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Research Article

Deciphering the estimates of combining ability and heterosis for selecting superior parents and hybrids in rice (*Oryza sativa* L.)

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Abstract
Twenty F_1s, parents and checks *viz*., MTU 1010 and RNR 15048 were assessed for grain yield and its contributing attributes to study combining ability and heterosis. The mean of hybrids was greater than that of the parents except for days to 50% flowering and plant height. For majority of the investigated characters, the analysis of variance indicated considerable variations among parents and hybrids. Degree of dominance was more than unity for majority of traits including grain yield. For the examined characters, SCA variances were equal to GCA variances, indicating the dominance of additive and non-additive gene activity. The traits days to 50 % flowering, plant height, panicle length, test weight, kernel length and kernel length/breadth ratio showed additive gene action whereas the remaining traits showed non-additive gene action. The *gca* effects revealed that among the lines IR 72 had significant *gca* effects in desired direction for yield and yield attributing traits. Among the 20 hybrids, MTU 1001 x Akshyadhan was found to be a good specific combiner for grain yield per plant. Similarly, the hybrids NLR 34449 x IR10N270 and IR 72 x IR10N270 were found to be good specific combiners for grain yield and yield contributing characters. The standard heterosis of these three hybrids was positively significant over the check varieties MTU 1010 and RNR 15048. Based on mean, sca and heterosis estimates, MTU 1001 x Akshyadhan, NLR 34449 x IR10N270 and IR 72 x IR10N270 were identified as promising hybrids.

Keywords: Combining ability, gene action, heterosis and hybrid rice

INTRODUCTION

Rice is a staple food crop cultivated in Asian continent (Vinitha *et al.,* 2020). There is a dire need to increase the rice yield proportionally to feed the ever-increasing population, which rises in geometrical proportion (Gunasekaran *et al.,* 2023). Theoretically, rice still has great yield potential to be tapped and there are many ways to raise rice yield, such as molecular breeding, new plant type and hybrid rice technology. The success of hybrid rice technology in China (Lin and Yuan, 1980) is seen as a crucial and readily adaptable solution to address the ongoing food challenges faced by different nations (Rai, 2009; Sanghera and Wani, 2008; Virmani *et al*., 2003). Hybrid rice is produced by crossing the male parent (restorer lines) and female parental lines (cytoplasmic male sterile lines (CMS)) (Ashraf *et al.,* 2024).

Genetic variation is a pre-requisite for any plant breeding programme (Kylash *et al.,* 2023). Conscientious selection of suitable genotypes as parents for hybridization lays the foundation for an efficient hybrid breeding programme which eventually results in the development of potential high yielding hybrids. The phenotypic performance of parents alone proves to be an unreliable strategy since lines with superior phenotype may not necessarily yield favourable recombination in subsequent generations (Nivedha *et al.,* 2024). Relying solely on individual performance is inadequate for this selection process, which necessitates the consideration of gene actions. Therefore, the purpose of conducting combining ability analysis is to assess a particular parental line's capacity to transmit genetic traits to its offspring (Aly, 2013; Sprague and Tatum, 1942).

Biometrical methods, specifically combining ability studies, allow for the evaluation of the parent's contributions in a cross and their combining ability when crossed with others. One effective mating design used for this purpose is the Line × Tester analysis, developed by Kempthorne (1957). This method enables the estimation of general combining ability (GCA) and specific combining ability (SCA), facilitating the efficient screening of parental lines. Combining ability analysis stands out as a potent method for assessing the impact of combining abilities, facilitating the selection of favourable parents and crosses to leverage heterosis (Sarker *et al.,* 2002). This knowledge gives breeders insights into the nature and relative magnitude of genetic variances that can be stabilized through breeding efforts, distinguishing between fixable and non-fixable components arising from dominance or epistasis (Pratap *et al.,* 2013). Combining ability analysis besides furnishing knowledge on nature and magnitude of gene effects governing yield and yield contributing traits, also helps in recognizing the superior parents, cross combinations and development of systemic breeding plan for augmenting yield (AnandaLekshmi *et al.,* 2020).Breeding strategies based on the selection of hybrids require expected level of heterosis as well as the specific combining ability (Satheesh kumar *et al*., 2016). In this study, 20 rice hybrid combinations were evaluated for combining ability and heterosis to identify good combiners among parents and superior hybrid combinations for commercial exploitation.

MATERIALS AND METHODS

The experiment was done at the Institute of Rice Research, Agricultural Research Institute, Hyderabad, Telangana, India. A total of four lines and five testers (**Table 1**) were planted in three staggered sowings during *rabi* season of 2018-19 and hybridization among the parents was undertaken in a line × tester mating fashion, resulting in 20 hybrids. During the *kharif,* 2019, the 20 hybrids, along with their nine parents and two standard checks (RNR 15048 and MTU 1010), were raised in a single row, each measuring 4 meters in length. The experiment adopted a randomized block design (RBD) with two replications and a spacing of 20 × 15 cm.

Observations on plant height (in centimeters), effective bearing tillers, panicle length (in cm), spikelet fertility (percentage) and number of grains per panicle were recorded from five randomly selected plants. For days to 50% flowering and grain yield (in kg per plot), the observations were recorded at the whole plot level. Test weight (in grams) was assessed from a random sample collected within each plot and qualitative traits, namely, head rice recovery (%), kernel length (mm), kernel breadth (mm), KL/KB, kernel expansion ratio, Alkali spreading value, gel consistency, amylose content (%), and kernel length after cooking (mm) were obtained from random grain sample taken from each plot in each replication. Days to 50% flowering is however, recorded on plot basis.

The character means of each replication were subjected to combining ability analysis. The significance of different genotypes was tested using the procedure outlined by Kempthorne (1957). Additionally, heterosis in comparison to the better parent and standard variety (MTU 1010 and RNR 15048) were assessed following the approach proposed by Fonseca and Patterson (1968). All the data analyses were performed using Indostat version 9.1.

Table 1. Experimental materials utilized in the study

S. No	Genotype	Source
	Lines	
1.	IR 64	IRRI, Philippines
2.	NLR 34449	RARS, Nellore
3.	IR 72	IRRI, Philippines
4.	MTU 1001	RARS, Maruteru
	Testers	
1.	AAGP - 9772	IIRR, Hyderabad
2.	RNR 19399	RRC, ARI, Hyderabad
3.	Akshyadhan	IIRR, Hyderabad
4.	RNR 17497	RRC, ARI, Hyderabad
5.	IRION270	IRRI, Philippines

RESULTS AND DISCUSSION

The hybrids exhibited higher *per se* performance for most of the traits compared to their respective parents. Among the 30 hybrids, none of the hybrids was superior for all the traits studied. The hybrids Akshyadhan x MTU 1001, IR10N270 x NLR 34449, IR10N270 x IR 72, AAGP 9772 x MTU 1001, AAGP -9772 x IR 64, Akshyadhan x NLR 34449 and RNR 19399 x NLR34449 recorded better *per se* performance for most of the yield attributing traits. Three hybrids *viz.,* NLR 34449 X IR10N270 (23.07), IR 72 X IR10N270 (22.26) and MTU 1001 X AKSHYADHAN (24.88) outperformed and four hybrids namely IR 64 X AAGP -9772 (9.42), NLR 34449 X AAGP -9772 (2.72), NLR 34449 X AKSHYADHAN (6.51), and MTU 1001 X AAGP -9772 (11.08) were comparable to the check variety MTU 1010 in terms of grain yield per plant.

The analysis of variance indicated that there were significant variations observed for all the traits examined in the hybrids (**Table 2**). Mean sum of squares for the crosses was partitioned into lines, testers and line x tester components. In the case of lines, significant variances were observed for all the traits except ear bearing tillers and panicle length whereas among in testers. In lines × testers, significant variances were observed for most of the traits except days to 50% flowering, ear bearing tillers, panicle length, filled grains, kernel length, kernel breadth, amylose content and grain yield. Parents × hybrids showed significant variance for all characters except ASV (alkali spreading value) indicating the superiority of hybrids and the presence of heterosis for almost all the traits studied. The findings underscore the significance of conducting combining ability studies in the material. They highlight the potential to identify promising parent plants and hybrid combinations that can effectively enhance yield through improvements in its various components.

In the present investigation, the degree of dominance was more than unity for the traits effective bearing tillers (1.50), kernel breadth (1.03), head rice recovery (1.01) kernel

Table 2. Analysis of variance for different characters in rice

Source of variation	d.f	DFF	PH	EBT	PL	FG	TW	GY	KL
Replications	2	5.21	0.75	0.13	0.11	20.88	0.32	5.49	0.026
Treatments	28	145.27 **	121.09 **	7.08 **	8.87 **	3614.82 **	38.50**	81.87 **	0.52 **
Parents	8	134.43 **	187.09 **	4.52 **	6.12 **	3704.35 **	53.95**	44.69 **	0.61**
Lines	3	112.53 **	152.49 **	1.63	1.923	3544.95 **	76.79**	62.84 **	0.92 **
Testers	4	182.73 **	217.19 **	7.81 **	9.09 **	4677.75 **	48.43**	39.68 **	0.49 **
Line x Tester	1	6.89	170.47 **	0.01	6.78	288.94	7.49*	10.24	0.17
Parents x hybrids	1	1698.91 **	228.11 **	8.66 **	83.36 **	18024.71 **	9.78**	175.51 **	0.37**
Hybrids	19	68.07 **	87.67 **	8.07 **	6.110 **	2818.71 **	33.51**	92.60 **	0.49 **
Error	56	8.64	10.20	0.86	0.95	193.69	1.16	4.80	0.05
Total	86	53.04	46.08	2.87	3.51	1303.52	13.30	29.91	0.20

*Significant at 0.05% level, **Significant at 0.01%, d.f- degrees of freedom, DFF- days to 50 % flowering, PH-plant height, EBT-Effective bearing tillers, PL- Panicle length, FG-No. of filled grains per panicle, TW-1000 Grain weight, GY-Grain yield per plant, KL-kernel length

Table 2. continued…

Source of variation	d.f	KB	KL/KB	HRR	KLAC	KER	ASV	GC	AC
Replications	2	0.01	0.02	1.78	0.004	0.002	0.003	6.07	2.72*
Treatments	28	0.09**	0.32**	79.20**	1.97**	0.07**	3.42**	578.28 **	32.01**
Parents	8	0.10**	0.20**	114.61**	3.84**	0.08**	3.75**	335.77 **	38.98**
Lines	3	0.09**	0.21**	75.73**	0.68**	0.02**	6.19**	157.52 **	38.55**
Testers	4	0.12**	0.22**	155.23**	6.68**	0.13**	1.73**	279.27 **	49.04**
Line x Tester	1	0.01	0.10*	68.79**	1.96**	0.03*	4.54**	1096.54 **	0.01
Parents x hybrids	1	0.17**	0.95**	110.26**	2.21**	0.03*	0.06	819.33 **	93.62**
Hybrids	19	0.08**	0.34**	62.66**	1.17**	0.07**	3.45**	667.70 **	25.83**
Error	56	0.01	0.02	1.18	0.01	0.01	0.13	15.04	0.81
Total	86	0.03	0.12	26.60	0.65	0.03	1.20	198.21	11.01

* Significant at 0.05% level, **Significant at 0.01%, d.f- degrees of freedom, KB-Kernel breadth, KL/KB -Kernel length/ Kernel breadth ratio, HRR-Head rice recovery, KLAC- Kernel length after cooking, KER-Kernel expansion ratio, ASV-Alkali spreading value, GC- Gel consistency, AC-Amylose content

length after cooking (1.72), kernel elongation ratio (1.00), ASV (1.53), GC (2.16) and grain yield (1.90) indicating predominance of non-additive gene action, while days to 50 per cent flowering (0.68), plant height (0.23), panicle length (0.49), test weight (0.25) filled grains,(0.87) test weight (0.25), kernel length (0.13) L/B ratio (0.62) and amylose content (0.89) exhibited additive gene action. GCA variances were higher than SCA variances for days to 50 % flowering, plant height, panicle length, filled grains, test weight, kernel length, L/B ratio and amylose content, which again confirmed the predominance of additive gene action for these traits (**Table 3**). Similar to the present findings, earlier workers reported the importance of additive components in rice for days to 50 per cent flowering (Parimala *et al.,* 2018), plant height (Ramesh *et al*., 2017; Virender *et al.,* 2020a) panicle length (Rukmini *et al.,* 2018), test weight and grain yield per plant (Sanjeev *et al.,* 2007), 100-grain weight (Aarti and Hemant, 2021).

Among the lines, the *gca* effect was significant and positive for IR 72 (1.79) for grain yield per plant whereas in testers Akshyadhan (2.83) exhibited significant and positive *gca* effect for grain yield per plant. However, MTU 1001 (-2.00) and RNR 17497 (-4.35) recorded significant negative *gca* effects among lines and testers, respectively and hence identified as poor combiners for grain yield. The *gca* effects revealed that among the lines IR 72 had significant *gca* effects in the desired direction for important traits *viz.,* grain yield per plant, days to 50 % flowering, plant height, ear bearing tillers, panicle length, kernel length after cooking, and test weight (**Table 4**). Among the testers, Akshyadhan was a good general combiner for the traits *viz*., grain yield per plant, panicle length, kernel length after cooking, and test weight.

The *sca* effects revealed that among the 20 hybrids, MTU 1001 x Akshyadhan (7.80) had highest significant positive *sca* effect for grain yield per plant followed by MTU 1001 x AAGP 9772 (6.20), NLR 34449 x IR10N270 (5.96), IR 72 x IR10N270 (4.99), IR 64 x AAGP 9772 (4.60), NLR 34449 x RNR 19399 (2.97) and were considered as desirable hybrids (**Table 5**). The hybrid IR 64 x RNR 19399 exhibited significant and negative *sca* effects for days to flowering (-3.66) and considered to be highly desirable for earliness. Four hybrids namely, IR 72 x RNR 17498 (33.66), NLR 34449 x RNR 19399 (31.78), MTU 1001 x AAGP 9772 (23.66) and IR 64 x Akshyadhan (16.42) exhibited significant positive *sca* effect for filled grains. The hybrid MTU 1001 x Akshyadhan (1.15) recorded significant positive *sca* effects for panicle length. A hybrid NLR 34449 x IR10N270 (1.39) exhibited significant positive effect for test weight. Whereas for quality traits, MTU 1001 x AAGP 9772 (0.35) recorded significant positive effect for kernel length. The hybrid MTU 1001 x RNR 19399 recorded significant negative (-0.28) and positive (0.44) effect for kernel breadth and L/B ratio respectively, which is desirable for more slender grain selection. Six hybrids *viz.,* MTU 1001 x AAGP 9772 (5.43), NLR 34449 x IR10N270 (4.57), IR 64 x RNR 17497 (4.09), IR 72 x Akshyadhan (3.52) and IR64 x RNR 19399 (2.78) exhibited significant positive *sca* effect for

Table 3. Estimates of general and specific combining ability variances and proportionate gene action in rice

Character	Source of variation			Degree of Dominance (σ^2sca/ σ^2gca)$^{1/2}$	Nature of gene action
	σ^2gca	σ^2sca	σ^2gca/ σ^2sca		
Days to 50% flowering	32.55	30.27	1.08	0.96	Additive
Plant height (cm)	56.41	6.32	8.93	0.34	Additive
Effective bearing tillers	2.17	9.85	0.22	2.13	Non-Additive
Panicle length (cm)	3.38	1.67	2.02	0.70	Additive
Number of filled grains per panicle	1310.63	2012.66	0.65	1.24	Non-Additive
Test weight (g)	24.97	3.24	7.70	0.36	Additive
Grain yield per plant (g)	18.55	134.10	0.14	2.69	Non-Additive
Kernel length (mm)	0.39	0.01	28.85	0.19	Additive
Kernel Breadth(mm)	0.03	0.06	0.47	1.46	Non-Additive
Kernel Length/Breadth Ratio	0.21	0.17	1.28	0.88	Additive
Head rice recovery (%)	27.03	56.04	0.48	1.44	Non-Additive
Kernel length after cooking (mm)	0.30	1.76	0.17	2.43	Non-Additive
Kernel Elongation ratio	0.03	0.06	0.50	1.42	Non-Additive
Alkali spreading value	0.96	4.51	0.21	2.17	Non-Additive
Gel Consistency (mm)	114.10	1064.35	0.11	3.05	Non-Additive
Amylose content (%)	13.67	22.04	0.62	1.27	Non-Additive

σ^2: variances; gca: general combining ability; sca: specific combining ability.

Table 4. Estimates of general combining ability effects in lines and testers for yield and yield contributing characters in rice

Parent	DFF	PH	EBT	PL	FG	TW	GY	KL
Lines								
IR 64	-0.17	-1.65	-0.73**	0.83**	-3.91	1.38**	-0.81	0.48**
NLR 34449	-0.17	0.97	0.41	-0.64*	23.52**	-3.66**	1.01	0.16*
IR 72	-1.57*	-2.80**	1.03**	0.51*	-8.57*	0.87**	1.79**	-0.25**
MTU 1001	1.90*	3.48**	-0.70**	-0.71**	-11.05**	1.40**	-2.00**	-0.39**
Tester								
AAGP - 9772	-3.97**	-3.49**	0.40	-1.11**	-21.20**	3.70**	1.06	0.28**
RNR 19399	-2.80**	0.63	-0.70*	0.27	27.11**	-0.60	-0.77	0.07
Akshyadhan	5.78**	8.02**	-0.46	1.83**	-21.70**	1.35**	2.83**	-0.04
RNR 17497	-1.88*	-1.17	-0.15	-0.51	4.38	-2.98**	-4.35**	-0.11
IRION270	2.87**	-4.00**	0.91**	-0.48	11.42**	-1.47**	1.22	-0.19**

* Significant at 0.05% level, **Significant at 0.01%   DFF- days to 50 % flowering, PH-plant height, EBT- Effective bearing tillers, PL-Panicle length, FG-No. of filled grains per panicle, TW-1000 Grain weight, GY-Grain yield per plant, KL-kernel length

Table 4. continued..

Parent	KB	KL/KB	HRR	KLAC	KER	ASV	GC	AC
LINES								
IR 64	-0.01	0.26**	3.14**	0.17**	-0.06**	-0.31**	-0.40	2.24**
NLR 34449	-0.10**	0.25**	-0.61*	0.23**	0.13**	-0.51**	-5.63**	1.99**
IR 72	0.03	-0.19**	-1.34**	0.13**	-0.05*	0.53**	1.47	-2.66**
MTU 1001	0.08**	-0.31**	-1.19**	-0.52**	-0.02	0.29**	4.57**	-1.57**
TESTER								
AAGP - 9772	0.08**	-0.01	1.26**	-0.14**	-0.10**	0.60**	-8.28**	0.02
RNR 19399	-0.01	0.05	4.60**	0.10**	0.11**	-0.69**	-4.66**	0.40
Akshyadhan	0.13**	-0.21**	-1.50**	0.00	-0.05*	0.39**	8.22**	-0.17
RNR 17497	-0.11**	0.12**	-3.71**	0.15**	0.05*	-0.23*	0.59	0.16
IRION270	-0.10**	0.04	-0.65*	-0.11**	-0.02	-0.07	4.13**	-0.42

* Significant at 0.05% level, **Significant at 0.01%, KB-Kernel breadth, KL/KB -Kernel length/ Kernel breadth ratio, HRR-Head rice recovery, KLAC- Kernel length after cooking, KER-Kernel elongation ratio, ASV-Alkali spreading value, GC- Gel consistency, AC-Amylose content

head rice recovery. Four hybrids *viz.,* IR 64 x IR10N270 (1.23), MTU 1001 x IR10N270 (1.13), IR 72 x RNR 17497 (0.43) and IR 72 AAGP 9772 (0.41) recorded significant positive effect for kernel length after cooking. Hybrids IR 64 x IR10N270 (0.19), NLR 34449 x Akshayadhan (0.19) and MTU 1001 x IR10N270 (0.16) recorded significant positive effect for kernel elongation ratio. The estimates of combining ability effects aid in selecting desirable parents, crosses, as well as breeding procedure for further improvement (Sarkar *et al*., 2002, and Raju *et al*, 2014).

The hybrid MTU 1001 x Akshyadhan was found to be good specific combiner for traits *viz., g*rain yield per plant, ear bearing tillers, panicle length and amylose content. Similarly, the hybrids MTU 1001 x AAGP 9772, NLR 34449 x IR10N270, IR 72 x IR10N270, IR 64 x AAGP -9772 and NLR 34449 x RNR 19399 were found to be good specific combiners for effective bearing tillers, number of filled grains per panicle and grain yield.

The investigation on heterosis revealed that the range of heterobeltiosis over the better parent for grain yield varied from -56.08% to 62.91% (**Table 6**). Eight hybrids showed significant positive heterosis for this trait. Highest significant positive heterobeltiosis was recorded by AAGP -9772 x IR 64, followed by NLR 34449 x IR10N270, IR 72 x IR10N270, IR 72 x Akshyadhan, NLR 34449 x Akshyadhan, IR 72 x AAGP -9772, IR 72 x RNR 17497 and MTU 1001 x Akshyadhan.

Three hybrids exhibited positive and significant standard

Table 5. Estimates of specific combining ability effects in crosses for yield and yield contributing characters in rice

S. No.	Hybrids	DF	PH	EBT	PL	FG	TW	GY	KL
1	IR 64 X AAGP -9772	-1.17	-0.61	-0.22	-1.09	-12.01	1.04	4.61**	-0.11
2	IR 64 X RNR -19399	-3.67*	3.19	0.55	0.65	-21.85**	-0.07	2.39	-0.05
3	IR 64 X AKSHYADHAN	-1.25	-2.60	-0.42	0.20	16.42*	0.47	-5.00**	0.01
4	IR 64 X RNR -17497	6.08**	-0.81	0.34	0.20	15.21	0.56	-0.62	0.07
5	IR 64 X IR10N270	0.00	0.83	-0.26	0.04	2.23	-2.01**	-1.37	0.08
6	NLR 34449 X AAGP -9772	-2.50	-1.77	-0.42	0.24	-5.97	-1.23	-8.04**	-0.07
7	NLR34449 X RNR -19399	2.00	0.57	2.01**	0.54	31.79**	-0.15	2.98*	0.12
8	NLR 34449 X AKSHYADHAN	3.42	2.25	-0.09	-0.13	5.86	-0.61	0.31	0.01
9	NLR 34449 X RNR -17497	-3.25	0.68	-2.09**	0.09	-31.15**	0.60	-1.22	-0.02
10	NLR 34449 X IR10N270	0.33	-1.73	0.60	-0.75	-0.53	1.39*	5.97**	-0.04
11	IR 72 X AAGP -9772	0.90	2.87	-0.04	0.23	-5.68	0.71	-2.78*	-0.16
12	IR72 X RNR -19399	-0.60	-1.39	-1.28*	0.17	-23.69**	0.45	-1.37	-0.04
13	IR 72 X AKSHYADHAN	1.15	0.82	-0.71	-1.23*	-18.85*	0.57	-3.11*	0.04
14	IR 72 X RNR -17497	-2.85	-2.33	-0.35	-0.11	33.67**	-1.23	2.26	0.06
15	IR 72 X IR10N270	1.40	0.04	2.38**	0.94	14.56	-0.49	4.99**	0.10
16	MTU 1001 X AAGP -9772	2.77	-0.48	0.68	0.63	23.66**	-0.52	6.20**	0.35*
17	MTU 1001 X RNR -19399	2.27	-2.37	-1.28*	-1.37*	13.76	-0.23	-4.00**	-0.03
18	MTU 1001 X AKSHYADHAN	-3.32	-0.47	1.22*	1.16*	-3.44	-0.43	7.81**	-0.06
19	MTU 1001 X RNR -17497	0.02	2.46	2.11**	-0.19	-17.72*	0.07	-0.42	-0.11
20	MTU 1001 X IR10N270	-1.73	0.87	-2.72**	-0.22	-16.26	1.11	-9.59**	-0.14

* Significant at 0.05% level, **Significant at 0.01% , DFF- Days to 50% flowering, PH- Plant height, EBT- Effective bearing tillers, PL- Panicle Length, TW- Test weight, NGP/P- No. of grains per panicle, SF- Spikelet fertility, GYP- Grain yield per plant.

Table 5. continued…

S. No.	Hybrids	KB	KL/KB	HRR	KLAC	KER	ASV	GC	AC
1	IR 64 X AAGP -9772	-0.05	0.03	-3.53**	-0.24**	0.00	-0.40	13.15**	1.26*
2	IR 64 X RNR -19399	0.07	-0.14	2.78**	0.00	0.02	-0.11	-11.48**	-0.43
3	IR 64 X AKSHYADHAN	-0.10	0.13	-2.17**	-0.47**	-0.06	-0.19	-4.35	-0.62
4	IR 64 X RNR -17497	0.04	-0.02	4.09**	-0.52**	-0.15**	-0.57	1.78	-3.03**
5	IR 64 X IR10N270	0.04	0.00	-1.16	1.23**	0.19**	1.27	0.90	2.81**
6	NLR 34449 X AAGP -9772	0.07	-0.16	-2.27**	0.06	0.05	-0.70	8.38**	3.06**
7	NLR34449 X RNR -19399	0.08	-0.08	-0.37	-0.01	-0.04	0.59	26.26**	-1.14*
8	NLR 34449 X AKSHYADHAN	-0.04	0.02	0.31	0.76**	0.19**	-0.99	-11.62**	-2.08**
9	NLR 34449 X RNR -17497	-0.08	0.17	-2.23**	-0.26**	-0.07	2.13	-21.49**	0.44
10	NLR 34449 X IR10N270	-0.02	0.05	4.57**	-0.54**	-0.12**	-1.03	-1.53	-0.28
11	IR 72 X AAGP -9772	-0.02	-0.04	0.38	0.41**	0.03	0.27	-10.22**	-2.18**
12	IR72 X RNR -19399	0.14*	-0.22*	-4.50**	0.43**	0.06	-0.94	-3.34	1.37*
13	IR 72 X AKSHYADHAN	-0.08	0.12	3.52**	-0.04	-0.04	0.98	21.28**	-0.34
14	IR 72 X RNR -17497	-0.09	0.17	-1.00	-0.35**	0.07	-0.40	-6.09**	3.13**
15	IR 72 X IR10N270	0.05	-0.03	1.60*	-0.45**	-0.12**	0.10	-1.63	-1.99**
16	MTU 1001 X AAGP -9772	-0.01	0.18	5.43**	-0.22**	-0.08	0.83	-11.32**	-2.14**
17	MTU 1001 X RNR -19399	-0.28**	0.44**	2.10**	-0.42**	-0.04	0.46	-11.44**	0.19
18	MTU 1001 X AKSHYADHAN	0.22**	-0.28**	-1.67*	-0.25**	-0.10*	0.21	-5.32*	3.03**
19	MTU 1001 X RNR -17497	0.14*	-0.32**	-0.86	1.13**	0.16**	-1.17	25.81**	-0.54
20	MTU 1001 X IR10N270	-0.07	-0.02	-5.00**	-0.24**	0.05	-0.33	2.27	-0.54

* Significant at 0.05% level, **Significant at 0.01%, KB-Kernel breadth, KL/KB -Kernel length/ Kernel breadth ratio, HRR-Head rice recovery, KLAC- Kernel length after cooking, KER-Kernel elongation ratio, ASV-Alkali spreading value, GC- Gel consistency, AC- Amylose content

Table 6. Heterobeltiosis and standard heterosis of hybrids for yield and yield contributing traits in rice

S. No.	Hybrids	Days to 50 % flowering			Plant Height (cm)			Effective Bearing Tillers			Panicle Length (cm)		
		HB	SV1	SV2	HB	SV1	SV2	HB	SV1	SV2	HB	SV1	SV2
1	IR 64 X AAGP -9772	-8.28 **	-15.02 **	-12.50 **	3.58	-17.80 **	-11.35 **	-17.83 *	-18.35 *	-17.83 *	4.24	-9.08 **	3.02
2	IR 64 X RNR -19399	-12.37 **	-16.29 **	-13.82 **	-1.66	-9.56 **	-2.46	-21.02 **	-21.52 **	-21.02 **	12.82 **	3.33	17.08 **
3	IR 64 X AKSHYADHAN	-1.34	-5.75 *	-2.96	-7.45 **	-7.89 **	-0.67	-28.03 **	-28.48 **	-28.03 **	8.51 *	7.68 *	22.01 **
4	IR 64 X RNR -17497	3.16	-6.07 *	-3.29	6.37	-15.58 **	-8.96 **	-17.83 *	-18.35 *	-17.83 *	12.86 **	-1.56	11.54 **
5	IR 64 X IR10N270	-3.01	-7.35 **	-4.61	-1.96	-16.83 **	-10.31 **	-24.44 **	-13.92	-13.38	8.01 *	-2.08	10.94 **
6	NLR 34449 X AAGP -9772	-9.66 **	-16.29 **	-13.82 **	6.33	-16.27 **	-9.71 **	0.7	-9.49	-8.92	9.25 *	-9.61 **	2.42
7	NLR34449 X RNR -19399	-9.71 **	-10.86 **	-8.22 **	-1.66	-9.56 **	-2.46	7.95	3.16	3.82	5.99	-2.93	9.99 **
8	NLR 34449 X AKSHYADHAN	-5.21 *	-1.28	1.64	0.35	-0.14	7.69 *	-4.93	-14.56	-14.01	1.33	0.55	13.94 **
9	NLR 34449 X RNR -17497	-6.67 *	-15.02 **	-12.50 **	11.75 **	-11.31 **	-4.36	-29.71 **	-30.60 **	-30.16 **	6.01	-7.81 *	4.46
10	NLR 34449 X IR10N270	-8.78 **	-7.03 **	-4.28	-1.88	-16.76 **	-10.23 **	-7.78	5.06	5.73	-1.83	-11.01 **	0.84
11	IR 72 X AAGP -9772	-7.59 **	-14.38 **	-11.84 **	3.47	-15.37 **	-8.74 **	17.04	0.00	0.64	5.98	-5.12	7.51 *
12	IR72 X RNR -19399	-9.18 **	-14.70 **	-12.17 **	-8.13 **	-15.51 **	-8.89 **	-18.54 *	-22.15 **	-21.66 **	9.37 **	0.16	13.49 **
13	IR 72 X AKSHYADHAN	1.36	-4.79 *	-1.97	-5.08	-5.54 *	1.87	0	-14.56	-14.01	1.54	0.77	14.17 **
14	IR 72 X RNR -17497	-7.72 **	-15.97 **	-13.49 **	-0.17	-18.35 **	-11.95 **	-7.05	-8.23	-7.64	7.16 *	-4.06	8.70 *
15	IR 72 X IR10N270	-1.36	-7.35 **	-4.61	-4.33	-18.84 **	-12.47 **	12.22	27.85 **	28.66 **	10.54 **	0.21	13.55 **
16	MTU 1001 X AAGP -9772	-2.07	-9.27 **	-6.58 **	-4.24	-12.33 **	-5.45	-8.92	-9.49	-8.92	9.63 *	-8.37 *	3.83
17	MTU 1001 X RNR -19399	-7.44 **	-8.63 **	-5.92 *	-2.15	-10.01 **	-2.95	-38.22 **	-38.61 **	-38.22 **	-2.59	-10.79 **	1.08
18	MTU 1001 X AKSHYADHAN	-10.61 **	-5.75 *	-2.96	0.14	-0.35	7.47 *	-12.1	-12.66	-12.1	6.2	5.38	19.41 **
19	MTU 1001 X RNR -17497	-1.05	-9.90 **	-7.24 **	1.74	-6.86 *	0.45	-0.64	-1.27	-0.64	4.4	-9.21 **	2.87
20	MTU 1001 X IR10N270	-8.78 **	-7.03 **	-4.28	-3.28	-11.45 **	-4.51	-44.64 **	-36.93 **	-36.53 **	0.15	-9.21 **	2.87

* Significant at 0.05% level, **Significant at 0.01% , HB- Heterobeltiosis, SV1- Standard variety 1 (RNR 15048) , SV2- Standard variety 2 (MTU 1010)

Table 6. contd..

S.No	Hybrids	No of filled grains per panicle			Test Weight (g)			Grain yield/plant			Kernel Length (mm)		
		HB	SV1	SV2	HB	SV1	SV2	HB	SV1	SV2	HB	SV1	SV2
1	IR 64 X AAGP -9772	12.48	-52.19 **	8.95	6.23	132.56 **	20.36 **	62.91 **	11.70	9.42	44.97**	41.26 **	5.36
2	IR 64 X RNR -19399	-15.50 *	-37.17 **	43.15**	-6.4	87.57 **	-2.92	-5.68	-5.21	-7.15	31.61**	38.05 **	2.97
3	IR 64 X AKSHYADHAN	50.57 **	-41.29 **	33.79 **	3.95	108.31 **	7.81 *	15.14	-21.05 **	-22.67 **	41.91**	36.73 **	1.98
4	IR 64 X RNR -17497	23.24 **	-31.58 **	55.90 **	-13.66 **	73.01 **	-10.46 **	-3.29	-32.77 **	-34.15 **	27.29**	36.62 **	1.90
5	IR 64 X IR10N270	30.11 **	-33.90 **	50.62 **	-18.06 **	64.20 **	-15.02 **	8.01	-12.64	-14.43	52.78**	35.18 **	0.83
6	NLR 34449 X AAGP -9772	9.14	-39.13 **	38.71 **	-21.47 **	71.90 **	-11.03 **	-14.85	-33.52 **	-34.88 **	18.04*	34.96 **	0.66
7	NLR34449 X RNR -19399	27.05 **	-5.54	115.23 **	-7.22	45.10 **	-24.90 **	4.34	4.86	2.72	43.25**	34.51 **	0.33
8	NLR 34449 X AKSHYADHAN	17.07 *	-34.70 **	48.78 **	-15.83 **	57.48 **	-18.50 **	39.28 **	8.74	6.51	65.40**	29.76 **	-3.22
9	NLR 34449 X RNR -17497	9.42	-38.97 **	39.06 **	1.02	31.51 **	-31.94 **	-7.32	-27.64 **	-29.13 **	18.92*	27.54 **	-4.87
10	NLR 34449 X IR10N270	35.77 **	-24.27 **	72.55 **	-9.35 *	50.66 **	-22.02 **	55.33 **	25.64 **	23.07 **	26.42**	25.44 **	-6.44 *
11	IR 72 X AAGP -9772	14.01	-51.53 **	10.43	3.04	125.55 **	16.74 **	31.69 **	-8.29	-10.17	58.41**	24.00 **	-7.51 *
12	IR72 X RNR -19399	-18.91 **	-39.71 **	37.37 **	-4.78	87.65 **	-2.88	-10.49	-10.05	-11.89	1.87	22.01 **	-8.99 **
13	IR 72 X AKSHYADHAN	19.54	-56.87 **	-1.72	3.98	104.90 **	6.05	40.30 **	-2.30	-4.3	1.09	21.46 **	-9.41 **
14	IR 72 X RNR -17497	32.94 **	-26.20 **	68.17 **	-21.86 **	53.99 **	-20.30 **	29.41 **	-9.88	-11.72	55.85**	20.24 **	-10.31 **
15	IR 72 X IR10N270	36.00 **	-30.91 **	57.44 **	-12.41 **	72.62 **	-10.66 **	54.32 **	24.82 **	22.26 **	5.83	19.47 **	-10.89 **
16	MTU 1001 X AAGP -9772	-8	-41.05 **	34.32 **	0.39	119.77 **	13.74 **	3.66	13.40	11.08	19.61	32.18 **	-1.41
17	MTU 1001 X RNR -19399	-0.56	-26.07 **	68.46 **	-9.90 **	86.46 **	-3.5	-42.32 **	-36.90 **	-38.19 **	56.37**	19.14 **	-11.14 **
18	MTU 1001 X AKSHYADHAN	-24.81 **	-51.82 **	9.78	-2.86	101.02 **	4.04	16.54 *	27.49 **	24.88 **	43.74	16.04 **	-13.45 **
19	MTU 1001 X RNR -17497	-17.62 *	-47.22 **	20.27	-18.26 **	69.16 **	-12.45 **	-42.34 **	-36.92 **	-38.21 **	37.51**	13.38 **	-15.43 **
20	MTU 1001 X IR10N270	-12.44	-43.90 **	27.83 **	-8.04 *	90.31 **	-1.5	-56.08 **	-51.96 **	-52.94 **	37.30**	11.06 *	-17.16 **

* Significant at 0.05% level, **Significant at 0.01% , HB- Heterobeltiosis, SV1- Standard variety 1 (RNR 15048), SV2- Standard variety 2 (MTU 1010)

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Table 6. contd..

S. No	Hybrids	Kernel Breadth (mm)			Kernel Length/Breadth Ratio			Head Rice Recovery			Kernel length after cooking		
		HB	SV1	SV2	HB	SV1	SV2	HB	SV1	SV2	HB	SV1	SV2
1	IR 64 X AAGP -9772	-0.52	31.94 **	-7.47	5.69	7.05	31.68 **	13.75 **	-10.23 **	-0.60	-14.42 **	15.04 **	2.46 *
2	IR 64 X RNR -19399	0.52	33.33 **	-6.49	2.41	3.73	27.60 **	32.67 **	4.53 **	15.74 **	-1.83 *	21.18 **	7.92 **
3	IR 64 X AKSHYADHAN	-0.79	31.60 **	-7.71	2.58	3.90	27.80 **	-16.33 **	-12.35 **	-2.96	-7.75 **	13.87 **	1.42
4	IR 64 X RNR -17497	3.46	24.65 **	-12.58 **	8.17 *	9.56 *	34.77 **	5.46 **	-6.18 **	3.88 *	-6.70 **	15.17 **	2.57 **
5	IR 64 X IR10N270	-1.09	25.69 **	-11.85 **	6.19	7.62	32.39 **	6.91 **	-9.52 **	0.18	8.90 **	34.42 **	19.72 **
6	NLR 34449 X AAGP -9772	11.85 *	34.38 **	-5.76	8.45	0.70	23.87 **	-8.02 **	-14.02 **	-4.80 **	-11.06 **	19.56 **	6.49 **
7	NLR34449 X RNR -19399	6.36	27.78 **	-10.39 *	13.39 **	5.29	29.52 **	0.56	-6.01 **	4.07 *	9.09 **	21.82 **	8.50 **
8	NLR 34449 X AKSHYADHAN	8.09	29.86 **	-8.93 *	7.77	0.07	23.10 **	-18.17 **	-14.29 **	-5.10 **	10.08 **	30.55 **	16.27 **
9	NLR 34449 X RNR -17497	-8.09	10.42	-22.56 **	22.96 **	15.48 **	42.05 **	-16.08 **	-21.56 **	-13.15 **	6.77 **	19.24 **	6.20 **
10	NLR 34449 X IR10N270	-4.05	15.28 **	-19.16 **	7.39	8.83 *	33.88 **	0.04	-6.49 **	3.54 *	0.46	12.19 **	-0.08
11	IR 72 X AAGP -9772	-3.9	36.81 **	-4.06	-6.24	-9.23 *	11.66 *	12.64 **	-11.10 **	-1.57	-8.65 **	22.79 **	9.36 **
12	IR72 X RNR -19399	-0.49	40.63 **	-1.38	-10.38 *	-13.24 **	6.73	10.11 **	-13.44 **	-4.16 **	3.88 **	26.22 **	12.41 **
13	IR 72 X AKSHYADHAN	-4.63	35.76 **	-4.79	-7.62	-10.56 *	10.02 *	-14.56 **	-10.50 **	-0.91	-2.13 *	18.91 **	5.91 **
14	IR 72 X RNR -17497	-1.73	18.40 **	-16.96 **	4.86	1.52	24.88 **	-10.97 **	-20.80**	-12.30 **	-3.83 **	16.85 **	4.07 **
15	IR 72 X IR10N270	1.64	29.17 **	-9.42 *	-8.74 *	-7.51	13.78 **	3.79 *	-12.16**	-2.74	-7.71 **	12.13 **	-0.13
16	MTU 1001 X AAGP -9772	-4.09	41.20 **	-0.97	12.31 *	-6.36	15.19 **	22.72 **	-3.15*	7.23***	-20.91 **	6.31 **	-5.31 **
17	MTU 1001 X RNR -19399	-18.43 **	15.28 **	-19.16 **	27.04 **	3.76	27.63 **	25.32 **	-3.13*	7.25**	-4.67 **	6.96 **	-4.74 **
18	MTU 1001 X AKSHYADHAN	9.79 *	59.72 **	12.01 **	-17.84 **	-27.35 **	-10.63 *	-21.92 **	-18.21**	-9.44**	-9.10 **	7.80 **	-3.99 **
19	MTU 1001 X RNR -17497	14.51 **	37.96 **	-3.25	-12.59 **	-17.91 **	0.98	-10.48 **	-20.36**	-11.82**	13.77 **	27.64 **	13.68 **
20	MTU 1001 X IR10N270	-2.09	24.42 **	-12.74 **	-12.14 **	-10.96 **	9.53	-7.86 **	-22.02**	-13.66**	-5.13 **	6.44 **	-5.20 **

* Significant at 0.05% level, **Significant at 0.01% , HB- Heterobeltiosis, SV1- Standard variety 1 (RNR 15048) , SV2- Standard variety 2 (MTU 1010)

Table 6. contd..

S.No	Hybrids	Kernel Expansion Ratio			Alkali Spreading Value			Gel Consistency			Amylose content		
		HB	SV1	SV2	HB	SV1	SV2	HB	SV1	SV2	HB	SV1	SV2
1	IR 64 X AAGP -9772	-19.40 **	-15.79 **	-12.02 **	-22.22 **	-30.00 **	-30.00 **	-18.14**	212.77 **	14.84 **	44.97**	12.96 **	18.40 **
2	IR 64 X RNR -19399	6.36	-2.14	2.24	-37.50 **	-50.00 **	-50.00 **	-32.34**	123.40 **	-17.97 **	31.61**	7.01 *	12.16 **
3	IR 64 X AKSHYADHAN	-8.86 *	-15.79 **	-12.02 **	-12.5	-30.00 **	-30.00 **	-3.20	208.51 **	13.28 *	41.91**	3.62	8.61 *
4	IR 64 X RNR -17497	-12.73 **	-15.79 **	-12.02 **	-37.50 **	-50.00 **	-50.00 **	-3.43	202.13 **	10.94 *	27.29**	-5.82	-1.28
5	IR 64 X IR10N270	8.69 *	0.00	4.48	12.5	-10.00	-10	-8.06	213.48 **	15.10 **	52.78**	17.96 **	23.64 **
6	NLR 34449 X AAGP -9772	-6.16	-1.95	2.44	-33.33 **	-40.00 **	-40.00 **	-2.03	170.21 **	-0.78	18.04*	19.95 **	25.72 **
7	NLR34449 X RNR -19399	4.85	5.26	9.98 **	-25.00 **	-40.00 **	-40.00 **	-4.20	261.70 **	32.81 **	43.25**	2.68	7.63 *
8	NLR 34449 X AKSHYADHAN	9.32 **	9.75 **	14.66 **	-37.50 **	-50.00 **	-50.00 **	-7.41	155.32 **	-6.25	65.40**	-4.10	0.52
9	NLR 34449 X RNR -17497	-0.19	0.19	4.68	25.00 **	0.00	0.00	-19.85**	80.85 **	-33.59 **	18.92*	8.77 *	14.01 **
10	NLR 34449 X IR10N270	-6.80 *	-6.43	-2.24	-50.00 **	-60.00 **	-60.00 **	-9.73	180.85 **	3.13	26.42**	2.86	7.82 *
11	IR 72 X AAGP -9772	-16.79 **	-13.06 **	-9.16 *	11.11	0.00	0	-4.27	121.28 **	-18.75 **	58.41**	-24.74 **	-21.11 **
12	IR72 X RNR -19399	14.13 **	0.78	5.30	-16.67	-50.00 **	-50.00 **	-8.38	165.96 **	-2.34	1.87	-7.05 *	-2.57
13	IR 72 X AKSHYADHAN	-6.75	-13.84 **	-9.98 **	83.33 **	10.00	10	-18.37**	325.53 **	56.25 **	1.09	-17.29 **	-13.31 **
14	IR 72 X RNR -17497	1.41	-2.14	2.24	0.00	-30.00 **	-30.00 **	-23.94**	176.60 **	1.56	55.85**	-0.12	4.69
15	IR 72 X IR10N270	-5.74	-16.76 **	-13.03 **	66.67 **	-16.67 **	-16.67 **	-7.29	210.64 **	14.06 **	5.83	-25.88 **	-22.31 **
16	MTU 1001 X AAGP -9772	-21.46 **	-17.93 **	-14.26 **	-11.11 *	6.67	6.67	-7.61	129.79 **	-15.63 **	19.61	-19.64 **	-15.77 **
17	MTU 1001 X RNR -19399	3.96	-2.73	1.63	-38.89 **	-26.67 **	-26.67 **	-3.91	144.68 **	-10.16 *	56.37**	-7.41 *	-2.95
18	MTU 1001 X AKSHYADHAN	-9.58 *	-15.40 **	-11.61 **	-25.00 **	-10.00	-10	-7.77	225.53 **	19.53 **	43.74	2.89	7.85 *
19	MTU 1001 X RNR -17497	9.09 *	5.26	9.98 **	-58.33 **	-50.00 **	-50.00 **	-7.46	325.53 **	56.25 **	37.51**	-11.78 **	-7.53 *
20	MTU 1001 X IR10N270	1.46	-5.07	-0.81	-41.67 **	-30.00 **	-30.00 **	-13.93**	240.43 **	25.00 **	37.30**	-14.40 **	-10.28 **

* Significant at 0.05% level, **Significant at 0.01% , HB- Heterobeltiosis, SV1- Standard variety 1 (RNR 15048), SV2- Standard variety 2 (MTU 1010)

heterosis over the varietal checks MTU 1010 and RNR 15048. The highest significant positive standard heterosis was observed in the hybrid combination of MTU 1001 x Akshyadhan, followed by NLR 34449 x IR10N270 and IR 72 x IR10N270. All these three hybrids were identified as potential hybrids for most of the traits studied based on their *per se* performance and heterosis estimates. Marked variation in the expression of heterobeltiosis and standard heterosis for yield and yield components was observed for all the cross combinations. These findings are in accordance with the findings of Manjunath *et al.* (2020), Virender *et al.* (2020b) Babu Ramesh (2020) and Chandra Mohan *et al.* (2022) for grain yield.

In the current study, none of the 20 hybrids were identified superior for all the traits. Nevertheless, various cross combinations demonstrated superiority in different traits under consideration. The study concluded that among the lines IR 72 (1.79) and in the testers, Akshyadhan (2.83) had significant *gca* effects in the desired direction for most of the traits including grain yield. The degree of dominance was more than unity for most of the traits especially grain yield which indicated the predominance of additive and non-additive gene action. Among the 20 F_1 hybrids *viz*., MTU 1001 x Akshyadhan, NLR 34449 x IR10N270 and IR 72 x IR10N270 were identified as promising with good specific combining ability and *per se* performance for yield and yield contributing traits which is ideal for the exploitation of heterosis breeding.

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