enhancing the number of filled grains per panicle. These outcomes align with earlier studies of Patel *et al.* (2019), Ramakrishna *et al*. (2022) and Maring *et al*. (2023).

The hybrids, JMS 18A × BV 166 (2.22), CMS 52A × BV 166 (1.89), CMS 64A × SN 232(1.49), CMS64A×SN233(1.36) and CMS64A×SN2397(1.33) were identified to be good specific combiners for 1000 grain weight.These outcomes were earlier reported by Manivelan *et al*. (2022) and Ibrahim *et al.* (2024). Five hybrids expressed significant positive *sca* effects for kernel length. The cross RMS 2A × SN 2397(0.48) exhibited maximum positive *sca* effect and was followed by CMS 64A × SN 223 (0.40) and CMS64A × SN 2397 (0.39). The findings aligned with the results of Al-Daej (2023) and Kushal *et al*. (2023). For kernel breadth, JMS18A×SN223 (0.13) was observed as good specific combiner.Similar findings were reported by Al-Daej (2023) and Vennala *et al*. (2023). Four crosses recorded positive and significant *sca* effects for kernel L/B ratio and RMS 2A×SN223 (0.47) was found as good specific combiners for this trait. The results are in accordance with the findings of Ramakrishna *et al*. (2022) and Vennala *et al*. (2023). For hulling percentage, out of the 24 hybrids, only one hybrid, CMS 64A × SN 2397 (2.99), exhibited good specific combining ability. Similar findings were earlier reported by Santha *et al*. (2017) and Singh *et al*. (2020). Three crosses *viz*., JMS 18A × SN1326(3.79), CMS64A×SN223(3.37) and CMS64A×SN232(3.25) were identified as good specific combiniers for milling percentage and recorded positive and significant values. This aligns with the findings of Singh *et al*. (2020) and Ramakrishna *et al*. (2022).

In the present study, CMS 64B, SN 223 and SN 232 were identified as good general combiners for both grain yield and head rice recovery. Based on *sca* effects the hybrids, CMS52A×SN223,CMS64A×SN2397 and CMS64A×BV166, were found to be promising for grain yield per plant and head rice recovery.These hybrids may be thoroughly evaluated in diverse agro climatic zones across the seasons to confirm their stability before commercial release.

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