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COMBINING ABILITY AND GENE ACTION STUDIES FOR GRAIN YIELD, AND OTHER AGRO-MORPHOLOGICAL CHARACTERS IN RICE (*ORYZA SATIVA* L.)

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ABSTRACT

The combining ability test is one of several biometrical methods used to identify good general and specific combiners. In this research, four diverse CMS lines were crossed with eight testers by line × tester mating design. A total of twelve parents and thirty-two hybrids, along with two standard checks, were assessed in a randomized block design with three replications. Data for 13 traits were collected. The findings revealed that non-additive gene action was significant in controlling yield and related components, such as days to 50% flowering, plant height, panicle length, number of productive tillers per plant, kernel length, hulling percentage, milling percentage and head rice recovery. On the other hand, additive gene action was important for traits like the number of filled grains per panicle, 1000-grain weight, grain yield per plant, kernel breadth and L/B ratio. The parents IR 65514-5-2-19R-1, IR 65483-14-1-1-4-13R, IR 63870-7-3-2-3-3R, and CMS 64A showed significant positive *gca* effects for grain yield per plant and related traits, making them suitable for the development of superior hybrids. Meanwhile, nine hybrids exhibited positive *sca* effects for grain yield per plant and related traits, marking them a promising specific combiners and candidates for heterosis breeding.
***Keywords* :** Combining ability, grain yield, head rice recovery, rice, line × tester

Introduction

Rice (*Oryza sativa* L.) is a vital cereal crop globally, providing food for one-third of the world's population and growing in a variety of climatic conditions and agro-ecological zones. In Asia, rice consumption remains dominant, accounting for approximately 90% and global rice demand is projected to reach 650 million tonnes by 2050 (Chukwu *et al*., 2019). Rice is cultivated on about 165 million hectares worldwide, yielding approximately 508.9 million tonnes (INDIASTAT, 2022-2023). In India, rice is cultivated on 47.832 million hectares, producing 135.755 million tonnes with a productivity of 2838 kg/ha (INDIASTAT, 2022-2023). Improving rice yield and associated traits is essential to meet the increasing global food demand.

Meeting the demands of a growing population while ensuring self-sufficiency is a challenging task, especially with the plateauing yield potential of high-yielding cultivars and the shrinking availability of natural resources. The success of any plant breeding program largely relies on selecting the right parent plants for hybridization and understanding the gene action of various economic traits. Rice breeding strategies typically focus on selecting high-yielding varieties, which require both the expected level of heterosis and specific combining ability. Combining ability analysis is an effective tool for identifying both good and poor combiners, allowing breeders to select suitable parental material and understand the type of gene action involved in the inheritance of traits. The utilization of heterosis is largely determined by the general combining ability (*gca*) and specific combining ability (*sca*) of the parents in the hybrids. The line × tester analysis (Kempthorne *et al*., 1957) provides valuable insights for rice breeders, aiding in decisions regarding the breeding system and selection of breeding material with the highest potential for successful selection.

Material and Methods

The study was carried out at the Regional Agricultural Research Station in Polasa, Jagtial, Telangana, India, located at an altitude of 243.4 meters above sea level, at coordinates 18°49'40" N latitude and 78°56'45" E longitude, within the Northern Zone of Telangana. Four different CMS lines: CMS 14A, CMS 23A, CMS 64A and CMS 69A were crossed with eight testers: IR 63870-7-3-2-3-3R, IR 63877-43-2-1-3-1R, IR 65483-14-1-1-4-13R, IR 65514-5-2-19R-1, JGL 21005, JGL 24444, JGL 27347 and JGL 29651, following a line × tester mating design introduced by Kempthorne during the kharif season of 2022. The twelve parental lines and their thirty-two hybrid combinations were evaluated alongside two standard reference varieties, KPH 4 and KPH 46, in a randomized block design (RBD) with three replications. Standard agricultural practices were followed to ensure healthy crop growth. Data was collected from five randomly selected healthy plants per entry in each replication, focusing on 13 different traits, including days to 50% flowering, plant height (cm), panicle length (cm), number of productive tillers per plant, number of grains per panicle, 1000-grain weight (g), grain yield per plant (g), hulling percentage, milling percentage, head rice recovery (%), kernel length (mm), kernel breadth (mm), and kernel L/B ratio. The trait,days to 50% flowering were recorded on a plot basis. Line × tester analysis was applied to estimate the general combining ability (*gca*) and specific combining ability (*sca*) variances, along with their effects, based on the observations from the F_1 generation of the line × tester crosses.

Results and Discussion

The variance associated with parents, treatments, and crosses (as shown in Table 1) revealed significant differences for all the traits examined, except for plant height and the L/B ratio. For the remaining traits, the variance between parents vs. crosses was significant. The variance due to lines was significant for days to 50% flowering, panicle length, kernel breadth, kernel L/B ratio and hulling percentage. In contrast, the variance due to testers was significant for the number of filled grains per panicle, 1000-grain weight and grain yield per plant. Interaction effects between lines and testers were significant for the trait's days to 50% flowering, plant height, number of filled grains per panicle, 1000-grain weight, grain yield per plant and milling percentage when the effects of parents were divided into lines, testers, and line × tester interactions. This suggests that there is adequate variability present in the material under investigation. Similar findings have been reported by Hasan *et al*. (2013) for parent *vs*. crosses and testers, Devi *et al*. (2017) for parents, crosses, parents *vs*. crosses and lines, Elshenawy *et al*. (2018) for lines, Amit Kumar *et al*. (2019) and Salah *et al*. (2020) for parents and parent *vs*. crosses and Bano and Singh (2019), El-Mowaf *et al*. (2021) and Islam *et al*. (2022) for parent *vs*. crosses and line × tester interactions.

The line, CMS 69B (-8.81) and the tester, JGL 21005 (-3.39) exhibited strong negative significant general combining ability effects for days to 50% flowering, making them good general combiners. Therefore, these identified lines and testers will be valuable for developing early-maturing rice hybrids.

The cross CMS 23A × JGL 24444 (-10.72) exhibited the most significant and negative *sca* effect, followed by CMS 64A × JGL 21005 (-5.02), both of which are favorable for earliness. Among the lines, CMS 69B (-8.81) was the top general combiner, while JGL 21005 (-3.39) was the best among the testers. These results are consistent with those reported by Rahman (2022) and Maring *et al*. (2023).

For the trait of plant height, negative *gca* effects are more desirable for developing non-lodging and semi-dwarf rice genotypes. The cross CMS 69A × JGL 21005 (-11.29) showed the highest significant negative *sca* effect (Table 2), followed by CMS 69A × IR 65514-5-2-19R-1 (-7.90) and CMS 69A × IR 63870-7-3-2-3-3R (-7.82), which are favourable for this trait. CMS 69B (-5.93) line is a good general combiner, while the best general combiner among the testers is JGL 21005 (-4.57). These findings align with those of Rahman (2022) and Maring *et al*. (2023).

The three parents CMS 14B (1.25), CMS 64B (1.08) and IR 65483-14-1-1-4-13R (0.87) exhibited positive and significant *gca* effect for panicle length. Five hybrids demonstrated positive and significant sca effect. These results are consistent with the findings of Rahman (2022) and Wang *et al*. (2023).

Two lines and two testers, CMS 69B (0.51) and CMS 64B (0.37), along with JGL 27347 (1.12) and JGL 21005 (0.40), exhibited significant positive gca effect for the number of productive tillers per plant. Among these, the cross combinations CMS 69A × JGL 27347 (2.31), CMS 69A × JGL 21005 (2.09) and CMS 64A × JGL 24444 (2.08) demonstrated the highest positive significant *sca* effect (Table 3). These results are consistent with the findings of Islam *et al*. (2022) and Wang *et al*. (2023).

Among the lines, CMS 64B (19.35) exhibited a significant positive *gca* effect, while among the testers, JGL 24444 (49.01), IR 63870-7-3-2-3-3R (18.31) and IR 65483-14-1-1-4-13R (14.11) showed highly positive gca effect for the number of filled grains per panicle. Among the crosses, CMS 69A × JGL 24444 (49.27), followed by CMS 23A × IR 65514-5-2-19R-1 (41.18) and CMS 64A × JGL 29651 (30.10), exhibited the highest positive sca effects. These results align with the findings of Islam *et al.* (2022) and Wang *et al.* (2023).

The *gca* effects of the lines showed that two lines, CMS 23B (0.91) and CMS 69B (0.75), along with five testers: IR 65514-5-2-19R-1 (2.04), IR 63870-7-3-2-3-3R (1.36), IR 63877-43-2-1-3-1R (1.14), JGL 29651 (1.12) and IR 65483-14-1-1-4-13R (0.66) demonstrated significant positive *gca* effects for 1000 grain weight. Among the hybrids, CMS 23A × JGL 24444 (3.59), CMS 69A × JGL 21005 (2.70) and CMS 14A × IR 63877-43-2-1-3-1R (1.72) showed high positive significant *sca* effects. These findings are consistent with earlier reports by Islam *et al.* (2022) and Maring *et al.* (2023).

The genotypes CMS 64B (3.21), IR 65514-5-2-19R-1 (7.98), IR 65483-14-1-1-4-13R (3.99) and IR 63870-7-3-2-3-3R (1.19) demonstrated significant positive *gca* effects for grain yield per plant. Out of the 32 hybrids, nine exhibited significant positive *sca* effects. CMS 64B line showed significant positive *gca* effects for the number of filled grains per panicle, panicle length, and grain yield per plant. The tester IR 65483-14-1-1-4-13R showed significant positive *gca* effects for the number of filled grains per panicle, panicle length, 1000 grain weight and grain yield per plant, while IR 65514-5-2-19R-1 demonstrated significant positive *gca* effects for 1000 grain weight and grain yield per plant. Among the crosses, CMS 14A × IR 65483-14-1-1-4-13R (6.83), followed by CMS 64A × JGL 29651 (6.26), CMS 64A × IR 63870-7-3-2-3-3R (5.48), CMS 23A × IR 65514-5-2-19R-1 (5.18) and CMS 23A × IR 63877-43-2-1-3-1R (5.05) exhibited the highest significant positive *sca* effects for grain yield per plant. These results are consistent with the findings of Islam *et al.* (2022) and Wang *et al.* (2023).

The line CMS 14B (0.08) and the testers IR 63877-43-2-1-3-1R (0.26), JGL 29651 (0.23), IR 65483-14-1-1-4-13R (0.22) and IR 63870-7-3-2-3-3R (0.18) exhibited significant positive *gca* effect for kernel length. Among the 32 hybrids, CMS 69A × JGL 21005 (0.73), CMS 23A × IR 63877-43-2-1-3-1R (0.50), CMS 64A × IR 63870-7-3-2-3-3R (0.46) and CMS 64A × JGL 27347 (0.40) showed the highest significant positive *sca* effects.

Among the lines, CMS 23B (0.14) demonstrated a significantly positive *gca* effect, while among the testers, JGL 29651 (0.11), IR 63870-7-3-2-3-3R (0.05) and IR 65514-5-2-19R-1 (0.05) showed significantly negative *gca* effects for the character of kernel breadth. Among the 32 hybrids, five exhibited positive *sca* effects. These hybrids include CMS 23A × JGL 24444 (0.16), CMS 64A × JGL 27347 (0.16), CMS 69A × JGL 21005 (0.13) and CMS 14A × IR 65483-14-1-1-4-13R (0.13), which demonstrated significant positive *sca* effects.

For the grain length to breadth ratio, CMS 64B (0.20) and CMS 14B (0.15) showed positive and significant *gca* effect. Among the testers, IR 65483-14-1-1-4-13R (0.29) and IR 63877-43-2-1-3-1R (0.15) also reported positive and significant *gca* effects. Among the 32 hybrids, five crosses showed significant positive *sca* effects. Notably, CMS 69A × JGL 24444 (0.31) and CMS 14A × IR 63870-7-3-2-3-3R (0.22) exhibited the highest positive significant *sca* effects. These results are consistent with the findings of Rahman *et al.* (2022) and Al-Daej (2023).

Three testers, JGL 21005 (1.68), IR 63870-7-3-2-3-3R (1.44) and IR 65483-14-1-1-4-13R (1.18), along with one line, CMS 14B (1.82), exhibited positive and significant *gca* effects. Additionally, three hybrids, CMS 23A × JGL 24444 (2.97), CMS 69A × IR 65483-14-1-1-4-13R (2.86) and CMS 23A × IR 63877-43-2-1-3-1R (2.70) showed highly positive and significant *sca* effects for hulling percentage.

For milling percentage, two lines, CMS 23B (1.62) and CMS 14B (0.86), along with four testers: IR 65483-14-1-1-4-13R (1.26), JGL 29651 (1.07), JGL 21005 (1.01) and JGL 24444 (0.99) demonstrated positive and significant *gca* effects. Among the 32 hybrids, eight showed significant positive *sca* effects.

For the character of head rice recovery, CMS 14B (6.17) exhibited a positive significant *gca* effect, while among the testers, IR 65483-14-1-1-4-13R (7.21) and JGL 24444 (3.84) showed positive and significant *gac* effect. Among the 32 hybrids, CMS 23A × IR 63877-43-2-1-3-1R (18.06), CMS 14A × IR 65514-5-2-19R-1 (11.15) and CMS 14A × JGL 21005 (10.49) demonstrated highly significant positive *sca* effects.

The GCA variance of parents and SCA variance of hybrids for different traits are essential for effective hybrid breeding improvements. General combining ability effects and additive gene action are fixable, whereas specific combining ability, which results from non-additive gene action, could be due to dominance, epistasis, or a combination of both, and is not fixable. The success of a hybrid program depends on the results of combining ability, with the predominance of non-additive gene action being a crucial factor for utilizing desirable traits through hybrid breeding. The comparative variances for general combining ability and specific combining ability across various traits and their ratios are shown in Table 4.

In this study, traits such as days to 50% flowering, plant height, panicle length, number of productive tillers per plant, hulling percentage, milling percentage, head rice recovery, and kernel length displayed higher SCA variance than GCA variance, indicating that non-additive gene action plays a dominant role in the inheritance of these traits. Therefore, hybrid breeding would be more advantageous for improving these traits. On the other hand, the GCA variance exceeded the SCA variance for traits like the number of filled grains per panicle, 1000-grain weight, grain yield per plant, kernel breadth and L/B ratio, suggesting that additive gene action dominates the inheritance of these traits. Similar findings have been reported by researchers such as Rahman *et al.* (2022) and Maring *et al.* (2023).

Conclusion

The results from the combining ability analysis indicated that the mean variance for specific combining ability (SCA) was larger than that for general combining ability (GCA) in traits such as days to 50% flowering, plant height, panicle length, number of productive tillers per plant, kernel length, hulling percentage, milling percentage and head rice recovery. This suggests that these traits are primarily influenced by non-additive gene action. In contrast, for traits like the number of filled grains per panicle, 1000-grain weight, grain yield per plant, kernel breadth and L/B ratio, the mean GCA variance was greater than the SCA variance, indicating that these traits are mainly controlled by additive gene action.

The combining ability analysis (Table 5) revealed that the tester IR 65514-5-2-19R-1 was a good general combiner for grain yield per plant, days to 50% flowering, 1000-grain weight, kernel length and kernel breadth. Meanwhile, IR 65483-14-1-1-4-13R was a good general combiner for grain yield per plant, days to 50% flowering, plant height, panicle length, number of filled grains per panicle, 1000-grain weight, kernel length, kernel L/B ratio, hulling percentage, milling percentage and head rice recovery. The tester IR 63870-7-3-2-3-3R was a good combiner for grain yield per plant, days to 50% flowering, plant height, number of filled grains per panicle, 1000-grain weight, kernel length, kernel breadth and hulling percentage. The line CMS 64A was identified as a good combiner for grain yield per plant, panicle length, number of productive tillers per plant, number of filled grains per panicle, kernel L/B ratio and head rice recovery.

Significant positive *gca* effects for grain yield per plant and related traits were observed in parents IR 65514-5-2-19R-1, IR 65483-14-1-1-4-13R, IR 63870-7-3-2-3-3R and CMS 64A, suggesting that these parents could be utilized in developing superior hybrids. Additionally, nine hybrids demonstrated positive *sca* effects for grain yield per plant and related traits. The hybrid CMS 14A × IR 65483-14-1-1-4-13R showed the highest *sca* effects for grain yield per plant, while CMS 23A × IR 65514-5-2-19R-1 exhibited the highest *sca* effects for panicle length. Furthermore, CMS 23A × IR 63877-43-2-1-3-1R displayed the highest positive *sca* effects for milling percentage and head rice recovery. These hybrids are considered excellent specific combiners and are recommended for heterosis breeding.

Table 1 : Analysis of variance for combining ability (Line × Tester) for grain yield and quality traits in rice

Source of Variation	Df	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 perplant (g)
Replicates	2	0.96	8.62	0.13	0.52	112.98	0.05	3.58
Treatments	43	147.87**	175.20**	8.69**	5.10**	7067.25**	26.97**	88.86**
Parents	11	57.56**	164.57**	6.10**	1.78**	14789.61**	49.93**	20.72**
Parents (Line)	3	119.41**	213.49**	5.53**	1.07*	721.31*	20.99**	11.22*
Parents (Testers)	7	34.89**	97.58**	7.20**	2.22**	15805.13**	57.27**	23.91**
Parents (L *vs.* T)	1	30.68**	486.72**	0.20	0.76	49885.87**	85.36**	26.87**
Parents *vs.* Crosses	1	940.36**	0.12	8.94**	31.26**	3183.41**	74.29**	81.79**
Crosses	31	154.35**	184.62**	9.60**	5.43**	4452.34**	17.29**	113.26**
Line Effect	3	1100.23**	485.34	53.57**	7.50	4822.51	24.42	132.59
Tester Effect	7	54.42	95.50	4.96	5.38	9215.44*	40.71**	238.03*
Line × Tester Effect	21	53.20**	171.36**	4.86**	5.15**	2811.76**	8.47**	68.92**
Error	86	0.66	3.82	0.80	0.36	185.02	0.44	3.65
Total	131	48.99	60.15	3.38	1.92	2442.97	9.14	31.62

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

(Cont..)

Source of Variation	Df	Kernel length (mm)	Kernel breadth (mm)	Kernel L/ BRatio.	Hulling (%)	Milling (%)	Head Rice Recovery (%)
Replicates	2	0.007	0.002	0.003	0.32	0.20	13.86
Treatments	43	0.60**	0.08**	0.27**	24.34**	30.98**	305.95**
Parents	11	0.80**	0.15**	0.29**	11.89**	18.36**	327.72**
Parents (Line)	3	0.34**	0.18**	0.47**	13.02**	3.55	308.66**
Parents (Testers)	7	1.11**	0.16**	0.26**	12.52**	18.79**	381.77**
Parents (L *vs.* T)	1	0.03	0.0002	0.007	4.10	59.76**	6.61
Parents *vs.* Crosses	1	0.20**	0.07**	0.07	83.49**	208.07**	465.32**
Crosses	31	0.55**	0.06**	0.27**	26.86**	29.74**	293.09**
Line Effect	3	0.25	0.29**	1.15**	77.78**	57.69	616.16
Tester Effect	7	0.88	0.05	0.31	38.12	25.29	248.10
Line × Tester Effect	21	0.48**	0.02**	0.13**	15.83**	27.23**	261.93**
Error	86	0.02	0.003	0.02	2.22	1.48	4.27
Total	131	0.21	0.03	0.10	9.45	11.14	103.45

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

Table 2 : Estimates of general combining ability (*gca*) effects for lines and testers for grain yield and quality traits in rice

Source	Days to 50% flowering	Plant height (cm)	Panicle length (cm)	No. of productive tillersper plant	No. of filled grains per panicle	1000 - grain weight (g)	Grain yield per plant (g)
Parents							
Lines							
CMS 14B	5.89**	4.03**	1.25**	-0.18	-10.44**	-1.19**	0.24
CMS 23B	-1.77**	-0.95*	-0.38*	-0.70**	-10.75**	0.91**	-1.40**
CMS 64B	4.68**	2.85**	1.08**	0.37**	19.35**	-0.47**	3.21**
CMS 69B	-8.81**	-5.93**	-1.95**	0.51**	1.84	0.75**	-2.05**
Testers							
IR 63870-7-3-2-3-3R	-0.97**	-1.67**	0.41	0.22	18.31**	1.36**	1.19*
IR 63877-43-2-1-3-1R	1.02**	0.54	-0.15	-0.78**	-31.54**	1.14**	-4.30**
IR 65483-14-1-1-4-13R	1.77**	5.19**	0.87**	-0.92**	14.11**	0.66**	3.99**
IR 65514-5-2-19R-1	2.43**	0.27	-0.04	0.22	-3.23	2.04**	7.98**
JGL 21005	-3.39**	-4.57**	-0.93**	0.40*	6.14	-1.71**	-5.51**
JGL 24444	1.77**	-1.67**	0.37	0.06	49.01**	-3.03**	-1.97**
JGL 27347	-0.47*	1.13*	0.36	1.12**	-26.01**	-1.59**	-2.07**
JGL 29651	-2.14**	0.76	-0.89**	-0.33	-26.80**	1.12**	0.70
CD 95%GCA(Line)	0.33	0.79	0.36	0.24	5.55	0.27	0.77
CD 95%GCA(Tester)	0.47	1.12	0.51	0.34	7.84	0.38	1.10

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

(Cont...)

Source	Kernel length (mm)	Kernel breadth (mm)	Kernel L/ B Ratio.	Hulling (%)	Milling (%)	Head Rice Recovery (%)
Parents						
Lines						
CMS 14B	0.08*	-0.07**	0.15**	1.82**	0.86**	6.17**
CMS 23B	-0.002	0.14**	-0.24**	0.43	1.62**	-6.07**
CMS 64B	0.06	-0.09**	0.20**	0.22	-0.64*	0.93*
CMS 69B	-0.14**	0.02	-0.12**	-2.48**	-1.84**	-1.03*
Testers						
IR 63870-7-3-2-3-3R	0.18**	0.05**	-0.004	1.44**	-0.01	-0.15
IR 63877-43-2-1-3-1R	0.26**	-0.007	0.15**	-1.71**	-0.72*	0.16
IR 65483-14-1-1-4-13R	0.22**	-0.07**	0.29**	1.18**	1.26**	7.21**
IR 65514-5-2-19R-1	-0.13**	0.05**	-0.16**	-2.96**	-3.02**	0.73

JGL 21005	-0.48**	-0.04*	-0.20**	1.68**	1.01**	-1.50*
JGL 24444	-0.07	-0.03	0.01	0.14	0.99**	3.84**
JGL 27347	-0.21**	-0.06**	-0.01	-1.33**	-0.59	-1.83**
JGL 29651	0.23**	0.11**	-0.07	-1.33**	1.07**	-8.46**
CD 95%GCA(Line)	0.06	25.35	0.06	0.60	0.49	0.84
CD 95%GCA(Tester)	0.09	35.85	0.08	0.86	0.70	1.19

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

Table 3 : Estimates of specific combining ability (*sca*) effects for yield and quality traits in rice

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	1000-grain weight (g)	Grain yield per plant (g)
C	CMS 14A × IR 63870-7-3-2-3-3R	0.35	3.66**	-0.26	0.88*	29.46**	1.66**	2.57*
2	CMS 14A × IR 63877-43-2-1-3-1R	-2.97**	0.91	0.56	1.30**	-23.64**	1.72**	-5.11**
3	CMS 14A × IR 65483-14-1-1-4-13R	-2.72**	-2.93*	-0.53	1.71**	22.79**	-0.86*	6.83**
4	CMS 14A × IR 65514-5-2-19R-1	-0.72	1.18	-0.74	-1.24**	19.61*	-0.43	-2.88*
5	CMS 14A × JGL 21005	0.10	-2.03	0.14	-0.95**	-19.17*	-0.38	1.29
6	CMS 14A × JGL 24444	4.60**	0.79	0.83	-0.81*	-29.23**	-0.09	2.59*
7	CMS 14A × JGL 27347	3.18**	-0.07	-0.02	-1.21**	-2.87	-1.23**	-5.14**
8	CMS 14A × JGL 29651	-1.81**	-1.50	0.03	0.32	3.04	-0.38	-0.14
9	CMS 23A × IR 63870-7-3-2-3-3R	3.02**	-5.87**	-1.76**	-0.32	-42.63**	-2.43**	-7.88**
10	CMS 23A × IR 63877-43-2-1-3-1R	1.68**	0.84	0.73	0.22	27.35**	-0.31	5.05**
11	CMS 23A × IR 65483-14-1-1-4-13R	-1.39**	-7.07**	0.03	0.06	-41.49**	0.36	-1.30
12	CMS 23A × IR 65514-5-2-19R-1	-0.06	6.58**	2.39**	1.20**	41.18**	-0.97*	5.18**
13	CMS 23A × JGL 21005	6.10**	15.19**	1.57**	-0.63	0.60	-0.08	0.94
14	CMS 23A × JGL 24444	-10.72**	-5.47**	-0.93	0.29	17.80*	3.59**	-0.43
15	CMS 23A × JGL 27347	-2.81**	-1.48	-1.51**	-0.72*	0.96	0.23	1.91
16	CMS 23A × JGL 29651	4.18**	-2.70*	-0.53	-0.09	-3.78	-0.39	-3.46**
17	CMS 64A × IR 63870-7-3-2-3-3R	-1.77**	10.04**	1.36*	0.46	-6.47	1.28**	5.48**
18	CMS 64A × IR 63877-43-2-1-3-1R	0.89	-4.37**	-1.20*	-0.72*	-1.34	-1.66**	1.12
19	CMS 64A × IR 65483-14-1-1-4-13R	-1.18*	-3.42**	-0.96	-0.91*	14.85	-0.01	-9.41**
20	CMS 64A × IR 65514-5-2-19R-1	0.47	0.13	-1.44**	-0.71*	-13.72	0.84*	-0.36
21	CMS 64A × JGL 21005	-5.02**	-1.85	-0.82	-0.51	26.35**	-2.23**	-3.77**
22	CMS 64A × JGL 24444	6.14**	7.17**	0.86	2.08**	-37.84**	-0.71	0.99
23	CMS 64A × JGL 27347	3.06**	-6.49**	0.61	-0.37	-11.94	0.94*	-0.31
24	CMS 64A × JGL 29651	-2.60**	-1.19	1.59**	0.69	30.10**	1.55**	6.26**
25	CMS 69A × IR 63870-7-3-2-3-3R	-1.60**	-7.82**	0.66	-1.01**	19.64*	-0.51	-0.17
26	CMS 69A × IR 63877-43-2-1-3-1R	0.39	2.62*	-0.09	-0.80*	-2.36	0.24	-1.05
27	CMS 69A × IR 65483-14-1-1-4-13R	5.31**	13.43**	1.46**	-0.85*	3.84	0.50	3.89**
28	CMS 69A × IR 65514-5-2-19R-1	0.31	-7.90**	-0.20	0.75*	-47.07**	0.57	-1.93
29	CMS 69A × JGL 21005	-1.18*	-11.29**	-0.89	2.09**	-7.79	2.70**	1.53
30	CMS 69A × JGL 24444	-0.02	-2.49*	-0.76	-1.56**	49.27**	-2.78**	-3.15**
31	CMS 69A × JGL 27347	-3.43**	8.05**	0.93	2.31**	13.84	0.05	3.54**
32	CMS 69A × JGL 29651	0.22	5.40**	-1.09*	-0.91*	-29.37**	-0.77*	-2.65*
33	CD 95% SCA	0.94	2.25	1.03	0.69	15.69	0.77	2.20

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

S. No	Crosses	Kernel length (mm)	Kernel breadth (mm)	Kernel L/ B Ratio.	Hulling (%)	Milling (%)	Head Rice Recovery (%)
34	CMS 14A × IR 63870-7-3-2-3-3R	0.39**	0.005	0.22*	1.29	0.69	7.36**
35	CMS 14A × IR 63877-43-2-1-3-1R	-0.11	0.05	-0.14	-1.01	-6.79**	-16.63**
36	CMS 14A × IR 65483-14-1-1-4-13R	0.35**	0.13**	-0.04	0.89	3.15**	8.10**
37	CMS 14A × IR 65514-5-2-19R-1	0.14	-0.01	0.10	-0.53	3.34**	11.15**
38	CMS 14A × JGL 21005	-0.18	-0.07	0.01	0.05	0.007	10.49**
39	CMS 14A × JGL 24444	-0.03	-0.02	0.02	-2.40**	-0.77	-4.67**

40	CMS 14A × JGL 27347	-0.36**	-0.08*	-0.05	1.51	0.88	-8.37**
41	CMS 14A × JGL 29651	-0.20*	0.004	-0.12	0.19	-0.51	-7.43**
42	CMS 23A × IR 63870-7-3-2-3-3R	0.03	-0.11**	0.19*	0.17	-0.32	-4.04**
43	CMS 23A × IR 63877-43-2-1-3-1R	0.50**	-0.07	0.38	2.70**	6.25**	18.06**
44	CMS 23A × IR 65483-14-1-1-4-13R	-0.09	0.03	-0.15	-3.08**	-3.96**	-12.77**
45	CMS 23A × IR 65514-5-2-19R-1	-0.37**	-0.02	-0.14	2.45**	0.72	-5.28**
46	CMS 23A × JGL 21005	-0.41**	-0.00	-0.22*	-1.83*	-3.34**	-5.15**
47	CMS 23A × JGL 24444	0.15	0.16**	-0.16	2.97**	1.63*	-5.44**
48	CMS 23A × JGL 27347	0.21*	0.02	0.08	-1.60	-0.13	8.73**
49	CMS 23A × JGL 29651	-0.03	-0.01	0.03	-1.78*	-0.83	5.91**
50	CMS 64A × IR 63870-7-3-2-3-3R	0.46**	0.08*	0.09	0.86	0.74	-5.23**
51	CMS 64A × IR 63877-43-2-1-3-1R	-0.32**	-0.05	-0.07	2.15*	3.28**	7.49**
55	CMS 64A × IR 65483-14-1-1-4-13R	-0.23*	-0.14**	0.21*	-0.67	-0.93	1.75
53	CMS 64A × IR 65514-5-2-19R-1	0.03	-0.008	0.009	0.70	-1.18	0.88
54	CMS 64A × JGL 21005	-0.13	-0.06	0.01	-0.38	1.18	-7.63**
55	CMS 64A × JGL 24444	-0.34**	-0.03	-0.17*	-1.87*	-2.43**	5.56**
56	CMS 64A × JGL 27347	0.40**	0.16**	-0.05	-1.55	-1.34	-1.59
57	CMS 64A × JGL 29651	0.13	0.04	-0.02	0.76	0.69	-1.24
58	CMS 69A × IR 63870-7-3-2-3-3R	-0.89**	0.02	-0.51**	-2.33**	-1.11	1.91
59	CMS 69A × IR 63877-43-2-1-3-1R	-0.07	0.06	-0.16	-3.84**	-2.74**	-8.93**
60	CMS 69A × IR 65483-14-1-1-4-13R	-0.02	-0.02	-0.01	2.86**	1.74*	2.91*
61	CMS 69A × IR 65514-5-2-19R-1	0.20*	0.04	0.03	-2.62**	-2.87**	-6.75**
62	CMS 69A × JGL 21005	0.73**	0.13**	0.19*	2.15*	2.15**	2.30
63	CMS 69A × JGL 24444	0.22*	-0.11**	0.31**	1.29	1.57*	4.55**
64	CMS 69A × JGL 27347	-0.26**	-0.10**	0.03	1.64	0.59	1.24
65	CMS 69A × JGL 29651	0.09	-0.03	0.11	0.83	0.66	2.75
66	CD 95% SCA	0.18	71.70	0.17	1.721	1.40	2.38

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

Table 4 : Estimates of general and specific combining ability variance, proportionate and gene action in rice

Character	Source of variation			Nature of GeneAction
	σ^2gca	σ^2 sca	σ^2gca/ σ^2 sca	
Days to 50 % flowering	0.23	39.26	0.006	Non-Additive
Plant height (cm)	0.074	107.21	0.001	Non-Additive
Panicle length (cm)	0.76	3.37	0.22	Non-Additive
Number of productive tillers per plant	0.62	2.91	0.21	Non-Additive
Number of filled grains per panicle	676.92	343.37	1.97	Additive
1000 grain weight (g)	4.17	2.18	1.91	Additive
Grain yield per plant (g)	63.74	39.09	1.63	Additive
Kernel length (mm)	0.23	0.75	0.31	Non-Additive
Kernel breadth (mm)	0.01	0.004	3.46	Additive
Kernel L/ B Ratio.	0.08	0.07	1.12	Additive
Hulling (%)	8.77	13.68	0.64	Non-Additive
Milling (%)	1.14	1.89	0.60	Non-Additive
Head Rice Recovery (%)	51.98	240.41	0.21	Non-Additive

Table 5 : Promising general and specific combiners for grain yield and quality traits in rice

S.No	Parent	Characters
1	IR 65514-5-2-19R-1	Grain yield per plant (g), days to 50% flowering, 1000 - grain weight (g), kernel length (mm), kernelbreadth (mm).
2	IR 65483-14-1-1-4-13R	Grain yield per plant (g), days to 50% flowering, plant height (cm), panicle length (cm), no. of filled grains per panicle, 1000 - grain weight (g), kernel length (mm), kernel L/ B Ratio, hulling (%), milling (%), head rice recovery (%)
3	CMS 64B	Grain yield per plant (g), panicle length (cm), no. of productive tillers per plant, no. of filled grains perpanicle, kernel L/ B Ratio, head rice recovery (%)
4	IR 63870-7-3-2-3-3R	Grain yield per plant (g), days to 50% flowering, plant height (cm), no. of filled grains per panicle, 1000 - grain weight (g), kernel length (mm), kernel breadth (mm), hulling (%)

(Cont...)

S.No	Cross	Characters
1	CMS 14A × IR 65483-14-1-1-4-13R	Grain yield per plant (g), days to 50% flowering, plant height (cm), no. of productive tillersper plant, no. of filled grains per panicle
2	CMS 64A × JGL 29651	Grain yield per plant (g), days to 50% flowering, panicle length (cm), no. of filled grains per panicle, 1000 - grain weight (g),
3	CMS 64A × IR 63870-7-3-2-3-3R	Grain yield per plant (g), days to 50% flowering, panicle length (cm), 1000 - grain weight (g),kernel length (mm) and kernel breadth (mm)
4	CMS 23A × IR 65514-5-2-19R-1	Grain yield per plant (g), panicle length (cm), no. of productive tillers per plant, no. of filledgrains per panicle and hulling (%)
5	CMS 23A × IR 63877-43-2-1-3-1R	Grain yield per plant (g), no. of filled grains per panicle, grain yield per plant (g), kernel length(mm), hulling (%), milling (%) and head rice recovery (%).

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