Received: 05 Mar 2022 | Revised: 13 May 2022 | Accepted: 17 May 2022

Electronic Journal of Plant Breeding

Research Article

Combining ability and heterosis for yield and grain quality characters in rice (*Oryza sativa* L.)

K. Manivelan[1], S. Juliet Hepziba[1*], R. Suresh[2], M. Theradimani[1], R. Renuka[1] and R. P.Gnanamalar[3]

[1]Agricultural College and Research Institute, Tamil Nadu Agricultural University, Madurai
[2]Tamil Nadu Rice Research Institute, TamilNadu Agricultural University, Aduthurai
[3]Department of Pulses, TamilNadu Agricultural University, Coimbatore
***E-Mail:** juliethepziba@gmail.com

Abstract
Twelve F_1 crosses derived from four lines and three testers, crossed in L x T mating design were utilized to estimate the combining ability and heterosis for 17 yield and grain quality traits and also to detect the superior crosses for the breeding program. Analysis of variance showed significant differences among all the traits under study except for plant height in lines. In the case of testers, the traits *viz*., the number of tillers per plant, the number of productive tillers per plant, hundred seed weight, single plant yield, alkali spreading value, amylose content, gel consistency, kernel length, kernel length breadth ratio, kernel length after cooking and kernel breadth after cooking showed significant values. The SCA variance was higher than the GCA variance for all the characters under study except the alkali spreading value indicating the predominance of non-additive gene action in the inheritance of all the characters. The parents TKM 13, CO 52, ADT 52 and IRBB 21 were adjudged as good general combiners with respect to single plant yield. Hence, these parents can be exploited through pedigree breeding to obtain better recombinants by selection in later generations. Based on the results of *per se* performance, standard heterosis, and *sca* effects, the hybrids *viz*., CO 52 × IRBB 60 and ADT 52 × IRBB 21 were identified as the best specific combiners and these could be used for future breeding.

Keywords: Combining ability, Heterosis, SCA, GCA, Rice

INTRODUCTION

Rice is known as the "grain of life" (Singh *et al*., 2020) because it is the most important and staple food for more than half of the world's population, making it a critical component of food security. India is one of the world's largest countries by area, which ranked the second and next to China. According to the Directorate of Economics and Statistics (D&ES, 2019- 20), India has 43.78 million hectares of area, producing 118.43 million tonnes, and holding productivity of 2705 kg per hectare. More than 80 per cent of the country's population depends fully or partially on rice as their main cereal food and staple diet. Developing a high yielding variety with resistance/ tolerance to biotic stresses would be an effective way to meet the required amount of production for an enormously increasing population and to prevent the losses caused by biotic stress like Bacterial leaf blight. Bacterial leaf blight (BLB) disease is one of the most destructive diseases caused by *Xanthomonas oryzae* pv.*oryzae* producing yield losses ranging from 74 to 81% in severe conditions, depending on the stage of the crop, the cultivar's susceptibility, and the environmental conditions in India (Srinivasan and Gnanamanickam, 2005).

Effective control of this disease is limited by the use of chemicals and the health issues posed by the chemicals. It is important to discover the precise methods based on the different breeding methods to cope with the needs. Many biometrical tools are accessible to the breeder for selecting appropriate parents. Combining ability is a powerful technique for identifying good combiners, as well as selecting appropriate parental material for heterosis exploitation. It helps the breeder to choose suitable parents for developing hybrids or varieties. Hence, the present study was undertaken to evaluate selected rice genotypes for BLB resistance along with yield and yield components under field conditions.

MATERIALS AND METHODS

Twelve F_{1s} were generated from four high yielding lines *viz.,* TKM 13, ADT 49, CO 52 and ADT 52 and three testers *viz*., IRBB 21, IRBB 60 and Improved Samba mahsuri (ISM), which possess bacterial leaf blight resistance genes crossed in L x T mating design. The initial crossing programme was carried out at the Department of Plant Breeding and Genetics, Agricultural College and Research Institute (AC&RI), Madurai during *rabi,* 2019 and F_1 evaluation was done at Tamil Nadu Rice Research Institute (TRRI), Aduthurai during *kharif,* 2020. The hybrids along with parental lines were evaluated in a randomized complete block design with three replications. Seedlings with 25 days duration were transplanted in the main field with a spacing of 20 cm × 15 cm in a single row of 3 m in length. For effective crop growth, all prescribed agronomic practices and plant protection measures were followed. Six biometrical and 11 grain quality traits *viz*., plant height, the number of tillers, the number of productive tillers, panicle length, hundred grain weight, single plant yield, hulling percentage, milling percentage, head rice recovery, alkali spreading value, amylose content, gel consistency, kernel length, kernel breadth, kernel length breadth ratio, kernel length after cooking and kernel breadth after cooking were recorded.

The combining ability analysis was carried out in line × tester mating design, as given by Kempthorne (1957) and further elaborated by Arunachalam (1974). In this mating system, a random sample of 'l' lines is taken and each line is mated to each of the 't' testers (Singh and Chaudhary, 1977). Line × tester analysis was used to estimate general combining ability (GCA) and specific combining ability (SCA) variances and their effects using the observations taken on the F_1 progenies. Standard heterosis against the standard check variety, ADT 52 was estimated and tested according to Singh and Singh (1994).

RESULTS AND DISCUSSION

Among the various methods of combining ability analysis, line x tester analysis (Kempthorne, 1957) has been widely utilized for screening germplasm to identify valuable donor parents and promising crosses in many crops including rice (Lavanya, 2000; Swamy *et al*., 2003; Punitha *et al*., 2004; Dalvi and Patel, 2009; Saleem *et al.,* 2010; Saidaiah *et al*., 2010 ; Yadav *et al*., 2020). Analysis of variance showed significant differences among all the traits under study except plant height in lines. In the case of testers, the traits *viz*., the number of tillers per plant, the number of productive tillers per plant, hundred seed weight, single plant yield, alkali spreading value, amylose content, gel consistency, kernel length, kernel length breadth ratio. Kernel length after cooking and kernel breadth after cooking showed significant values (**Table 1**). Line x tester component of variances was significant for all the characters except for hulling percentage and alkali spreading value indicating that female parents interacted sufficiently with the male parents. These results are in confirmation with the findings of Waza *et al.* (2015) in rice, who also reported the significant interaction between female and male parents.

Based on the mean performance (**Table 2**), the parent IRBB 21 (86.73) and IRBB 60 (87.86) showed significance

Table 1. Analysis of variance for combining ability in rice

Source of Variation	d.f.	PH	NOT	NPT	PL	HSW	SPY	HP	MP	HRR	ASV	AC	GC	KL	KB	KLBR	KLAC	KBAC
Replication	2	1.02	0.68	0.67	0.35	0.02	0.96	6.54	6.80	20.56	0.12	0.44	3.94	0.05	0.001	0.01	0.00	0.03
Genotypes	18	45.29**	18.59**	29.29**	8.88**	0.25**	57.17**	54.90**	54.71*8	59.61**	2.87**	3.89**	235.47**	1.96**	0.10**	0.34**	1.34**	0.31**
Crosses	11	11.49**	12.15**	43.10**	8.92**	0.23**	76.31**	53.13**	65.13**	67.02**	2.23**	5.57**	206.94**	1.16**	0.04**	0.32**	1.13**	0.36**
Line	3	5.69	28.06**	136.31**	7.60**	0.42**	228.37**	107.77**	130.94**	71.27**	5.52**	7.34**	267.41**	1.58**	0.04**	0.32**	1.75**	0.64**
Tester	2	1.40	3.06*	12.65**	1.00	0.12**	30.08**	20.02	8.34	47.15	2.03*	4.50**	323.53**	2.84**	0.03**	0.39**	2.09**	0.34**
Line x tester	6	17.76**	7.22**	6.65**	12.21**	0.17**	15.70**	36.84	51.15**	71.52**	0.66	5.04**	137.85**	0.39**	0.04**	0.29**	0.51**	0.23**
Error	36	2.38	0.73	1.06	0.83	0.01	0.87	17.88	12.92	14.58	0.49	0.69	3.55	0.03	0.009	0.01	0.002	0.03

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

PH-Plant height, NOT- Number of tillers per plant, NPT - Number of productive tillers per plant, PL – Panicle length, HSW – Hundred seed weight, SPY – Single plant yield, HP – Hulling percentage, MP – Milling percentage, HHR – Head Rice Recovery, ASV – Alkali spreading value, AC – Amylose content, GC - Gel consistency, KL – Kernel length, KB – Kernel breadth, KLBR- Kernel length breadth ratio, KLAC – Kernel length after cooking, KBAC – Kernel breadth after cooking.

Table 2. ***Per se*** **performance of parents and hybrids in rice**

S.No.	Parents	PH	NOT	NPT	PL	HSW	SPY	HP	MP	HRR	ASV	AC	GC	KL	KB	KLBR	KLAC	KBAC
									LINES									
1	L_1(TKM 13)	100.39	25.67	20.13	23.37	2.03	36.00**	75.28	66.67	50.14	3.00	22.05	71.30	4.80	1.70	2.82	6.09	2.53
2	L_2(ADT 49)	98.53	21.00	19.30	24.27*	1.48	29.00	71.63	64.21	52.24	2.67	23.00	75.10	5.30	2.10**	2.52	7.11	2.57
3	L_3(CO 52)	97.61	25.03	21.49	25.63*	1.92	35.03	67.88	60.46	49.66	2.67	23.67	79.33	5.20	1.70	3.06	7.74**	2.50
4	L_4(ADT 52)	101.24	24.00	20.57	25.60*	1.78	37.00**	82.56	71.76*	61.07	2.33	23.33	74.20	5.60	1.90	2.95	7.89**	2.20
	Mean(Lines)	**99.44**	**23.92**	**20.37**	**24.71**	**1.80**	**34.25**	**74.33**	**65.77**	**53.27**	**2.66**	**23.01**	**74.98**	**5.22**	**1.84**	**2.83**	**7.21**	**2.45**
									TESTERS									
5	T_1(IRBB 21)	86.73**	22.00	21.80	22.80	2.25**	31.67	77.07	62.78	54.00	5.00**	22.67	65.83	5.80	2.10**	2.76	6.92	2.30
6	T_2(ISM)	93.61	21.33	20.30	26.04*	1.47	30.33	77.08	64.45	53.21	2.33	23.50	78.13	5.40	1.60	3.37**	7.91**	2.23
7	T_3(IRBB60)	87.86**	19.67	17.50	22.27	2.31**	31.00	77.96	61.60	54.44	5.00**	22.44	63.63	6.21	1.80	3.45**	8.53**	2.10
	Mean (Testers)	89.39	**89.39**	**21.00**	**19.86**	**23.70**	**2.01**	**31.00**	**77.37**	**62.94**	**53.88**	**4.11**	**22.86**	**69.20**	**5.80**	**1.83**	**3.19**	**7.78**
									CROSSES									
8	$L_1 \times T_1$	91.21*	26.50**	22.50	22.03	1.86	37.50**	81.21	67.45	61.28	2.00	21.19	82.13*	6.70**	2.00	3.35**	7.05	2.33
9	$L_1 \times T_2$	93.17	27.37**	25.27**	26.00*	1.82	32.00	75.71	57.97	52.68	2.00	24.13	81.97*	6.60**	1.90	3.47**	7.15	2.17
10	$L_1 \times T_3$	91.34	23.33	20.07	25.17*	1.73	36.00**	76.89	66.15	57.77	1.67	22.47	74.03	6.80**	2.10**	3.24	7.23	2.67
11	$L_2 \times T_1$	93.54	24.00	16.40	23.00	1.52	27.00	75.79	62.45	56.61	3.33	24.50	77.03	5.70	2.00	2.85	6.13	2.33
12	$L_2 \times T_2$	92.13	22.00	15.87	26.40*	1.62	25.00	76.44	65.44	56.67	3.33	23.31	87.43**	5.50	2.20	2.50	7.15	2.50
13	$L_2 \times T_3$	95.40	23.47	15.00	26.40*	1.82	28.00	71.33	64.64	49.45	2.67	24.27	81.93*	7.00**	2.00	3.50	8.07**	2.40
14	$L_3 \times T_1$	96.49	27.77**	25.43**	27.30**	2.22**	35.33*	73.12	63.72	51.72	4.67**	24.47	81.77	6.90**	2.20**	3.14	7.23	3.00**
15	$L_3 \times T_2$	91.50	25.70	24.00**	25.20*	1.92	34.00	74.22	65.00	59.40	3.00	22.79	106.17**	6.30	2.10**	3.00	7.99**	2.77
16	$L_3 \times T_3$	90.39**	28.77**	25.20**	25.10*	2.35**	38.00**	68.66	60.07	48.08	3.67	25.54**	82.93**	7.80**	2.20**	3.55**	8.13**	3.00**
17	$L_4 \times T_1$	91.47	26.13*	23.47**	28.43**	2.30**	41.67**	74.76	66.62	54.57	3.67	21.00	81.07	6.90**	1.90	3.63**	7.82**	2.20
18	$L_4 \times T_2$	93.45	25.37	21.73	25.23*	1.76	38.00**	82.62	71.84*	62.78*	2.33	23.00	78.00	6.60**	2.10**	3.14	8.02**	3.00**
19	$L_4 \times T_3$	95.36	26.20*	20.00	26.03*	1.62	35.00	81.85	75.17**	60.39	3.00	23.77	75.50	7.20**	2.20**	3.27**	8.10**	3.13**
	Mean (Crosses)	92.95	25.55	21.24	25.52	1.88	33.96	76.05	65.54	55.95	2.94	23.37	82.50	6.67	2.07	3.22	7.51	2.63
	General Mean	**93.76**	**24.49**	**20.84**	**25.07**	**1.88**	**33.55**	**75.90**	**65.18**	**55.06**	**3.07**	**23.22**	**78.82**	**6.23**	**1.99**	**3.14**	**7.49**	**2.52**
	SE	0.89	0.49	0.59	0.52	0.07	0.54	2.44	2.08	2.20	0.41	0.48	1.09	0.09	0.03	0.06	0.03	0.10
	CD(P=5)	2.53	1.41	1.69	1.49	0.19	1.53	6.94	5.90	6.27	1.15	1.36	3.09	0.27	0.09	0.16	0.07	0.28
	CD(P=1)	3.38	1.87	2.25	1.99	0.25	2.04	9.25	7.87	8.36	1.54	1.82	4.12	0.36	0.12	0.21	0.10	0.37

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

PH-Plant height (cm), NOT- Number of tillers per plant, NPT - Number of productive tillers per plant, PL – Panicle length (cm), HSW – Hundred seed weight (g), SPY – Single plant yield (g), HP – Hulling percentage MP – Milling percentage, HHR – Head Rice Recovery (%), ASV – Alkali spreading value, AC – Amylose content (%), GC - Gel consistency, KL – Kernel length (mm), KB – Kernel breadth (mm), KLBR- Kernel length breadth ratio, KLAC – Kernel length after cooking (mm), KBAC – Kernel breadth after cooking (mm) $L_1 \times T_1$ - TKM13 × IRBB21, $L_1 \times T_2$ - TKM13 × ISM, $L_1 \times T_3$ - TKM13 × IRBB60, $L_2 \times T_1$ - ADT49 × IRBB21, $L_2 \times T_2$ - ADT49 × ISM , $L_2 \times T_3$ - ADT49 × IRBB60, $L_3 \times T_1$ - CO52 × IRBB21, $L_3 \times T_2$ - CO52 × ISM , $L_3 \times T_3$ - CO52 × IRBB60, $L_4 \times T_1$ - ADT52 × IRBB21, $L_4 \times T_2$ - ADT52 × ISM , $L_4 \times T_3$ - ADT52 × IRBB60.

in a negative direction for plant height. For single plant yield, the parents TKM 13, and ADT 52 showed a significant increase over the general mean, besides the crosses TKM 13 × IRBB 21, TKM 13 × IRBB 60, CO 52 × IRBB 21, CO 52 × IRBB 60, ADT 52 × IRBB 21 and ADT 52 × ISM. The line, ADT 52 showed a significant increase for the characters *viz*., panicle length, single plant yield, milling percentage and kernel length after cooking followed by ADT 49 for panicle length and kernel breadth and CO 52 for panicle length and kernel length after cooking.

Among the testers, IRBB 21 showed a significant increase for the characters *viz.,* plant height, hundred seed weight, alkali spreading value and kernel breadth, followed by IRBB 60 for the traits, plant height, hundred grain weight, alkali spreading value, kernel length breadth ratio and kernel length after cooking. The hybrid, CO 52 x IRBB 60 exhibited a significant increase for thirteen characters, while the crosses CO 52 x IRBB 21, ABT 52 x IRBB 21, ABT 52 x ISM and CO 52 x IRBB 60 showed a significant increase for eight characters.

The estimates of variance due to GCA and variance due to SCA for various characters are given in (**Table 3**). The SCA variance was higher than the GCA variance for all the characters under study except the alkali spreading value indicating the predominance of non-additive gene action in the inheritance of all the characters (Tiwari and Singh, 2016; Sahu *et al*. 2016; Rahaman, 2016; Vartika *et al.,* 2020). The ratios of GCA/SCA variances were less than unity for the traits, suggesting a predominance of non-additive gene effects. The importance of additive, as well as non-additive gene effects with a predominance of non-additive gene effects in the inheritance of grain yield and yield components of rice, has been reported earlier by Vishwakarma *et al.* (2003), Punitha *et al.* (2004), Pradhan *et al.* (2006), Rashid *et al.* (2007), Saleem *et al.* (2010) and Saidaiah *et al.* (2010).The traits with non-additive gene action can be further subjected to heterosis breeding. Many researchers Saidaiah *et al.* (2010), Singh *et al*. (2020) and Sandhyakishore *et al.* (2017) have reported the predominance of non-additive gene action for the above-mentioned traits. In the case of additive gene action, Widyastuti *et al*. (2017) and Zewdu *et al.* (2020) suggested pureline selection or pedigree breeding improve the traits.

General combining ability aids in the identification of superior parents, whereas specific combining ability aids in the identification of superior cross combinations. In the present study, good combiners for single plant yield were TKM 13, CO 52, ADT 52 and IRBB 21 (**Table 4**). Among the parental genotypes, CO 52 was found to be a good general combiner for most of the traits *viz.,* the number of tillers per plant, the number of productive tillers per plant, hundred seed weight, single plant yield, hulling percentage, alkali spreading value, amylose content, gel consistency, kernel length, kernel breadth, kernel length after cooking and kernel breadth after cooking. The variety ADT 52 exhibited a significant *gca* effects for more number of traits, panicle length, single plant yield, hulling percentage, milling percentage, head rice recovery, kernel length, kernel length breadth ratio, kernel length after cooking and kernel breath after cooking.

Table 3. General and specific combining ability variances for various characters in rice

S. No.	Characters	σ^2GCA	σ^2SCA	σ^2GCA/ σ^2SCA
1	Plant height	-0.2703	5.1191	-0.0528
2	Number of tillers per plant	0.2125	2.1274	0.0999
3	Number of productive tillers per plant	1.5725	1.8623	0.8444
4	Panicle length	-0.1421	3.7550	-0.0378
5	Hundred seed weight	0.0025	0.0505	0.0495
6	Single plant yield	2.6148	4.9090	0.5327
7	Hulling percentage	0.7026	3.4720	0.2024
8	Milling percentage	0.6029	11.7318	0.0514
9	Head Rice Recovery	-0.1941	18.4297	-0.0105
10	Alkali spreading value	0.0679	0.0281	2.4164
11	Amylose content	0.0227	1.3970	0.0162
12	Gel consistency	2.9805	44.1497	0.0675
13	Kernel length	0.0333	0.1189	0.2801
14	Kernel breadth	-0.0000	0.0124	0.0000
15	Kernel length breadth ratio	0.0013	0.0922	0.0141
16	Kernel length after cooking	0.0270	0.1691	0.1597
17	Kernel breadth after cooking	0.0056	0.0649	0.0863

Table 4. General combining ability (*gca*) effects of parents in rice

	PH	NOT	NPT	PL	HSW	SPY	HP	MP	HRR	ASV	AC	GC	KL	KB	KLBR	KLAC	KBAC
L_1 (TKM 13)	-1.05	0.18	1.37 **	-1.12 **	-0.07	1.21**	1.89	-1.69	1.29	-1.06 **	-0.77*	-3.12 **	0.03	-0.08**	0.13**	-0.36**	-0.24**
L_2 (ADT 49)	0.74	-2.39**	-5.49 **	-0.26	-0.23 **	-7.29 **	-1.53	-1.37	-1.71	0.17	0.66*	-0.36	-0.60**	-0.01	-0.27**	-0.39**	-0.21 **
L_3 (CO 52)	-0.16	1.86**	3.63**	0.34	0.29**	1.82**	-4.05*	-2.61	-2.88*	0.83**	0.90 **	7.79**	0.33**	0.09**	0.01	0.28**	0.30**
L_4 (ADT 52)	0.47	0.35	0.49	1.04**	0.01	4.26**	3.69*	5.67**	3.30*	0.06	-0.78*	-4.31**	0.23**	-0.01	0.13**	0.47**	0.15*
T_1 (IRBB 21)	0.22	0.55*	0.71*	-0.33	0.10*	1.42**	0.17	-0.48	0.10	0.47*	-0.58*	-2.00**	-0.12*	-0.05**	0.02	-0.45**	-0.16*
T_2 (ISM)	-0.39	-0.44	0.47	0.18	-0.10*	-1.71**	1.20	-0.48	1.93	-0.28	-0.06	5.89**	-0.42**	0.01	-0.19 **	0.07**	-0.02
T_3 (IRBB60)	0.17	-0.11	-1.18 **	0.15	0	0.29	-1.37	0.96	-2.03	-0.19	0.64*	-3.90**	0.53**	0.05**	0.17**	0.38**	0.17**
SE(lines)	0.52	0.31	0.34	0.32	0.04	0.33	1.71	1.33	1.34	0.25	0.31	0.77	0.06	0.02	0.03	0.01	0.07
SE(testers)	0.45	0.26	0.30	0.28	0.04	0.28	1.48	1.15	1.16	0.22	0.27	0.67	0.05	0.02	0.03	0.01	0.06

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

PH-Plant height, NOT- Number of tillers per plant, NPT - Number of productive tillers per plant, PL – Panicle length, HSW – Hundred seed weight, SPY – Single plant yield, HP – Hulling percentage, MP – Milling percentage, HHR – Head Rice Recovery, ASV – Alkali spreading value, AC – Amylose content, GC - Gel consistency, KL – Kernel length, KB – Kernel breadth, KLBR- Kernel length breadth ratio, KLAC – Kernel length after cooking, KBAC – Kernel breadth after cooking.

Similar results of significant *gca* effects for these characters were reported by Latha *et al.* (2013) and Priyanka *et al.* (2014). The testers IRBB 60 exhibited significant *gca* effects for amylose content, kernel length, kernel breadth, kernel length breadth ratio, kernel length after cooking and kernel breath after cooking followed by IRBB 21, which showed significant *gca* effects for the number of tillers per plant, the number of productive tillers per plant, hundred seed weight, single plant yield and alkali spreading value. Significant *gca* effects for the number of productive tillers, panicle length, hundred grain weight and single plant yield was reported earlier by Santha *et al.* (2017). The genotypes, TKM 13, CO 52, ADT 52 and IRBB 21 showing high *gca* effects for single plant yield can be used for pedigree breeding to obtain superior recombinants. The present findings are also in accordance with the results of Vadivel *et al*. (2018), Singh *et.al*. (2020) and Nanditha *et al.* (2021).

The specific combining ability variances were due to non-additive gene action and epistatic gene action (Sprague and Tatum, 1942). The usefulness of a particular cross in the exploitation of heterosis was judged by the specific combining ability effects. The crosses CO 52 x IRBB 60 and ADT 52 x IRBB 21 had significant positive *sca* effects for hundred seed weight, single plant yield and kernel length breadth ratio (**Table 5**). In addition, CO 52 x IRBB 60 possessed significant positive *sca* effects for the number of tillers per plant, the number productive tillers per plant and kernel length and ADT 52 x IRBB 21 for panicle length, gel consistency and kernel length after cooking. The hybrid TKM 13 x ISM recorded positive significant *sca* effects for the number of tillers per plant, the number of productive tillers per plant panicle length, amylose content, kernel length and kernel length breadth ratio followed by ADT 49 x IRBB 60 for hundred seed weight, gel consistency, kernel length, kernel length breadth ratio and kernel length after cooking.

The performance of F_1 hybrids was evaluated based on standard heterosis against the best high-yielding variety (Virmani *et al.,* 1982). As a result, plant breeders prefer standard heterosis to other types of heterosis. While evaluating the hybrids against the check variety ADT 52 in the study (**Table 6**), the cross combination ADT 52 × IRBB 21 alone showed a positive significant heterosis for single plant yield. All the hybrids possessed significant negative standard heterosis for plant height ranging from -4.69** to -10.71**. The crosses CO 52 × IRBB 21, CO 52 × IRBB 60 and ADT 52 × IRBB 21 exhibited a significant positive heterosis for the number of tillers per plant, the number of productive tillers per plant, hundred seed weight, alkali spreading value, gel consistency, kernel length and kernel length breadth ratio. In addition CO 52 × IRBB 21, possessed significant positive standard heterosis for panicle length, kernel breadth and kernel breadth after cooking; CO 52 × IRBB 60 for kernel breadth, kernel length after cooking and kernel breadth after cooking and ADT 52 × IRBB 21 for panicle length and single plant yield.

Table 5. Specific combining ability (*sca*) effects of hybrids in rice

Name of crosses	PH	NOT	NPT	PL	HSW	SPY	HP	MP	HRR	ASV	AC	GC	KL	KB	KLBR	KLAC	KBAC
$L_1 \times T_1$	-0.92	0.22	-0.82	-2.03**	-0.04	0.92	3.10	4.08	3.94	-0.36	-0.83	4.75**	0.12	0.05	-0.03	0.35 **	0.10
$L_1 \times T_2$	1.66	2.08 **	2.18**	1.42*	0.11	-1.46*	-3.42	-5.41*	-6.50*	0.39	1.60**	-3.31*	0.32**	-0.10**	0.31**	-0.06 **	-0.21
$L_1 \times T_3$	-0.73	-2.29 **	-1.37*	0.62	-0.08	0.54	0.32	1.33	2.56	-0.03	-0.77	-1.45	-0.43**	0.05	-0.28**	-0.29 **	0.10
$L_2 \times T_1$	-0.37	0.29	-0.06	-1.93**	-0.23**	-1.08	1.10	-1.25	2.27	-0.25	1.05	-3.10*	-0.25*	-0.02	-0.12*	-0.54 **	0.08
$L_2 \times T_2$	-1.17	-0.71	-0.36	0.95	0.06	0.04	0.72	1.75	0.50	0.50	-0.65	-0.59	-0.15	0.13**	-0.26**	-0.04	0.11
$L_2 \times T_3$	1.54	0.42	0.42	0.98	0.17*	1.04	-1.82	-0.50	-2.77	-0.25	-0.40	3.70*	0.40**	-0.12**	0.38**	0.58 **	-0.19
$L_3 \times T_1$	3.47 **	-0.19	-0.15	1.77**	-0.04	-1.86**	0.95	1.28	-1.44	0.42	0.79	-6.53**	0.02	0.09*	-0.11	-0.10 **	0.24*
$L_3 \times T_2$	-0.90	-1.27 *	-1.35*	-0.85	-0.14	-0.07	1.02	2.55	4.40	-0.50	-1.42*	9.98**	-0.28*	-0.07	-0.04	0.13 **	-0.14
$L_3 \times T_3$	-2.57 **	1.46 *	1.50*	-0.92	0.18*	1.93**	-1.97	-3.82	-2.96	0.08	0.63	-3.46*	0.27*	-0.02	0.15*	-0.03	-0.10
$L_4 \times T_1$	-2.18 *	-0.32	1.03	2.20**	0.31**	2.03**	-5.15	-4.11	-4.77	0.19	-1.01	4.88**	0.12	-0.12**	0.26**	0.29 **	-0.42 **
$L_4 \times T_2$	0.41	-0.09	-0.47	-1.52*	-0.04	1.49*	1.68	1.11	1.60	-0.39	0.47	-6.08**	0.11	0.03	-0.01	-0.03	0.24*
$L_4 \times T_3$	1.76	0.41	-0.56	-0.68	-0.28 **	-3.51**	3.47	3.00	3.17	0.19	0.54	1.21	-0.23*	0.08*	-0.25**	-0.26 **	0.18

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

PH-Plant height, NOT- Number of tillers per plant, NPT - Number of productive tillers per plant, PL – Panicle length, HSW – Hundred seed weight, SPY – Single plant yield, HP – Hulling percentage, MP – Milling percentage, HHR – Head Rice Recovery, ASV – Alkali spreading value, AC – Amylose content, GC - Gel consistency, KL – Kernel length, KB – Kernel breadth, KLBR- Kernel length breadth ratio, KLAC – Kernel length after cooking, KBAC – Kernel breadth after cooking.

$L_1 \times T_1$ - TKM 13 × IRBB 21, $L_1 \times T_2$ - TKM 13 × ISM, $L_1 \times T_3$ - TKM13 × IRBB60, $L_2 \times T_1$ - ADT49 × IRBB21, $L_2 \times T_2$ - ADT49 × ISM , $L_2 \times T_3$ - ADT49 × IRBB60, $L_3 \times T_1$ - CO52 × IRBB21, $L_3 \times T_2$ - CO52 × ISM , $L_3 \times T_3$ - CO52 × IRBB60, $L_4 \times T_1$ - ADT52 × IRBB21, $L_4 \times T_2$ - ADT52 × ISM , $L_4 \times T_3$ - ADT52 × IRBB60.

https://doi.org/10.37992/2022.1302.059

Table 6. Estimation of standard heterosis for yield and quality characters in rice (in per cent)

Crosses	PH	NOT	NPT	PL	HSW	SPY	HP	MP	HRR	ASV	AC	GC	KL	KB	KLBR	KLAC	KBAC
$L_1 \times T_1$	-9.91**	10.42**	9.40*	-13.93**	4.49	1.36	-1.64	-6.00	0.34	-14.29	-9.20**	10.69**	19.64 **	5.45*	13.45 **	-10.68 **	6.06
$L_1 \times T_2$	-7.97**	14.03**	22.85**	1.56	2.06	-13.51**	-8.30	-19.21**	-13.75**	-14.29	3.43	10.47**	17.86 **	0.18	17.74 **	-9.42 **	-1.52
$L_1 \times T_3$	-9.78 **	-2.78	-2.43	-1.69	-2.80	-2.70	-6.88	-7.82	-5.40	-28.57	-3.71	-0.22	21.49 **	10.72 **	9.72 **	-8.40 **	21.21 **
$L_2 \times T_1$	-7.60 **	0	-20.26**	-10.16**	-14.95**	-27.03**	-8.21	-12.97**	-7.30	42.86	5.00	3.82	1.73	5.27 *	-3.50	-22.34 **	6.06
$L_2 \times T_2$	-9.00 **	-8.33**	-22.85**	3.12	-9.35	-32.43**	-7.42	-8.80*	-7.20	42.86	-0.10	17.83**	-1.79	16.17 **	-15.25 **	-9.42 **	13.64 *
$L_2 \times T_3$	-5.77**	-2.22	-27.07**	3.12	2.24	-24.32**	-13.60**	-9.92*	-19.04**	14.29	4.00	10.42**	25.00 **	5.62*	18.64**	2.24**	9.09
$L_3 \times T_1$	-4.69**	15.69**	23.66**	6.64*	24.49**	-4.50*	-11.43**	-11.20**	-15.31**	100.00**	4.89	10.20**	23.21 **	15.99 **	6.44*	-8.40 **	36.36 **
$L_3 \times T_2$	-9.62**	7.08*	16.69**	-1.56	7.85	-8.11**	-10.10*	-9.42*	-2.73	28.57	-2.33	43.08**	12.50 **	10.72 **	1.58	1.18*	25.76 **
$L_3 \times T_3$	-10.71*	19.86**	22.53**	-1.95	31.78**	2.70	-16.84**	-16.29**	-21.28**	57.14*	9.46**	11.77**	39.29 **	15.99 **	20.23 **	3.00 **	36.36 **
$L_4 \times T_1$	-9.65**	8.89**	14.10**	11.07**	28.97**	12.61**	-9.45*	-7.16	-10.65*	57.14*	-10.00**	9.25 **	23.21 **	0.01	23.05 **	-0.93 *	0.01
$L_4 \times T_2$	-7.70**	5.69	5.67	-1.43	-1.50	2.70	0.07	0.12	2.79	0.01	-1.43	5.12*	17.80 **	10.72 **	6.55*	1.60**	36.36 **
$L_4 \times T_3$	-5.81**	9.17**	-2.76	1.69	-9.16	-5.41*	-0.87	4.75	-1.12	28.57	1.86	1.75	28.57 **	15.99 **	10.85 **	2.62 **	42.42 **

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

PH-Plant height, NOT- Number of tillers per plant, NPT - Number of productive tillers per plant, PL – Panicle length, HSW – Hundred seed weight, SPY – Single plant yield, HP – Hulling percentage, MP – Milling percentage, HHR – Head Rice Recovery, ASV – Alkali spreading value, AC – Amylose content, GC - Gel consistency, KL – Kernel length, KB – Kernel breadth, KLBR- Kernel length breadth ratio, KLAC – Kernel length after cooking, KBAC – Kernel breadth after cooking.

L_1 x T_1 - TKM13 × IRBB21, L_1 x T_2 - TKM13 × ISM, L_1 x T_3 - TKM13 × IRBB60, L_2× T_1 - ADT49 × IRBB21, L_2× T_2 - ADT49 × ISM , L_2× T_3 - ADT49 × IRBB60, L_3× T_1 - CO52 × IRBB21, L_3× T_2 - CO52 × ISM , L_3× T_3 - CO52 × IRBB60, L_4× T_1 - ADT52 × IRBB21, L_4× T_2 - ADT52 × ISM , L_4× T_3 - ADT52 × IRBB60.

In the present study, TKM 13, CO 52, ADT 52 and IRBB 21 were adjudged as good general combiners among the parents with respect to single plant yield. However, these parents did not yield significant *sca* effects on their combinations. Hence, these parents can be exploited through pedigree breeding to obtain better recombinants by selection in later generations. Based on the results of *per se* performance, standard heterosis, and *sca* effects, the hybrids *viz*., CO 52 × IRBB 60 and ADT 52 × IRBB 21 were identified as the best hybrids and these could be used for future breeding.

REFERENCES

Arunachalam, V. 1974. The fallacy behind the use of modified line x tester design. *Indian J. Genet.,* **34** (2): 200-207.

Dalvi, V. V. and Patel, D. U. 2009. Combining ability analysis for yield in hybrid rice. *Oryza*., **46** (2): 97-102.

Directorate of Economics and Statistics (D&ES, 2019- 20). hpps://www.DES.org/data.

Kempthorne, O. 1957. An introduction of genetic statistics. John Willey & Sons Inc. *New York, USA*: 468-473.

Latha, S., Sharma, D. and Sanghera, G. S. 2013. Combining ability and heterosis for grain yield and its component traits in rice (*Oryza sativa* L.). *Notulae Sci. Biolog.,* **5**(1): 90-97. [Cross Ref]

Lavanya, C. 2000. Combining ability for yield and its components in hybrid rice. *Oryza*, **37**(1): 11-14.

Nanditha, R. S, Pushpam, R., Geetha S., Krishna Surendar, K. and Ganesamurthy, K. 2021. Assessment of combining ability, gene action and heterosis for yield and grain characters in rice (*Oryza sativa* L.). *Electronic Journal of Plant Breeding*, **12**(3):976 – 982. [Cross Ref]

Pradhan, S. K., Bose, L. K. and Meher, J. 2006. Studies on gene action and combining ability analysis in Basmati rice. *J. Cent. Euro. Agr.*, **7** (2): 267-272.

Priyanka, K., Jaiswal, H. K. and Waza, S. A. 2014. Combining ability and heterosis for yield, its component traits and some grain quality parameters in rice (*Oryza sativa* L.). *J. Appl. Nat. Sci.,* **6**(2): 495-506. [Cross Ref]

Punitha, D., Joel, A. J., Manonmani, S. and Thiyagarajan, K. 2004. Combining ability for yield and its components in rice (*Oryza sativa* L.). *Adv. Pl. Sci.*, **17** (1): 345-348.

Rahaman, M. A. 2016. Study of nature and magnitude of gene action in hybrid rice (*Oryza sativa L.*) through experiment of line x tester mating design. *Int. J. App. Res.,* **2**(2): 405-410.

Rashid, M., Cheema, A. A. and Ashraf, M. 2007. Line x tester analysis in basmati rice. *Pak. J. Bot.*, **36** (6): 2035-2042.

Sahu, K. P., Sharma, D., Singh, S. and Sahu, P. 2016. Gene action and combining ability analysis in CMS based hybrid rice for grain yield and quality attributing traits. *Int. J. Agri. Sci.,* **8**(48): 2024-2029.

Saidaiah, P., Sudheer Kumar, S. and Ramesha, M. S. 2010. Combining ability studies for development of new hybrids in rice over environments. *J. Agri. Sci.,* **2** (2): 225-233. [Cross Ref]

Saleem, M. Y., Mirza, J. I. and Haq, M. A. 2010. Combining ability analysis for yield and related traits in basmati rice (*Oryza sativa* L.). *Pak. J. Bot.*, **42**(1): 627-637.

Sandhyakishore, N., Praveenkumar, G., Pallavi, M., Kamalakar, J., Shahana, F. and Tagore, K. 2017. Combining ability analysis for yield and related traits in rice (*Oryza sativa* L.). *Agri. Res. J.,* **12**: 1573-1577. [Cross Ref]

Santha, S., Vaithilingam, R., Karthikeyan, A. and Jayaraj, T. 2017. Combining ability analysis and gene action of grain quality traits in rice (*Oryza sativa* L.) using line × tester analysis. *J. App. & Nat. Sci.,* **9** (2): 1236 – 1255. [Cross Ref]

Singh, R. K. and Chaudhary, B. D. 1977. Biometrical Methods in Quantitative Genetic Analysis. *Kalyani Publ.,* New Delhi, India.

Singh, R.K. and Singh, P.K. 1994. A manual on Genetics and Plant Breeding. Experimental Techniques. *Kalyani Publs.* Pp: 99-107.

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. eco. Env. Sci.,* **2**(3): 67-75.

Sprague, G.P. and Tatum, L.A. 1942. General vs specific combining ability in single crosses of corn. *Agronomy*, **34**: 923-932. [Cross Ref]

Srinivasan, B. and Gnanamanickam, S. 2005. Identification of a new source of resistance in wild rice, *Oryza rufipogon* to bacterial leaf blight of rice caused by Indian strains of *Xanthomonas oryzae* pv. *oryzae*, *Curr. Sci.,* **88**: 1229-1231.

Swamy, M. H., Rao, M. R. G. and Vidyachandra, B. 2003. Studies on combining ability in rice hybrids involving new CMS lines. *Karnat. J. Agri. Sci.,* **16** (2): 228-233.

Tiwari, G.C. and Singh, S.S. 2016. Diallel analysis for yield and yield components in rice (*Oryza sativa L.*). *Adv. Life Sci.,* **5**(8): 3196-3202.

https://doi.org/10.37992/2022.1302.059

Vadivel, K. 2018. Studies on combining ability and heterosis in rice (*Oryza sativa* L.). *Electronic Journal of Plant Breeding*, **9**(3): 1115-1121. [Cross Ref]

Vartika, B., Karanwal, M. K. and Anjali, J. 2020. Studies on combining ability for grain yield and related traits in advanced breeding lines in rice (*Oryza sativa L.*). *Electronic Journal of Plant Breeding*, **11**(4):1078-1084. [Cross Ref]

Virmani, S.S., Aquino, R.C. and Khush, G.S. 1982. Heterosis breeding in rice (*Oryza sativa* L.) *Theo. App. Gen.,* **63**: 373–380. [Cross Ref]

Vishwakarma, D. N., Vishwakarma, S. R., Verma, L. P. and Kanti Prasad. 2003. Combining ability analysis of some quantitative characters in rice. *Ann. Pl. Soil Res.,* **5** (1): 72-75.

Waza, S.A., Jaiswal, H.K., Sravan, T., Priyanka, K., Bano, D.A. and Rai, V.P. 2015. Combining ability analysis for various yield and quality traits in rice (*Oryza sativa* L.). *J. App. Nat Sci.,* **7**(2):865-873. [Cross Ref]

Widyastuti, Y., Kartina, N. and Rumanti, I. A. 2017. Prediction of combining ability and heterosis in the selected parents and hybrids in rice (*Oryza Sativa* L). *Info. Pert.,* **26**(1): 31-40. [Cross Ref]

Yadav, A. K., Vyas. R.P., Yadav. V. K., Yadav. and Vimilesh, K. 2020. Combining ability analysis for yield and its contributing traits in rice (*Oryza sativa* L.). *Electronic Journal of Plant Breeding*, **12**(3):757 – 765. [Cross Ref]

Zewdu, Z. 2020. Combining ability analysis of yield and yield components in selected rice (*Oryza sativa* L.) genotypes. *Cogent Food Agriculture,* **6**: 1811594. [Cross Ref]