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Research Article

Combining ability analysis for yield and its contributing traits in rice (*Oryza sativa* L.)

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Abstract
Forty eight cross combinations were obtained by the crossing of sixteen lines with three testers in line × tester design and F_1 along with parents used for assessing the combining ability effects for the quantitative traits. The present study showed that the variances due to line x tester's differ significantly for all the traits which indicating the importance of SCA and non-additive gene action. The estimated values of sca variances were higher than the corresponding values of gca variance for all the traits. The average degree of dominance was more than unity (>1) indicating over-dominance for all the characters. Among the parents lines *viz*., CSAR 839-3, CSR-13, T-3, IR-79495-9-3-2-3, Sarjoo 52, CSR-36 and NDR 359 found to be good general combiner for grain yield/plant and several important traits to emerge as valuable parents for hybridization programme for obtaining high yielding varieties or transgressive segregants of rice. Among the cross combinations, seventeen combinations had significant and positive SCA effect for grain yield per plant and its attributes and best five crosses were, NDPK-5088×NDR-359, T-3 ×Pusa Basmati, Ramraj × CSR-36, Sarjoo-52 × NDR 359 and Usar-3 × Pusa Basmati could be used for heterosis breeding programme for improvement of quantitative and yield traits.

Key words: combining ability, SCA effect, GCA effect, Rice, gene action

INTRODUCTION

Rice (*Oryza sativa* L.) playing a pivotal place in Indian agriculture, as it forms the staple food for two- thirds peoples of the country, provides 43 per cent of calories requirement and 20-25 per cent agriculture income. More than ninety per cent of the world's rice is grown and consumed in Asia, known as the rice bowl of the world, where 60 per cent of the earth's people and two third of the world's poor live (Khush and Virk, 2000). To focus attention on the importance of rice in global food security and the necessity to increase rice production and productivity, United Nations General Assembly in 2002 declared to celebrate the year 2004 as the "International Year of Rice (IYR 2004)" with the theme of "Rice is Life". Rice is cultivated worldwide over an area of about 167.13 million hectares with an annual rice production of about 782.00 million tones with average productivity of 4.68 tonnes per hectare. India has the largest area of 44.50 million hectares constituting 26.62 per cent of the land under rice in the world. The annual production of rice in the country is more than 172.58 million tonnes, the second largest in the world after China (Anonymous, 2018). More than 80 per cent of our countrymen depend fully or partially on rice as their main cereal food and staple diet. Uttar Pradesh is an important rice growing state in the country. Uttar Pradesh is contributing about 13 per cent of rice to the total national production. The area and production of rice in this state are about 6.0 million hectares and 13.27 million tonnes, respectively, with a productivity of 2.49 tones per hectare (Anonymous, 2018 a).

The information regarding the nature and magnitude of gene action controlling the characters under consideration, combining ability of the parents, degree of heterosis and inbreeding depression are helpful in determining the success of the efficient breeding procedure. A good understanding of the inheritance pattern of desirable traits helps in the formulation of a suitable breeding strategy and of the most efficient breeding programme. The concept of combining ability has been frequently used in several crops for the selection of superior parents for use in hybridization programmes and for understanding the nature and pattern of genes governing various traits. The information about various aspects of heterosis with its manifestation is very crucial for the development of superior varieties.

MATERIALS AND METHODS

The present experiment was laid out at Crop Research Farm Nawabganj at C.S. Azad University of Agriculture & Technology, Kanpur. The hybrids along with parental lines and check varieties were evaluated in randomized complete block design with three replications. Three testers (males) *viz*., CSR-36, Pusa-Basmati-1, and NDR-359 were crossed with sixteen genetically diverse aromatic and non-aromatic rice genotypes/ varieties as lines (females) parents in a line × tester mating fashion. The sixteen female parents (lines) were Sarjoo 52, NDRK 5088, CSR 30, T-3, Pakistani Basmati, Ram Raj, CSAR 839-3, Pusa Sugandha-3, Pusa Sugandha 5, Narendra Usar 3, Pokkali, IR 79218-63-2-3-1, IR 79495-9-3-2-2, FL- 478, IR 82571-544-2-3 and CSR-13.

The combining ability analysis was carried out with line × tester mating design, as given by Kempthorne (1957) and further elaborated by Arunachalam (1974). 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 F_1 generation of the line × tester sets of crosses. 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).

RESULTS AND DISCUSSION

The results of the present study showed that ANOVA for combining ability revealed non-significant differences duo to testers from all the characters under study. The mean square due to line x tester's interaction was found significant for all the characters, indicating the importance of specific combining ability and non-additive gene effects (**Table 1**).

The estimated values of sca variance were higher than the corresponding estimates of gca variances for all the traits. The value of the mean degree of dominance was more than unity (> 1), which indicated over dominance for all the traits. The predictability ratio was lesser than one for all the characters studied. However, higher sca variance than gca variance for all the characters indicated the dominance of additive gene effects (**Table 2**). The lesser than one predictability ratio also suggested 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 inheritance of grain yield and yield components of rice, has been reported earlier (Radhidevi *et al.,* 2002; Vishwakarma *et al.,* 2003; Punitha *et al.,* 2004; Pradhan *et al.,* 2006; Rashid *et al.,* 2007; Saleem *et al.,* 2010; Saidaiah *et al.,* 2010).

Table 1. Analysis of variance for combining ability following line x tester mating design for 15 characters in rice

Characters	Source of variation				
	Replication	Lines	Testers	Line x tester	Error
d.f.	2	15	2	30	94
Days to 50% flowering	18.757	92.583	50.674	365.896**	9.743
Plant height	235.090*	277.107	151.090	359.401**	61.264
Panicle bearing tillers per plant	2.583	19.228	0.250	36.072**	2.293
Panicle length	0.154	29.248	0.210	39.938**	2.853
Spikelet per panicle	1244.882	777.496	184.549	1073.000**	265.917
Spikelet fertility	3.148	10.599	1.201	18.483**	6.987
1000-grain weight	301.072	231.304	382.719	369.462	324.232
Biological yield per plant	15.402	538.170	5.494	827.590**	34.909
Harvest index	9.449	85.674	14.438	120.861**	13.673
Grain yield per plant	0.549	143.666	9.514	186.079**	6.608
Kernel length	0.088	1.819	0.003	2.566**	0.111
Kernel breadth	0.011	0.197	0.003	0.269**	0.018
L:B ratio	3.273**	1.322	0.008	1.870**	0.045
Kernel length after cooking	0.082	11.948	0.219	19.368**	0.201
Kernel elongation ratio	0.004	0.125	0.014	0.155**	0.010

** : Significance at 1% level

Table 2. Component of genetic variances, average degree of dominance, predictability ratio and heritability in narrow sense and genetic advanced in 15 characters in rice

Characters	gca variances ($\delta^2 g$)	sca variances ($\delta^2 s$)	Average degree of dominance $\sqrt{\delta^2 s / 2\delta^2 g}$	Predictability ratio $2\delta^2 / 2\delta^2 g + \delta^2 s$	$\delta^2 A$	$\delta^2 D$	Heritability (h^2n) %	Genetic advance (%)
Days to 50% flowering	2.130	118.493	5.274	0.035	4.260	118.493	33.75	7.81
Plant height	4.1879	88.233	3.245	0.087	8.379	88.233	65.37	15.25
Panicle bearing tillers / plant	0.266	9.635	4.258	0.052	0.531	9.635	48.79	3.32
Panicle length	0.280	11.062	4.445	0.048	0.560	11.062	40.36	3.10
Spikelet/panicle	9.578	288.316	3.880	0.062	19.156	288.316	50.03	20.33
Spikelet fertility	-0.011	4.092	13.799	-0.005	-0.021	4.092	3.50	-0.18
1000-grain weight	2.626	45.764	2.952	0.103	5.252	45.764	40.90	9.55
Biological yield/plant	8.579	266.751	3.943	0.060	17.157	266.751	58.55	20.65
Harvest index	1.274	35.684	3.742	0.067	2.548	35.684	59.51	8.02
Grain yield/plant	2.492	60.174	3.474	0.077	4.985	60.174	74.39	12.54
Kernel length	0.029	0.826	3.781	0.065	0.058	0.826	63.25	1.24
Kernel breadth	0.003	0.085	3.741	0.067	0.006	0.085	63.57	0.40
L:B ratio	0.022	0.608	3.743	0.067	0.043	.600	65.08	1.09
Kernel length after cooking	0.207	4.392	3.259	0.087	0.413	4.392	84.91	3.86
Kernel elongation ratio	0.002	0.048	3.401	0.080	0.004	0.048	74.99	0.37

The significant and positive general combining ability effects (**Table 3**) was reported for grain yield per plant and was exhibited by CSR-13, CSAR 839-3, IR 79495-9-3-2-2, Sarjoo 52 and Usar-3. CSR 13 showed a significant GCA effect for panicle length, biological yield/plant after cooking (KLAC), and kernel elongation ratio but showed an undesirable and significant effect for number days to 50% flowering, plant height, panicle bearing tillers per plant, spikelet per panicle, spikelet fertility per cent, the weight of 1000-grains, harvest index and kernel breadth. CSAR 839-3 was recorded significant and desirable gca effects for length of panicle, spikelet per panicle, spikelet fertility per cent, biological yield per plant, harvest index, grain yield per plant, kernel length after cooking and kernel elongation ratio. However, CSAR 839-3 appeared poor general combiner for early flowering, plant height, panicle bearing tillers per plant, the weight of 1000-grains, kernel length, kernel breadth and length: breadth ratio. Usar-3 emerged as a good general combiner for panicle bearing tillers per plant, biological yield per plant, grain yield per plant and kernel breadth. However, it was a poor general combiner for number days to 50% flowering, plant height, panicle length, spikelet per panicle, spikelet fertility per cent, the weight of 1000-grains, harvest index, kernel length, L:B ratio, kernel length after cooking and kernel elongation ratio.

The crosses showed significant and positive specific combining ability effects for grain yield per plant and other yield contributing traits were, NDRK 5088 x NDR 359, Ram raj x CSR 36, T-3 x PB-1, FL 478 x PB-1, Usar-3 x CSR-36, CSR 13 x CSR 36, Pokkali x NDR 359, IR 79495-9-3-2-2 x NDR 359, PS-3 x CSR 36, PS-3 x PB-1, PS-5 x CSR 36, Sarjoo 52 x NDR 359, IR 79218-63-2-3-1 x PB-1, Pakistan Basmati x CSR-36, Pakistan Basmati x PB-1, CSAR 839-3 x PB-1 and CSR 30 x CSR 36. The cross combinations with the highest positive and significant specific combining ability effects for grain yield per plant was also showed significant specific combining ability effects in desirable direction for biological yield per plant, harvest index, kernel breadth and spikelet fertility (**Table 4**). The second ranking cross for higher positive and significant SCA effects for grain yield per plant was, Ram raj x CSR 36. Which showed significant and desirable SCA effects for spikelet per panicle, 1000-grain and kernel breadth. The third r anking cross T-3 x PB-1 exhibited significant and desirable SCA effects for biological yield per plant, panicle bearing per tillers and spikelet fertility per cent. The remaining cross combinations had significant and positive SCA effects for grain yield per plant and also possessed significant specific combining effects in a desirable direction for some other phenotypic traits .

Among the various methods of combining ability analysis, line x tester analysis (Kempthorne, 1957) has been widely utilized for screening of germplasm to identify valuable donor parents and promising crosses in many crops reported including rice (Lavanya 2000, Swamy *et al.,* 2003, Punitha *et al.,* 2004, Dalvi and Patel, 2009, Saleem *et al.,* 2010, Saidaiah *et al.,* 2010).

Table 3. Estimates of general combining ability (GCA) effects of parents (lines and tester) for 15 characters rice

S. No.	Parents	Days of 50% flowering	Plant height	Panicle bearing tillers/ plant	Panicle length	Spikelets/ panicle	Spikelet fertility	1000 grain weight	Biological yield/ plant	Harvest index
	Lines									
1.	IR 82571-544-2-3	-1.01	-3.45	-1.21*	-3.69**	6.44	0.63	-1.83	-9.36**	0.46
2.	NDRK 5088	5.32**	10.94**	0.13	-0.22	-4.44	-0.09	-0.61	-4.43*	0.75
3.	Pokkali	-1.46	2.33	-1.32**	1.40	-9.00	0.84	18.63**	-5.83**	0.41
4.	CSR 13	0.99	-0.73	-1.32**	2.77**	7.00	0.59	-2.30	11.61**	0.29
5.	T-3	-2.01	-3.01	3.13**	-0.43	-4.22	-0.38	0.12	1.91	-1.24
6.	IR 79218-63-2-3-1	1.32	0.99	-0.21	-2.20*	8.22	-0.11	-1.17	1.35	-3.97**
7.	Pakistan Basmati	-0.13	4.33	-1.99**	0.13	-7.78	0.23	-1.22	-11.86**	0.57
8.	Ramraj	-5.57**	2.99	-0.10	1.78*	-22.33**	0.23	-2.22	-4.33*	0.69
9.	CSAR 839-3	-1.13	0.55	0.46	1.95*	12.67**	1.79*	-1.90	11.52**	4.62**
10.	IR 79495-9-3-2-2	-2.24*	-10.45*	2.90**	-0.47	-1.22	-0.77	0.75	8.25**	-3.28**
11.	Pusa Suhandha-3	1.43	3.88	-0.76	-0.55	9.56*	-1.88*	-2.27	1.70	-2.90*
12.	PS-5	0.10	-8.45**	-0.32	-2.69**	-2.56	1.45	0.17	-8.52**	2.20
13.	FL-478	8.21**	6.44	-1.21**	1.43	-9.11	0.12	-2.33	-6.55**	-2-90*
14.	Sarjoo-52	-1.01	-1.90	0.79	-1.13	6.67	0.01	-2.07	2.30	7.80**
15.	CSR-30	-2.57*	-6.45*	0.32	1.46	1.78	-0.10	-0.22	0.78	-2.96*
16.	Usar-3	-0.24	1.99	1.35**	0.47	8.33	-2.55**	-1.51	11.45**	-0.60
	Testers									
17	CSR 36	1.12*	1.01	0.04	0.03	0.97	0.10	-1.76	-0.28	0.46
18.	Pusa Basmati-1	-0.90	1.03	-0.08	0.05	1.28	-0.18	-1.49	-0.10	0-.60
19.	NDR 359	-0.22	-2.05	0.04	-0.08	-2.26	0.08	3.26	.38	0.14

Contd…..

S. No.	Parents	Grain yield/ plant	Kenrnel length	Kernel breadth	L::B ratio	Kernel length after cooking	Kernel elongation ratio
	Lines						
1.	IR 82571-544-2-3	-3.63**	-0.84**	0.21**	-0.64**	-1.69**	-0.03
2.	NDRK 5088	-0.84	-0.07	0.00	-0.13	0.24	0.05
3.	Pokkali	-2.56**	0.54**	-0.31**	0.84**	1.18**	0.02
4.	CSR 13	6.05**	0.28**	-0.04	0.16*	1.33**	0.12**
5.	T-3	0.31	0.05	0.21**	-0.42**	-0.89**	-0.13**
6.	IR 79218-63-2-3-1	-2.55**	-0.67**	-0.01	-0.29**	-1.53**	-0.05
7.	Pakistan Basmati	-4.80**	-0.15	-0.03	-0.11	-0.12	0.01
8.	Ramraj	-1.37	0.08	-0.13**	0.31**	0.22	0.00
9.	CSAR 839-3	8.24**	-0.12	-0.06	0.05	1.88**	0.30**
10.	IR 79495-9-3-2-2	1.96**	0.63**	0.05	0.18*	-0.91**	-0.25**
11.	Pusa Suhandha-3	-2.31**	-0.32**	-0.06	-0.13	-0.55**	0.00
12.	PS-5	-2.54**	-0.37**	0.20**	-0.56**	-1.28**	-0.09*
13.	FL-478	-4.58**	0.55**	-0.09*	0.38**	1.60**	0.08*
14.	Sarjoo-52	5.91**	-0.25*	-0.20**	0.23**	-0.01	0.07*
15.	CSR-30	-0.61	0.69**	0.11**	0.29**	1.17**	-0.03
16.	Usar-3	3.33**	-0.01	0.14**	-0.16*	-0.64**	-0.08*
	Testers						
17	CSR 36	0.25	-0.01	0.00	-0.01	0.01	0.01
18.	Pusa Basmati-1	-0.51	0.01	-0.01	0.01	-0.07	-0.02

Table 4. Estimates of specific combining ability (SCA) effects of crosses for 16 characters in rice

S. No.	Crosses	Days of 50% flowering	Plant height	Panicle bearing tillers/ plant	Panicle length	Spikelets/ panicle	Spikelet fertility	1000 grain weight	Biological yield/ plant	Harvest index
1.	IR82571-544-2-3 x CSR 36	1.33	-7.90	-0.04	-0.67	8.14	-4.72**	0.36	6.52*	-5.53*
2.	IR82571-544-2-3 x Pusa Basmati-1	3.35	4.08	2.08 *	0.57	-10.51	2.89 *	2.95	-4.16	-0.34
3.	IR82571-544-2-3 x NDR 359	-4.67*	3.83	-2.04*	0.10	2.37	1.83	-3.31	-2.37	5.88**
4.	NDRK5O88 x CSR36	-1.67	0.38	0.29	-0.51	-10.64	-1.57	4.96*	4.09	-4.35*
5.	NDRK 5088x Pusa Basmati-1	16.68 **	5.35	-4.58**	0.47	-17.62 *	-0.22	-1.71	-19.09**	-3.69
6.	NDRK 5088x NDR 359	-15.01 **	-5.73	4.29 **	0.04	28.26 **	1.79	-3.25	15.00 **	8.04**
7.	Pokkali x CSR 36	18.10**	17.32 **	-2.26**	5.37**	-17.42 *	-2.57*	-26.15**	2.23	-13.80**
8.	Pokkali x Pusa Basmati-1	-18.54**	-5.87	0.19	-1.65	-1.73	2.71*	-20.72 *	-13.46 **	8.11**
9.	Pokali x NDR 359	0.444	-11.45 *	2.07*	-3.73*	19.15*	-0.14	46.87**	11.24**	5.68**
10.	CSR 13 x CSR 36	14.66**	5.88	2.74**	-5.46**	0.58	-0.28	3.09	12.28 **	3.49
11.	CSR 13 x Pusa Basmati-1	-8.99**	14.69 *	-0.81	6.05**	0.94	-1.72	-0.95	-6.74 *	-0.39
12.	CSR 13 x NDR 359	-5.67**	-20.56**	-1.93 *	-0.59	-1.52	2.01*	-2.14	-5.54	-3.09
13.	T-3 x CSR 36	5.66**	-17.69**	2.29**	-3.77*	-23.19**	-2.05	5.53*	-11.85**	-4.14
14.	T-3 x Pusa Basmati-1	-4.99**	-2.37	3.42**	1.249	16.16	2.33*	1.69	26.70**	1.90
15.	T-3 x NDR 359	-0.67	20.05**	-5.71**	2.53	7.04	-0.28	-7.22*	-14.84 **	2.24
16.	IR79218-63-2-3-1 x Pusa Basmati-1	6.66**	6.99	0.96	2.27	-0.64	0.99	1.59	18.04**	-3.00
17	IR79218-63-2-3-1 x Basmati-1	-3.65	-8.37	-1.25	-1.19	8.38	-2.70*	1.43	-2.71	-0.19
18.	IR79218-63-2-3-1 x NDR 359	-3.01	1.38	0.29	-1.09	-7.74	1.71	-3.02	-15.34**	3.19
19.	Pakistan Basmati x CSR36	-8.56**	-8.68	-0.93	0.00	15.03	1.68	1.06	0.80	5.79**
20.	Pakistan Basmati x Pusa Basmati-1	-0.21	1.63	2.53**	-0.34	-4.95	-1.04	4.45*	11.33	-2.54
21.	Pakistan Basmati x NDR359	8.77	7.05	-1.60	0.34	-10.08	-0.64	-5.51	-12.13**	-3.25
22.	Ramraj x CSR36	-7.78**	-4.69	3.51**	-1.91	39.92**	1.68	4.05*	17.06**	5.86 **
23.	Ramraj x Pusa Basmati-1	17.57**	5.97	-2.36 **	4.60 **	-2.06	-3.37 *	0.74	0.54	-13.12 **
24.	Ramraj x NDR.359	-9.78 **	-1.29	-1.15	-2.69	-37.85 **	1.70	-4.79*	-17.60**	7.26**
25.	CSAR 839-3 x CSR 36	-2.90	-9.57	-0.04	-4.29 **	-4.75	-0.88	1.26	-10.73**	4.57*
26.	CSAR 839-3 x Pusa Basmati-1	11.46**	2.41	2.42 **	-1.73	5.27	2.74*	3.68	16.52**	-1.68
27.	CSAR 839-3 x NDR 359	-8.56**	7.16	-2.38**	6.02**	-0.52	-1.86	-4.94*	-5.79	-2.89
28.	IR79495-9-3-2-2 x CSR36	-1.45	-6.90	-4.82**	2.64	3.81	1.68	-0.20	-1.52	-1.05
29.	IR79495-9-3-2-2x Pusa Basmati-1	4.24 *	-4.92	1.64	-3.60*	-21.17 *	-4.04 **	3.17	-18.37**	-0.99
30.	IR79495-9-3-2-2x NDR 359	-2.78	11.83 *	3.18 **	0.96	17.37 *	2.36*	-2.97	19.90**	2.03
31.	Pusa Sugandha-3 x CSR36	4.78*	6.10	-1.49	1.57	-8.64	-0.88	0.30	13.97**	4.38*
32.	Pusa Sugandha-3 x Pusa Basmati-1	4.57 *	2.08	0.97	0.92	-3.29	0.07	2.17	17.50 **	-4.36 *
33.	Pusa Sugandha-3 x NDR 359	0.22	-8.17	0.51	-2.49	11.93	0.81	-2.46	-3.53	-0.02
34.	PS 5 x CSR 36	1.22	10.10	1.07	-0.63	-0.53	1.79	1.16	-4.81	-1.88
35.	PS 5 x Pusa Basmati-1	-5.43 **	5.75	-2.14*	-1.32	9.49	0.74	-0.63	-2.72	5.46*
36.	PS 5 x NDR 359	4.22*	-15.84**	1.07	1.95	-8.97	-2.53*	-0.53	7.53*	-3.58
37.	FL 478 x Pusa Basmati-1	7.11**	3.54	-2.71**	-1.35	-12.64	1.46	0.21	16.78**	1.56
38.	FL 478 x Pusa Basmati-1	-15.21**	-7.48	4.42**	-3.03 *	25.72 **	1.40	3.20	14.49 **	7.37**
39.	FL 478 x NDR 359	8.10 **	3.94	-1.71 *	4.38**	-13.08	-2.86 *	-3.42	2.29	-8.92**
40.	Sarjoo 52 x CSR 36	17.67**	1.04	1.71*	0.04	18.75*	1.23	0.42	-23.57**	1.04
41.	Sarjoo 52 x Pusa Basmati-1	2.35	-6.31	-0.25	-1.70	1.60	-0.82	0.81	-1.70	2.55
42.	Sarjoo 52 x NDR 359	15.33	5.27	1.96 *	1.68	17.15 *	-0.41	-1.23	25.27 **	-3.59
43.	CSR 30 x CSR36	-4.12*	10.76	-1.60	6.78**	25.14**	0.34	-1.29	5.61	5•46*
44.	CSR 30 x Pusa Basmati-1	-1.10	-8.59	-2.81**	0.09	1.49	2.29*	0.39	5.76	-2.43
45.	CSR 30 x NDR 359	5.22 **	-2.17	4.40 **	-6.88 **	-26.63**	-2.64*	0.91	-11.37**	-3.03
46.	Usar 3 x CSR 36	-5.79**	-6.68	4.74**	-0.07	4.58	2.12*	3.67	16.62**	1.61
47.	Usar 3 x Pusa Basmati-1	-2.10	1.97	-3.48 **	0.62	-7.73	-1.26	-0.66	-23.90 **	4.33 *
48.	Usar 3 x NDR 359	7.83**	4.72	-1.26	-0.55	3.15	-0.86	-3.00	7.29*	-5.95**

Table 4. Continued..

S. No.	Crosses	Grain yield/ plant	Kernel length	Kernel breadth	L::B ratio	Kernel length after cooking	Kernel elongation ratio
1.	IR82571-544-2-3 x CSR 36	-0.21	-0.26	-0.111	0.04	-0.16	0.04
2.	IR82571-544-2-3 x Pusa Basmati-1	-2.01	-0.09	0.22 **	-0.27*	0.43	0.10
3.	IR82571-544-2-3 x NDR 359	2.21	0.35 *	-0.11	0.23	-0.28	-0.14 *
4.	NDRK5O88 x CSR36	-2.03	-0.04	-0.06	-0.01	-1.04**	-0.14*
5.	NDRK 5088x Pusa Basmati-1	-10.30**	0.32	-0.13	0.34**	2.10**	0.21**
6.	NDRK 5088x NDR 359	12.33**	-0.28	0.19 **	-0.33 **	-1.06**	-0.07
7.	Pokkali x CSR 36	-7.61**	0.93**	-0.04	0.53**	2.07**	0.05
8.	Pokkali x Pusa Basmati-1	-1.55	-1.03**	0.04	-0.73 **	-3.05 **	-0.16**
9.	Pokali x NDR 359	9.16**	0.10	-0.01	0.20	0.98 **	0.11
10.	CSR 13 x CSR 36	7.68**	-1.22**	0.08	-0.77**	-2.22**	0.01
11.	CSR 13 x Pusa Basmati-1	-2.32	-0.58**	0.10	-0.69 **	2.30**	0.38**
12.	CSR 13 x NDR 359	-5.35**	1.80**	-0.18	1.46**	-0.08	-0.39**
13.	T-3 x CSR 36	-5.35**	-0.84 **	-0.17 ***	-0.20	-1.19**	0.03
14.	T-3 x Pusa Basmati-1	12.01**	0.49 **	0.13	0.05	-1.04**	-0.23 **
15.	T-3 x NDR 359	-6.66**	0.35 *	0.04	0.15	2.23**	0.21**
16.	IR79218-63-2-3-1 x Pusa Basmati-1	4.28**	0.07	-0.56**	0.63**	-0.03	-0.03
17	IR79218-63-2-3-1 x Basmati-1	-0.33	0.19	0.10	-0.02	-0.11	-0.06
18.	IR79218-63-2-3-1 x NDR 359	-3.93**	-0.25	0.46**	-0.61 **	0.14	0.09
19.	PakistanBasmati x CSR36	3.59**	-0.48 **	0.13	-0.29 *	-1.76**	-0.13 *
20.	Pakistan Basmati x Pusa Basmati-1	3.07 *	0.03	-0.04	-0.05	-0.59*	-0.08
21.	Pakistan Basmati x NDR359	-6.66**	0.45 **	-0.09	0.34 **	2.34**	0.20**
22.	Ramraj x CSR36	12.32**	-0.43*	0.32**	-0.76**	-0.97**	-0.02
23.	Ramraj x Pusa Basmati-1	8.10**	1.19**	-0.23**	1.03**	3.19**	0.14*
24.	Ramraj x NDR.359	-4.22 **	-0.76**	-0.09	-0.27*	-2.22**	-0.12*
25.	CSAR 839-3 x CSR 36	-1.38	0.76**	-0.28**	0.99**	0.34	-0.15**
26.	CSAR 839-3 x Pusa Basmati-1	5.63**	-0.87**	0.11	-0.70**	-2.68**	-0.13*
27.	CSAR839-3 x NDR 359	-4.25**	0.12	0.16*	-0.28*	2.33**	0.29**
28.	IR79495-9-3-2-2 x CSR36	-2.16	1.53**	-0.29**	1.39**	2.22**	-0.03
29.	IR79495-9-3-2-2 x Pusa Basmati-1	-6.30**	-1.43**	0.00	-0.85**	-1.08**	0.17
30.	IR79495-9-3-2-2x NDR 359	8.46**	-0.10	0.29**	-0.54**	-1.14**	-0.15*
31.	Pusa Sugandha-3 x CSR36	3.65**	0.64**	0.30**	-0.14	1.95**	0.11
32.	Pusa Sugandha-3 x Pusa Basmati-1	3.62 **	-0.34	-0.51**	0.42**	-0.92**	-0.03
33.	Pusa Sugandha-3 x NDR 359	0.01	-0.30	0.21**	-0.28*	-1.03**	-0.07
34.	PS 5 x CSR 36	3.18*	-0.23	0.25**	-0.33**	-0.18	0.03
35.	PS 5 x Pusa Basmati-1	2.23	-0.24	-0.01	-0.07	-0.38	0.01
36.	PS 5 x NDR 359	0.94	0.47**	-0.24**	0.40**	0.57*	-0.04
37.	FL 478 x Pusa Basmati-1	-6.14**	-0.27	-0.03	-0.15	0.61*	0.14*
38.	FL 478 x Pusa Basmati-1	10.94**	-0.53**	0.27**	-0.73**	-2.32**	-0.16**
39.	FL 478 x NDR 359	-4.81**	0.80**	-0.24**	0.89**	1.71**	0.02
40.	Sarjoo 52 x CSR 36	-10.89**	-0.32	0.00	-1.17	-1.64**	-0.16**
41.	Sarjoo 52 x Pusa Basmati-1	1.78	1.03**	-0.27**	-1.08**	2.32**	0.06
42.	Sarjoo 52 x NDR 359	9.11**	-0.71**	0.27**	0.91**	-0.68**	0.09
43.	CSR 30 x CSR36	5.44**	-0.37*	-0.00	-0.39**	3.21**	0.53**
44.	CSR 30 x Pusa Basmati-1	-0.55	1.60**	-0.01	-1.32**	-0.43	-0.46**
45.	CSR 30 x NDR 359	-4.90**	-1.23**	0.01	0.93**	-2.78**	-0.07
46.	Usar 3 x CSR 36	9.28**	0.52**	0.44**	-0.35**	-1.22**	-0.29**
47.	Usar 3 x Pusa Basmati-1	-7.85**	0.28	0.22**	-0.13	2.26**	0.24**
48.	Usar 3 x NDR 359	-1.43	-0.81**	-0.66**	-0.49**	-1.04**	0.04

*, **, significant at 5% and 1% probability levels

Table 5. Most promising cross combination for different characters along with their mean performance and gca effects of parents.

Characters	Crosses with significant effects	Mean performance of crosses	gca effects of parents
Days to 50% flowering	Pokkali x PBN-1	-18.54	A x A
	Sarjoo-52 x CSR-36	-17.67	A x H
	Sarjoo-52 x NDR 359	-15.33	A x A
	FL-478 x PB-1	-15.21	H x A
	NDRK 5088 x NDR 359	-15.01	H x A
Plant height	CSR-13 x NDR 359	-20.56	A x A
	T-3 x CSR-36	-17.68	A x A
	Pokkali x CSR-36	-17.32	A x A
	PS-5 x NDR-359	-15.84	L x A
	Pokkali x NDR 359	-11.45	A x A
Panicle bearing tillers / plant	Usar Dhan-3 x CSR-36	4.74	H x A
	FL-478 x PB-1	4.42	L x A
	CSR-30 x NDR-359	4.40	A x A
	NDRK 5088 x NDR-359	4.29	A x A
	T-3 x PB-1	3.42	H x A
Panicle length	CSR-30 x CSR-36	6.78	A x A
	CSR-13 x PB-1	6.05	H x A
	CSAR 839-3 x NDR 359	6.02	H x A
	Pokkali x CSR-36	5.37	A x A
	Ram Raj x PB-1	4.60	A x A
Spikelet/panicle	Ramraj x CSR-36	39.92	L x A
	NSRK 5088 x NDR-359	28.26	L x A
	FL-478 x PB-1	25.72	A x A
	CSR-30 x CSR-36	25.14	A x A
	Pokkali x NDR 359	19.15	A x A
Spikelet fertility	IR 82571-544-2-3 x PB-1	2.89	A x A
	CSAR 839-3 x PB-1	2.74	H x A
	Pokkali x PB-1	2.71	A x A
	IR 79495-9-3-2-2-32-2 X NDR-359	2.36	A x A
	T-3 x PB-1	2.33	A x A
1000-grain weight	Pokkali x NDR 359	46.87	H x A
	T-3 x CSR-36	-5.53	A x A
	NDRK 5088 x CSR-36	-4.95	A x A
	Pakistan Basmati x PB-1	4.45	A x A
	Ramraj x CSR-36	4.05	A x A
Biological yield/plant	T-3 x PB-1	26.70	A x A
	Sarjoo-52 x NDR 359	25.27	A x A
	IR 79495-9-3-2-2 x NDR 359	1989	H x A
	IR 79218-63-2-3-1 x CSR-36	18.04	A x A
	Ram raj x CSR-36	17.06	L x A
Harvest index	Pokkali x PB-1	8.11	A + A
	NDRK 5088 x NDR 359	8.04	A + A
	FL 478 x PB-1	7.37	L + A
	Ram raj x NDR 359	7.26	A + A
	Pakistan Basmati x CSR-36	5.79	A + A
Grain yield/plant	NDRK 5088 x NDR 359	12.33	A + A
	Ram raj x CSR-36	12.32	A + A
	T-3 x PB-1	12.01	A + A
	FL 478 x PB-1	10.94	L + A
	Usar Dhan-3 x CSR-36	9.28	H + A
Kernel length	CSR 13 x NDR 359	1.80	H + A
	CSR 30 x PB-1	1.59	H + A
	IR 79495-9-3-2-2 x CSR-36	1.53	H + A
	Ram raj x PB-1	1.19	A + A
	Sarjoo-52 x PB-1	1.03	L + A
Kernel breadth	IR 79218-63-2-3-1 x NDR 359	0.46	L + A
	Usar Dhan-3 x CSR-36	0.44	H + A
	Ram raj x CSR-36	0.32	L + A
	PS-3 x CSR-36	0.30	A + A
	IR 82571-544-2-3 x PB-1	0.22	H + A
L:B ratio	CSR-13 x NDR 359	1.46	H + A
	IR 79495-9-3-2-2 x CSR-36	1.39	A + A
	CSR-36 x PB-1	1.32	H + A
	Sarjoo-52 x PB-1	1.08	H + A
	Ramraj x PB-1	1.03	H + A
Kernel length after cooking	CSR-30 x CSR-36	3.21	H + A
	Ramraj x PB-1	3.19	A + A
	Pakistan Basmati x NDR 359	2.34	A + A
	CSAR 839-3 x NDR 359	2.33	H + A
	Sarjoo-52 x PB-1	2.32	A + A
Kernel elongation ratio	CSR-30 x CSR-36	0.53	A + A
	CSR-13 x PB-1	0.38	H + A
	CSAR 839-3 x NDR 359	0.29	H + A
	Usar 3 x PB-1	0.24	L + A
	NDRK 5088 x NDR 359	0.21	A + A

Table 6. The parents exhibiting significant and desirable general combining ability effects for different characters

Characters	Parents
Days to 50% flowering	NDRK 5088, FL 478, CSR 36
Plant height	NDRK 5088
Panicle bearing tillers / plant	T-3, IR 79495-9-3-2-2, Usar-3
Panicle length	CSR-13, Ramraj, CSAR 839-3
Spikelet/panicle	CSAR 839-3, Pusa Sugandha-3
Spikelet fertility	CSAR 839-3
1000-grain weight	Pokkali
Biological yield/plant	CSR-13, CSAR 839-3, IR 79495-9-3-2-2, Usar Dhan-3
Harvest index	CSAR 839-3, Sarjoo-52
Grain yield/plant	CSR-13, CSAR 839-3, IR 79495-9-3-2-2, Sarjoo-52, Usar-3
Kernel length	Pokkali, CSR-13, IR 79495-9-3-2-2, FL-478, CSR-30
Kernel breadth	IR 82571-544-2-3, T-3, PS-5, CSR-30, Usar-3
L:B ratio	Pokkali, CSR-13, Ramraj, IR 79495-9-3-2-2, FL-478, Sarjoo-52, CSR-30
Kernel length after cooking	Pokkali, CSR-13, CSAR 839-3, FL-478, CSR-30
Kernel elongation ratio	CSR-13, CSAR 839-3, FL-478, Sarjoo-52

The parents showed better general combining ability effects for different traits are given in **Table 6**. The cross combinations exhibited significant and desirable specific combining ability effects for different characters **(Table 5)**. The parents involved showed all types of combinations of general combining ability effects *viz.*, high x high (H x H), high x average (H x A) High x Low (H x L), average x average (A x A) low x low (L x L) general combiner parents. The foregoing observation indicated that there was no particular relationship between positive and significant specific combining ability effects of crosses with general combining ability effects of their parents for the characters under study.

The present study finally concluded that the additive gene action was found for most of the traits, which indicated that the phenotypic selection and could be applied for the improvement of rice crops.

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