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Heterosis and combining ability analysis for yield and its components in rice (*Oryza sativa* L.)

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Abstract
Study of heterosis and combining ability were conducted on 40 F1 hybrids along with of 2 CMS lines (females), 20 diverse rice varieties/genotypes as testers (males) to know the pattern of inheritance of some morphological traits for selecting superior genotypes. The experiment was carried out according to line x tester mating design. Analysis of variance revealed significant differences among genotypes, crosses, lines, testers and line x tester interactions for all the ten traits, *viz.*, days to 50% flowering, flag leaf area, plant height, panicle bearing tillers plant^{-1}, panicle length, spikelets panicle^{-1}, grain yield plant^{-1}, test weight, biological yield plant^{-1} and harvest index. The highest heterosis (197.81%) was observed in cross IR 688897A X Sarjoo 52 followed by other eight crosses for yield and most of its related traits. Among the testers high gca was recorded in Sarjoo 52 and Narendra Usar 3 for harvest index, grain yield plant$^{-1,}$ days to 50% flowering (earliness), plant height (dwarf stature), panicle bearing tillers plant^{-1} and biological yield. Among the female parental lines, IR 58025 was observed as a good general combiner only for seedling height, panicle length, spikelets panicle^{-1}, test weight, biological yield palnt^{-1}. Cross between IR 688897A X Sarjoo 52, IR 58025 A X 21-2-5-B-1-1, IR 58025 A X Narendra Usar 3 and IR 58025 A X IR 71829-3R-73-1-2-B shown favorable *per se* performances and higher significant positive sca effects in related to grain yield plant^{-1}.These combinations proved to be good hybrids based on CMS system in rice.

Keywords: Heterosis, combining ability, yield, components, Rice, *Oryza sativa* L.

Introduction
Breeding strategies based on selection of hybrids require expected level of heterosis as well as the specific combining ability. In breeding high yielding varieties of crop plant, the breeders often face with the problem of selecting parents and crosses. Combining ability analysis is one of the powerful tools available to estimate the combining ability effects and aids in selecting the desirable parents and crosses for the exploitation of heterosis. Line x tester analysis provides information about general combining ability (gca) and specific combining ability (sca) effects of parents and is helpful in estimating various types of gene actions. Manivannan & Ganesan (2001) [8] applied line x tester analysis in sesame. Presence of heterosis and SCA effects for yield and its related traits in rice are reported by Roy & Mandal (2001) [13]. Sarker *et al*., (2002) [14] observed 100.7% heterosis for grain yield per hill in rice. Zhang *et al*., (2002) [16] studied the heterosis and combining ability of hybrid rice. Ahmed *et al*., (2003) [2] used line x tester technique in Summer squash to calculate the combining ability. Singh & Kumar (2004) [15] also identified suitable parents through line x tester analysis in rice.

Materials and methods
The experimental material for this investigation comprised of 2 CMS lines *viz*., IR 68897 A and IR 58025 A possessing "wild abortive" (WA) cytoplasm as lines (females), 20 diverse rice varieties/genotypes as testers (males) and 40 crosses obtained through crossing in a "line × tester" mating design (Kempthorne, 1957) [7]. These diverse elite strains were selected from the collection of genetic stock available in Rice Section of the Department of Genetics and Plant Breeding, N.D. University of Agriculture & Technology, Narendra Nagar (Kumarganj), Faizabad. The resulting sets of 40 F_1's along with their 22 parents were evaluated in randomized complete block design with three replications during *Kharif*, 2010. All the recommended cultural practices were followed to raise a good crop. The experimental data collected on ten characters i.e. days to 50% flowering, flag leaf area, plant height, panicle bearing tillers plant^{-1}, panicle length, spikelets panicle^{-1}, grain yield plant^{-1}, test weight, biological yield plant^{-1} and harvest index.
Data were recorded on five randomly selected plants from parents and F_1's plant samples. The combining ability analysis was carried out following line × tester mating design outlined by Kempthorne (1957) [7] and further elaborated by Arunachalam (1974) [3].

The heterosis was computed as per cent increase or decrease of the mean values of crosses (F_1's) over better parent (Heterobeltiosis) and standard variety (Standard Heterosis).

Results and Discussion

The analysis of variance for 62 entries (2 female lines + 20 male lines + 40 crosses) was done for ten characters *viz.*, days to 50% flowering, flag leaf area, plant height, panicle bearing tillers plant^{-1}, panicle length, spikelets panicle^{-1}, grain yield plant^{-1}, test weight, biological yield plant^{-1} and harvest index. A perusal of Table 1 revealed that variance due to treatments, parent and crosses were highly significant for all the characters indicating sufficient variability existed in the treatments, parent and crosses. Mean squares due to parent vs crosses were highly significant for all the traits except spikelet fertility and test weight indicating the presence of substantial heterosis in the crosses.

Tables 1: Analysis of variance including parent and crosses for 10 characters in rice

Source of variation	Replications	Treatments	Parent (P)	P vs C	Crosses (C)
DF	2	61	21	1	39
Days to 50 per cent flowering	3.57028	63.89470**	74.05534**	74.57029**	59.92505**
Flag leaf area (cm^2)	6.54935*	58.21665**	29.46020**	166.66999**	67.10120**
Plant height (cm)	49.22565**	332.16561**	296.37668**	360.26262**	345.03441**
Panicle bearing tillers per plant	10.72101**	30.91970**	46.28136**	219.45789**	21.99606**
Panicle length (cm)	8.29988**	21.22930**	20.87312**	63.13962**	20.65176**
Spikelets per panicle	111.58668	3619.19725**	3080.81021**	79434.13423**	2534.95281**
Test weight (g)	2.83803**	26.43394**	23.929.80**	1.30959	27.79352**
Biological yield per plant (g)	1.40810	6208.78878**	1749.81149**	123148.89195**	5889.42263**
Harvest-index (%	54.75425**	286.97919**	263.16995**	68.62616**	299.55812**
Grain yield per plant (g)	74.93563*	1020.17782**	358.40551**	11471.26994**	1089.80323**

Heterosis

Economic heterosis is usually expressed as an increase or decrease of F_1 value over better parent (heterobeltiosis) but from practical point of view, increase of F_1 value over the best commercial variety (standard heterosis) is more relevant. In the present investigation, the relative magnitude of heterosis over pollen parent and SH (NDRH 2) have been studied for ten characters in 40 hybrids (table 2 and 3). The results suggested that the magnitude of hybrid vigour differed from character to character depending upon hybrid combinations. None of the crosses were consistently good for all the characters.

Among 40 hybrids, 32 hybrids showed significant heterosis over better parent for grain yield plant^{-1}. However, over the SH (NDRH-2) heterosis was manifested in 36 crosses. Top 5 hybrids exhibiting highest heterosis over SH (NDRH-2) are IR 688897A X Sarjoo 52 (197.81%) followed by IR 58025 A X 21-2-5-B-1-1 (185.04, IR 58025 A X Narendra Usar 3 (158.28%) and IR 58025 A X IR 71829-3R-73-1-2-B (131.61%). Heterosis for grain yield plant^{-1} in saline-alkali soil was also reported by Ghara *et al.* (2014) [5]. The quantum of heterosis obtained in present study fully justify the commercial exploitation of heterosis in rice as a yield advantage of 20-30% over BP is obtained to be sufficient to encourage farmers to take up hybrid rice cultivation. The results obtained from present study indicated that the yield heterosis was mainly influenced by spikelets panicle^{-1}, panicle length, spikelet fertility, and test weight did contribute to increased yield heterosis. A wide range of variations in the expression of heterosis for grain yield was reported by many workers.

Table 2: Estimates of heterosis over better parent (BP) of 40 rice hybrids for 10 characters

Hybrids	Seedling height (cm)	Number of leaves per seedling	Days to 50% flowering	Flag leaf area (cm^2)	Plant height (cm)	Panicle bearing tillers per plant
IR 688897A X IR 70023-4B-R-12-3-1-1-B	52.84**	5.26	10.57**	-1.88	5.15**	-47.63**
IR 688897A X IR 61920-3B-22-2-1	42.42**	19.30**	4.53	1.80	2.65	-46.52**
IR 688897A X PNL 1-8-5-17-2	33.52**	8.77	8.30**	-0.85	0.35	-36.21**
IR 688897A X NDRK 5095	37.21**	0.00	10.94**	-3.27	7.35**	-38.16**
IR 688897A X NDRK 5056	38.51**	5.26	7.17*	-2.00	5.00**	-37.05**
IR 688897A X NDRK 5086	47.09**	5.26	10.57**	0.10	1.14	-34.54**
IR 688897A X NDR 9830119	14.33**	-1.75	11.70**	2.34	2.68	-36.77**
IR 688897A X NDRK 5013	65.31**	3.51	6.04*	-2.87	0.40	-49.30**
IR 688897A X CST 7-1	10.52**	-5.26	12.83**	-3.33	0.40	-40.67**
IR 688897A X 21-2-5-B-1-1	58.11**	12.28	11.32**	-3.39	8.86**	-41.78**
IR 688897A X IR 64	29.80**	-12.28	10.94**	-2.25	7.02**	-38.16**
IR 688897A X NDR 9830148	34.24**	-7.02	16.60**	2.30	9.23**	-40.53**
IR 688897A X CSRC(S) 14-1-4-0	51.54**	7.02	9.43**	-1.71	13.60**	-38.72**
IR 688897A X PNL 5-8-1-7-21	41.18**	-10.53	8.68**	1.12	2.61	-34.26**
IR 688897A X IR 72048-B-R-2-2-2-1-B	87.50**	-8.77	18.11**	2.74	8.82**	-28.69**
IR 688897A X IR 71829-3R-73-1-2-B	31.31**	8.77	17.74**	-3.30	-0.33	-30.36**
IR 688897A X NDRK 5094	42.64**	3.51	21.51**	-0.62	5.74**	-43.45**
IR 688897A X 92-H 51-4	31.01**	-5.26	16.98**	-1.78	2.61	-38.72**
IR 688897A X Narendra Usar 3	15.34**	-14.04	11.70**	-5.38	4.08**	-29.25**
IR 688897A X Sarjoo 52	47.54**	14.04	8.68**	0.97	0.99	-4.74
IR 58025 A X IR 70023-4B-R-12-3-1-1-B	79.93**	-18.97*	15.85**	19.80**	37.21**	-11.06
IR 58025 A X IR 61920-3B-22-2-1	64.98**	-18.97*	21.51**	53.13**	37.43**	0.96
IR 58025 A X PNL 1-8-5-17-2	81.64**	10.34	27.55**	-0.19	9.71**	-7.21
IR 58025 A X NDRK 5095	79.33**	18.97*	10.94**	1.44	31.76**	-9.62

Hybrids	Seedling height (cm)	Number of leaves per seedling	Days to 50% flowering	Flag leaf area (cm^2)	Plant height (cm)	Panicle bearing tillers per plant
IR 58025 A X NDRK 5056	61.65**	-17.24	7.92**	5.20	9.56**	17.31**
IR 58025 A X NDRK 5086	70.64**	-8.62	7.17*	9.71**	27.35**	17.31**
IR 58025 A X NDR 9830119	28.37**	-24.14**	10.57**	41.90	26.40**	-16.83**
IR 58025 A X NDRK 5013	98.88**	27.59**	18.87**	-3.67	31.99**	-36.54**
IR 58025 A X CST 7-1	122.37**	-5.17	10.94**	-0.62	-3.16*	2.40
IR 58025 A X 21-2-5-B-1-1	105.83**	5.17	10.19**	17.44**	31.91**	15.87**
IR 58025 A X IR 64	126.38**	15.52	15.47**	13.63**	6.54**	-35.58**
IR 58025 A X NDR 9830148	69.69**	1.72	12.83**	7.66	35.07**	-39.42**
IR 58025 A X CSRC(S) 14-1-4-0	5.50	-46.55**	13.58**	32.62**	33.53**	-27.88**
IR 58025 A X PNL 5-8-1-7-21	88.35**	1.72	13.96**	-1.22	0.81	-8.17
IR 58025 A X IR 72048-B-R-2-2-2-1-B	38.19**	-27.59**	22.26**	-0.20	14.41**	2.80
IR 58025 A X IR 71829-3R-73-1-2-B	62.14**	-17.24*	18.49**	0.88	22.87**	21.63**
IR 58025 A X NDRK 5094	67.79**	-3.45	22.26**	35.26**	11.99**	-14.42*
IR 58025 A X 92-H 51-4	48.32**	-10.34	12.83**	29.00**	32.94**	-4.81
IR 58025 A X Narendra Usar 3	36.24**	-17.24*	22.26**	4.94	9.41**	11.54*
IR 58025 A X Sarjoo 52	11.17**	-15.52	3.40	-8.79**	2.35	3.13
PUSA 6A X IR 70023-4B-R-12-3-1-1-B	76.42**	-16.95*	20.38**	-0.40	9.30**	-17.83**
PUSA 6A X IR 61920-3B-22-2-1	43.27**	22.03**	15.09**	0.10	3.71**	-20.87**
PUSA 6A X PNL 1-8-5-17-2	37.97**	-22.03**	18.87**	2.16	3.79**	-1.30
PUSA 6A X NDRK 5095	62.92**	5.08	20.75**	-5.58*	-0.70	-9.57
PUSA 6A X NDRK 5056	38.19**	-16.95*	13.21**	-9.90**	3.71**	-11.74*
PUSA 6A X NDRK 5086	35.32**	3.39	21.51**	-2.07	-5.11**	-15.22**
PUSA 6A X NDR 9830119	39.19**	-8.47	16.98**	-2.75	4.82**	-12.61*
PUSA 6A X NDRK 5013	17.62**	-16.95*	14.34**	-1.78	2.61	17.83**
PUSA 6A X CST 7-1	36.73**	8.47	18.87**	-0.63	-7.32**	21.74**
PUSA 6A X 21-2-5-B-1-1	53.02**	-5.08	15.09**	-1.33	5.92**	-14.78**
PUSA 6A X IR 64	47.25**	-13.56	18.87**	-0.12	0.40	-16.52**
PUSA 6A X NDR 9830148	25.98**	16.95*	11.32**	-5.14	8.12**	-21.30**
PUSA 6A X CSRC(S) 14-1-4-0	56.10**	1.69	13.21**	-4.48	10.77**	-22.17**
PUSA 6A X PNL 5-8-1-7-21	32.94**	-10.17	15.09**	0.51	1.51	0.87
PUSA 6A X IR 72048-B-R-2-2-2-1-B	58.06**	-1.69	9.43**	-10.68**.	4.82	2.61
PUSA 6A X IR 71829-3R-73-1-2-B	26.43**	-10.17	16.23**	-1.54	-2.90	-16.52**
PUSA 6A X NDRK 5094	61.20**	0.00	12.45**	0.52	0.40	-12.61*
PUSA 6A X 92-H 51-4	29.89**	-8.47	17.36**	-2.05	-0.74	-16.09**
PUSA 6A X Narendra Usar 3	35.05**	8.47	19.25**	2.76	1.51	-12.61*
PUSA 6A X Sarjoo 52	52.46**	-3.39	13.58**	-3.27	4.01	4.69
Significant +ve heterosis	59	5	37	5	58	10
Significant -ve heterosis	-	12	-	40	-	3
Mean heterosis (%)	50.423	-3.162	14.251	3.183	9.118	-17.135
SE	0.770	0.316	2.466	0.961	1.218	0.784
Range	5.50-126.38	(-46.55)-27.59	3.40-27.55	(-10.58)-53.13	(-7.32)-37.43	(-49.30)-21.63

Hybrids	Panicle length (cm)	Spikelets per panicle	Spikelet fertility (%)	Test weight (g)	Biological yield(g)	Harvest index (%)	Grain yield per plant (g)
IR 688897A X IR 70023-4B-R-12-3-1-1-B	-3.73	2.93	-0.36	-23.40**	55.03**	-33.81**	17.24
IR 688897A X IR 61920-3B-22-2-1	6.57	10.50	-7.84**	-20.65**	48.04**	-27.39**	20.37
IR 688897A X PNL 1-8-5-17-2	1.78	9.12	-2.58	-21.78**	52.22**	-25.78**	58.23**
IR 688897A X NDRK 5095	1.19	-5.85	-5.37*	-15.02**	12.61**	-28.78**	36.00**
IR 688897A X NDRK 5056	-1.82	-7.06	-1.23	-29.51**	29.63**	-44.72**	17.68
IR 688897A X NDRK 5086	-4.99	3.44	-18.23**	-26.28**	9.77*	-35.91**	19.78
IR 688897A X NDR 9830119	2.36	-8.04	-2.25	-24.66**	12.91**	-37.22**	42.62**
IR 688897A X NDRK 5013	-2.70	-0.69	-29.19**	-6.13**	17.89**	-43.36**	-6.50
IR 688897A X CST 7-1	7.93*	-16.87**	-15.69**	-21.15**	31.17**	-32.44**	-9.05
IR 688897A X 21-2-5-B-1-1	1.02	1.72	-11.76**	-17.27**	26.91**	-37.70**	21.59
IR 688897A X IR 64	-5.04	-8.95	0.58	-4.26*	53.62**	-22.18**	66.38**
IR 688897A X NDR 9830148	0.00	5.85	-18.59**	-14.77**	37.45**	-33.57**	25.01*
IR 688897A X CSRC(S) 14-1-4-0	-2.09	-0.17	-11.73**	-13.64**	30.92**	-26.25**	41.30**
IR 688897A X PNL 5-8-1-7-21	-3.49	-3.79	-11.37	-13.64**	22.65**	-28.91**	14.62
IR 688897A X IR 72048-B-R-2-2-2-1-B	-0.33	-3.96	-22.29**	-17.40**	31.20**	-32.44**	29.55**
IR 688897A X IR 71829-3R-73-1-2-B	5.14	2.93	-34.28**	-36.92**	49.47**	-55.34**	-20.56
IR 688897A X NDRK 5094	0.71	-0.86	-3.05	-3.13	24.20**	-22.73**	28.70**
IR 688897A X 92-H 51-4	-1.07	1.20	-6.28**	-2.38	31.72**	-40.17**	33.56**
IR 688897A X Narendra Usar 3	-1.60	7.04	-5.16*	-21.03**	32.95**	-26.35**	52.21**
IR 688897A X Sarjoo 52	-6.59*	4.30	-6.95**	4.38*	31.82**	-13.94**	54.04**
IR 58025 A X IR 70023-4B-R-12-3-1-1-B	10.12**	-46.32**	-19.13**	-35.30**	46.97**	-76.65**	-65.53**
IR 58025 A X IR 61920-3B-22-2-1	12.59**	-25.83**	-20.09**	-42.75**	348.19**	-89.14	-51.50**

Hybrids	Panicle length (cm)	Spikelets per panicle	Spikelet fertility (%)	Test weight (g)	Biological yield(g)	Harvest index (%)	Grain yield per plant (g)
IR 58025 A X PNL 1-8-5-17-2	-8.89*	-17.58**	0.18	-7.32**	22.43**	-25.40**	12.40
IR 58025 A X NDRK 5095	11.53**	-26.12**	-21.17**	-2.44	38.32**	-62.39**	-23.46*
IR 58025 A X NDRK 5056	4.17	0.58	0.18	-11.17**	65.43**	-22.83**	71.17**
IR 58025 A X NDRK 5086	11.42**	-17.46**	-42.58**	1.16	44.30**	-60.44**	-14.76
IR 58025 A X NDR 9830119	16.23**	11.40*	1.00	-12.20**	88.60**	-60.75**	30.89**
IR 58025 A X NDRK 5013	21.58**	-26.64**	-27.86**	2.70	11.75*	-61.74**	-47.46**
IR 58025 A X CST 7-1	17.07**	5.74	0.18	3.21	272.64**	-47.88**	93.77**
IR 58025 A X 21-2-5-B-1-1	29.20**	18.18**	0.78	3.72	118.98**	-15.21**	149.77**
IR 58025 A X IR 64	-8.32*	4.10	0.48	-40.69**	34.18**	-64.99**	-42.69**
IR 58025 A X NDR 9830148	16.84**	-24.65**	1.89	-15.79**	31.80**	-66.13**	-46.45**
IR 58025 A X CSRC(S) 14-1-4-0	-1.04	-0.87	-25.71**	-2.95	132.84**	-74.39**	-23.19*
IR 58025 A X PNL 5-8-1-7-21	-1.40	5.48	0.63	-11.94**	66.38**	-41.53**	35.25**
IR 58025 A X IR 72048-B-R-2-2-2-1-B	-2.77	7.85	1.37	-8.43**	150.24**	-44.38**	77.75**
IR 58025 A X IR 71829-3R-73-1-2-B	14.44**	-7.94	0.33	5.85**	145.42**	-20.72**	102.95**
IR 58025 A X NDRK 5094	23.55**	6.23	1.07	-3.47	41.61**	-26.92**	46.16**
IR 58025 A X 92-H 51-4	-24.17**	-8.60	-73.07**	-35.56**	89.97**	-91.72**	-71.68**
IR 58025 A X Narendra Usar 3	9.36**	23.69**	1.22	-1.93	61.22**	-16.24**	121.74**
IR 58025 A X Sarjoo 52	4.23	-16.59**	21.58**	-22.61**	-17.38**	-31.33**	-18.14**
PUSA 6A X IR 70023-4B-R-12-3-1-1-B	-4.22	-16.31**	-3.60	-17.95**	58.78**	-34.53**	13.99
PUSA 6A X IR 61920-3B-22-2-1	-3.36	-9.38	-8.78**	-12.09**	33.18**	-11.38**	24.64
PUSA 6A X PNL 1-8-5-17-2	2.67	-6.46	-17.49**	-10.14**	44.95**	-23.51**	47.66**
PUSA 6A X NDRK 5095	-4.28	-7.23	-1.00	-6.24**	23.81**	-10.19	27.55**

Hybrids	Panicle length (cm)	Spikelets per panicle	Spikelet fertility (%)	Test weight (g)	Biological yield(g)	Harvest index (%)	Grain yield per plant (g)
PUSA 6A X NDRK 5056	-6.12	20.15**	-5.45*	-21.85**	69.40**	-27.90**	66.52**
PUSA 6A X NDRK 5086	-0.59	5.69	-0.93	-20.55**	74.13**	-44.42**	57.58**
PUSA 6A X NDR 9830119	3.66	11.08*	0.96	-19.90**	49.33**	-37.15**	37.41**
PUSA 6A X NDRK 5013	3.41	-8.15	-32.13**	-1.93	52.11**	-47.39**	6.81
PUSA 6A X CST 7-1	-0.14	-7.08	-2.22	-14.69**	65.99**	-19.40**	34.28**
PUSA 6A X 21-2-5-B-1-1	0.00	1.08	-8.86**	-10.14**	28.48**	-15.95**	58.19**
PUSA 6A X IR 64	3.89	11.38*	-3.08	0.78	33.57**	-8.93	61.69**
PUSA 6A X NDR 9830148	3.39	-11.85*	-32.95**	-7.93**	25.89**	-46.91**	-12.58
PUSA 6A X CSRC(S) 14-1-4-0	3.26	1.69	-5.45*	-8.39**	31.11**	-14.22**	56.98**
PUSA 6A X PNL 5-8-1-7-21	5.87	-7.38	1.22	-11.57**	30.25**	-1.96	38.46**
PUSA 6A X IR 72048-B-R-2-2-2-1-B	-4.10	-3.54	-3.41	-17.95**	37.76**	-4.60	82.83**
PUSA 6A X IR 71829-3R-73-1-2-B	-3.06	0.62	-15.68**	-29.52**	61.48**	-43.07**	4.23
PUSA 6A X NDRK 5094	-4.26	-17.69**	0.07	-5.33**	21.07**	-18.54**	9.48
PUSA 6A X 92-H 51-4	-4.74	13.38*	0.11	-3.25	11.29**	-1.33	54.11**
PUSA 6A X Narendra Usar 3	2.67	3.85	-0.93	-21.72**	19.99**	-26.18**	13.44
PUSA 6A X Sarjoo 52	-0.25	2.15	14.08**	0.88	26.70**	-5.21	41.06**
Significant +ve heterosis	12	6	-	2	59	-	32
Significant -ve heterosis	4	13	31	44	1	54	9
Mean heterosis (%)	2.378	-2.776	-8.964	-13.434	53.922	-34.875	26.735
SE	0.857	12.218	2.122	0.489	4.640	2.446	3.537
Range	(-24.17)-29.20	(-43.32)-23.69	(-73.07)-1.89	(-42.75)-5.85	9.77-348.19	(-91.72)-(-1.33)	(-71.68)-149.77

Table 3: Estimates of heterosis over standard hybrid (NDRH-2) of 40 rice hybrids for 10 characters

Hybrids	Seedling height (cm)	Number of leaves per seedling	Days to 50% flowering	Flag leaf area (cm^2)	Plant height (cm)	Panicle bearing tillers per plant
IR 688897A X IR 70023-4B-R-12-3-1-1-B	23.51**	-7.69	2.81	17.98**	0.35	-30.37**
IR 688897A X IR 61920-3B-22-2-1	14.32**	4.62	-2.81	19.98**	-2.04	-28.89**
IR 688897A X PNL 1-8-5-17-2	29.73**	-4.62	0.70	25.60**	-4.23**	-15.19**
IR 688897A X NDRK 5095	43.51**	-12.31	3.16	19.64**	2.46	-17.78**
IR 688897A X NDRK 5056	18.11**	-7.69	-0.35	16.67**	0.21	-16.30**
IR 688897A X NDRK 5086	36.76**	-7.69	2.81	15.36**	-3.47	-12.96**
IR 688897A X NDR 9830119	10.00**	-13.85	3.86	19.52**	-2.00	-15.93**
IR 688897A X NDRK 5013	59.73**	-9.23	-1.40	16.67**	-4.18**	-32.59**
IR 688897A X CST 7-1	-10.54**	-16.92*	4.91	10.48**	-4.18**	-21.11**
IR 688897A X 21-2-5-B-1-1	13.24**	-1.54	3.51	21.33**	3.89**	-22.59**
IR 688897A X IR 64	-10.54**	-23.08**	3.16	-1.55	2.14	-17.78**
IR 688897A X NDR 9830148	34.05**	-18.46*	8.42**	11.31**	4.25**	-20.93**
IR 688897A X CSRC(S) 14-1-4-0	25.95**	-6.15	1.75	9.76**	8.42**	-18.52**
IR 688897A X PNL 5-8-1-7-21	13.51**	-21.54**	1.05	18.69**	-2.07	-12.59**
IR 688897A X IR 72048-B-R-2-2-2-1-B	54.05**	-20.00**	9.82**	22.56**	3.86**	-5.19
IR 688897A X IR 71829-3R-73-1-2-B	5.41	-20.00**	9.47**	4.52	-4.88**	-7.41
IR 688897A X NDRK 5094	25.68**	-9.23	12.98**	14.76**	0.91	-24.81**
IR 688897A X 92-H 51-4	26.76**	-16.92*	8.77**	31.43**	-2.07	-18.52**
IR 688897A X Narendra Usar 3	17.84**	-24.62**	3.86	18.50**	-0.67	-5.93
IR 688897A X Sarjoo 52	21.62**	0.00	1.05	-0.83	-3.61**	26.67**

IR 58025 A X IR 70023-4B-R-12-3-1-1-B	45.41**	-27.69**	7.72**	44.05**	30.95**	-31.48**
IR 58025 A X IR 61920-3B-22-2-1	32.43**	-27.69**	12.98**	80.48**	31.16**	-22.22**
IR 58025 A X PNL 1-8-5-17-2	76.49**	-1.54	18.60**	26.43**	4.70**	-28.52**
IR 58025 A X NDRK 5095	87.57**	6.15	3.16	25.48**	25.75**	-30.37**

Hybrids	Seedling height (cm)	Number of leaves per seedling	Days to 50% flowering	Flag leaf area (cm^2)	Plant height (cm)	Panicle bearing tillers per plant
IR 58025 A X NDRK 5056	37.84**	-26.15**	0.35	25.24**	4.56**	-9.63*
IR 58025 A X NDRK 5086	58.65**	-18.46*	-0.35	26.43**	21.54**	-9.63*
IR 58025 A X NDR 9830119	23.51**	-32.31**	2.81	65.71**	20.63**	-35.93**
IR 58025 A X NDRK 5013	92.16**	13.85	10.53**	15.71**	25.96**	-51.11**
IR 58025 A X CST 7-1	80.00**	-15.38*	3.16	13.57**	-7.58**	-21.11**
IR 58025 A X 21-2-5-B-1-1	71.89**	-6.15	2.46	47.50**	25.89**	-10.74**
IR 58025 A X IR 64	89.05**	3.08	7.37**	23.10**	1.68	-50.37**
IR 58025 A X NDR 9830148	69.46**	-9.23	4.91	17.14**	28.91**	-53.33**
IR 58025 A X CSRC(S) 14-1-4-0	-11.89**	-52.31**	5.61*	48.10**	27.44**	-44.44**
IR 58025 A X PNL 5-8-1-7-21	57.30**	-9.23	5.96*	15.95**	-3.79**	-29.26**
IR 58025 A X IR 72048-B-R-2-2-2-1-B	15.41**	-35.38**	13.68**	19.05**	9.19**	-18.52**
IR 58025 A X IR 71829-3R-73-1-2-B	35.41**	-26.15**	10.18**	9.29**	17.26**	-6.30
IR 58025 A X NDRK 5094	47.84**	-13.85	13.68**	56.19**	6.88**	-34.07**
IR 58025 A X 92-H 51-4	43.51**	-20.00**	4.91	72.62**	26.88**	-26.67**
IR 58025 A X Narendra Usar 3	39.19**	-26.15**	13.68**	19.05**	4.42**	-14.07**
IR 58025 A X Sarjoo 52	-7.16*	-24.62**	-3.86	-1.19	-2.32	22.22**
PUSA 6A X IR 70023-4B-R-12-3-1-1-B	42.57**	-24.62**	11.93**	19.76**	4.32**	-30.00**
PUSA 6A X IR 61920-3B-22-2-1	15.00**	10.77	7.02**	17.98**	-1.07	-32.59**
PUSA 6A X PNL 1-8-5-17-2	34.05**	-29.23**	10.53**	29.40**	-0.95	-15.93**
PUSA 6A X NDRK 5095	70.41**	-4.62	12.28**	16.79**	-5.23**	-22.96**
PUSA 6A X NDRK 5056	17.84**	-24.62**	5.26*	7.26*	-1.02	-24.81**
PUSA 6A X NDRK 5086	25.81**	-6.15	12.98**	12.86**	-9.44**	-27.78**
PUSA 6A X NDR 9830119	33.92**	-16.92*	8.77**	13.57**	0.04	-25.56**
PUSA 6A X NDRK 5013	13.65**	-24.62**	6.32*	17.98**	-2.07	-30.00**
PUSA 6A X CST 7-1	10.68**	-1.54	10.53**	13.57**	-11.54**	-33.33
PUSA 6A X 21-2-5-B-1-1	9.59**	-13.85	7.02**	23.93**	1.09	-27.41**
PUSA 6A X IR 64	1.49	-21.54**	10.53**	0.60	-4.18**	-28.89**
PUSA 6A X NDR 9830148	25.81**	6.15	3.51	3.21	3.19	-32.96**
PUSA 6A X CSRC(S) 14-1-4-0	29.73**	-7.69	5.26*	6.67	5.72**	-33.70**
PUSA 6A X PNL 5-8-1-7-21	6.89*	-18.46*	7.02**	17.98**	-3.12*	-14.07**
PUSA 6A X IR 72048-B-R-2-2-2-1-B	29.86**	-10.77	1.75	6.55	0.04	-12.59**
PUSA 6A X IR 71829-3R-73-1-2-B	1.49	-18.46*	8.07**	6.43	-7.33**	-28.89**
PUSA 6A X NDRK 5094	42.03**	-9.23	4.56	16.07**	-4.18**	-25.56**
PUSA 6A X 92-H 51-4	25.68**	-16.92*	9.12**	31.07**	-5.26**	-28.52**
PUSA 6A X Narendra Usar 3	37.97**	-1.54	10.88**	28.69**	-3.12*	-25.56**
PUSA 6A X Sarjoo 52	25.68**	-12.31	5.61*	-5.00	-8.39**	24.07**
Significant +ve heterosis	53	-	33	-	23	3
Significant -ve heterosis	4	29	-	50	18	53
Mean heterosis (%)	32.282	-13.872	6.234	20.794	4.012	-21.689
SE	0.770	0.316	2.466	0.961	1.218	0.784
Range	(-11.89)-92.16	(-52.31)-13.85	(-3.86)-18.60	(-5.00)-80.48	(-11.54)-31.16	(-53.33)-26.67

Hybrids	Panicle length (cm)	Spikelets per panicle	Spikelet fertility (%)	Test weight (g)	Biological yield per plant (g)	Harvest index (%)	Grain yield per plant (g)
IR 688897A X IR 70023-4B-R-12-3-1-1-B	2.44	-9.80	7.61**	-7.27**	35.92**	-19.28**	10.46
IR 688897A X IR 61920-3B-22-2-1	-2.31	-3.17	-0.47	-3.94	25.83**	-11.45*	13.41
IR 688897A X PNL 1-8-5-17-2	-12.18**	-4.37	5.22*	-5.30*	63.04**	-9.49	49.08**
IR 688897A X NDRK 5095	9.10**	-17.50**	2.20	2.88	46.05**	-13.15*	28.14**
IR 688897A X NDRK 5056	-3.33	-18.55**	6.67**	-15.15**	63.33**	-32.59**	10.88
IR 688897A X NDRK 5086	-16.92**	-9.35	-11.69**	-10.76**	43.46**	-21.83**	12.86
IR 688897A X NDR 9830119	0.26	-7.84	5.57*	-8.79**	73.77**	-23.44**	34.38**
IR 688897A X NDRK 5013	-12.31**	-12.97*	-23.53**	13.64**	26.32**	-30.93**	-11.91
IR 688897A X CST 7-1	-16.67**	-27.15**	-8.94**	-4.55*	2.98	-17.61**	-14.30
IR 688897A X 21-2-5-B-1-1	-11.41**	-10.86	-4.71	0.15	48.95**	-24.03**	14.56
IR 688897A X IR 64	-15.51**	-20.21**	8.63**	15.91**	63.60**	-5.10	56.77**
IR 688897A X NDR 9830148	-2.56	-7.24	-12.08**	3.18	43.90**	-18.99**	17.79
IR 688897A X CSRC(S) 14-1-4-0	-3.85	-12.52*	-4.67	4.55*	46.54**	-10.05	33.13**
IR 688897A X PNL 5-8-1-7-21	-11.41**	-15.69**	-4.27	4.55*	55.70**	-13.30*	36.87**
IR 688897A X IR 72048-B-R-2-2-2-1-B	15.38**	-15.84**	-16.08**	0.00	46.62**	-17.60**	22.06*
IR 688897A X IR 71829-3R-73-1-2-B	-2.95	-9.80	-29.02**	-23.64**	35.96**	-45.53**	-25.15*
IR 688897A X NDRK 5094	-9.10**	-13.12*	4.71	17.27**	56.67**	-5.77	49.12**
IR 688897A X 92-H 51-4	7.05*	-11.31*	1.22	18.18**	110.75**	-27.04**	55.28**
IR 688897A X Narendra Usar 3	-5.64	1.36	2.43	-4.39	94.30**	-10.18	77.29**
IR 688897A X Sarjoo 52	-3.72	-8.60	0.78	26.36**	181.10**	4.95	197.81**
IR 58025 A X IR 70023-4B-R-12-3-1-1-B	17.18**	-43.89**	-14.27**	-23.64**	28.51**	-69.74**	-60.67**
IR 58025 A X IR 61920-3B-22-2-1	3.21	-22.47**	-15.29**	-32.42**	290.79**	-85.92**	-44.65**

Hybrids	Panicle length (cm)	Spikelets per panicle	Spikelet fertility (%)	Test weight (g)	Biological yield per plant (g)	Harvest index (%)	Grain yield per plant (g)
IR 58025 A X PNL 1-8-5-17-2	-17.18**	-13.85*	6.20*	9.39**	31.14**	-3.33	28.26**
IR 58025 A X NDRK 5095	20.26**	-22.78**	-16.55**	15.15**	79.39**	-51.26**	-11.73
IR 58025 A X NDRK 5056	2.56	5.13	6.20*	4.85*	93.51**	-0.01	95.35**
IR 58025 A X NDRK 5086	1.28	-13.73*	-39.14**	19.39**	88.60**	-48.74**	-2.72
IR 58025 A X NDR 9830119	13.85**	16.44**	7.06**	3.64	190.26**	-49.14**	49.38**
IR 58025 A X NDRK 5013	10.51**	-20.18**	-23.53**	21.21**	19.74**	-50.43**	-40.04**
IR 58025 A X CST 7-1	6.41	10.53	6.20*	21.82**	224.91**	-32.46**	121.14**
IR 58025 A X 21-2-5-B-1-1	17.44**	23.53**	6.82**	22.42**	157.02**	9.87	185.04**
IR 58025 A X IR 64	-16.67**	8.81	6.51*	-30.00**	42.89**	-54.64**	-34.59**
IR 58025 A X NDR 9830148	13.85**	-21.24**	8.00**	-0.61	37.98**	-56.11**	-38.89**
IR 58025 A X CSRC(S) 14-1-4-0	-2.82	3.62	-21.25**	14.55**	160.61**	-66.82**	-12.34
IR 58025 A X PNL 5-8-1-7-21	-6.92*	10.26	6.67**	3.94	111.23**	-24.23**	61.50**
IR 58025 A X IR 72048-B-R-2-2-2-1-B	12.56**	12.73*	7.45**	8.08**	179.65**	-27.93**	102.85**
IR 58025 A X IR 71829-3R-73-1-2-B	5.64	-3.77	6.35*	24.94**	123.25**	2.73	131.61**
IR 58025 A X NDRK 5094	12.31**	11.04*	7.14**	13.94**	78.63**	-5.31	69.36**
IR 58025 A X 92-H 51-4	-17.95**	-4.46	-71.45**	-23.94**	203.95**	-89.27**	-67.08**
IR 58025 A X Narendra Usar 3	4.87	29.29**	7.29**	15.76**	135.61**	8.53	158.28**
IR 58025 A X Sarjoo 52	7.44*	-12.82*	-15.06**	-6.67**	76.18**	-11.01*	58.25**
PUSA 6A X IR 70023-4B-R-12-3-1-1-B	1.92	-17.95**	2.00	-4.39	39.21**	-33.85**	-6.58
PUSA 6A X IR 61920-3B-22-2-1	-11.41**	-11.16*	-3.49	2.42	13.20*	-10.47	2.15
PUSA 6A X PNL 1-8-5-17-2	-11.41**	-8.30	-12.71**	4.70*	55.26**	-22.72**	21.01*
PUSA 6A X NDRK 5095	3.21	-9.05	4.75	9.24**	60.57**	-9.27	47.10**
PUSA 6A X NDRK 5056	-7.56*	17.80**	0.04	-8.94**	98.16**	-27.16**	45.60**
PUSA 6A X NDRK 5086	-13.08**	3.62	4.82	-7.42**	127.59**	-43.85**	29.15**
PUSA 6A X NDR 9830119	1.54	11.31*	6.82**	-6.67**	129.82**	-36.51**	47.38**
PUSA 6A X NDRK 5013	-6.79*	-9.95	-28.20**	15.61**	62.98**	-46.85**	-12.46
PUSA 6A X CST 7-1	-9.62**	-8.90	3.45	-0.61	33.51**	-18.57**	10.05
PUSA 6A X 21-2-5-B-1-1	-12.31**	-0.90	-3.57	4.70*	50.79**	-15.09**	29.64**
PUSA 6A X IR 64	-7.56*	-13.12*	2.55	17.42**	42.24**	-7.99	32.52**
PUSA 6A X NDR 9830148	-2.18	-13.57*	-29.06**	7.27**	31.80**	-46.36**	-28.36**
PUSA 6A X CSRC(S) 14-1-4-0	1.41	-0.30	0.04	6.74**	46.75**	-13.34*	28.65**
PUSA 6A X PNL 5-8-1-7-21	-2.82	-9.20	7.10**	3.03	65.35**	-0.95	65.34**
PUSA 6A X IR 72048-B-R-2-2-2-1-B	11.03**	-5.43	2020	-4.39	53.95**	-3.61	49.84**
PUSA 6A X IR 71829-3R-73-1-2-B	-10.51**	-1.36	-10.78**	-17.88**	46.89**	-42.48**	-14.58
PUSA 6A X NDRK 5094	-13.59**	-19.31**	5.88*	10.30**	52.72**	-17.71**	26.85*
PUSA 6A X 92-H 51-4	3.08	11.16*	5.92*	12.73**	78.07**	-0.31	79.17**
PUSA 6A X Narendra Usar 3	-1.54	1.81	4.82	-8.79**	75.35**	-25.42**	32.14**
PUSA 6A X Sarjoo 52	2.82	0.15	-6.94**	21.67**	170.18**	-0.01	172.71**
Significant +ve heterosis	13	8	18	28	59	-	36
Significant -ve heterosis	22	23	19	17	-	41	8
Mean heterosis (%)	-1.553	-6.083	29.473	2.690	80.884	-24.669	34.569
SE	0.857	12.218	2.122	0.489	4.640	2.446	3.537
Range	(-17.95)-20.26	(-43.89)-29.29	(-71.45)-8.63	(-32.42)-26.36	2.98-290.79	(-89.27)-9.87	(-67.08)-197.81

*, ** significant at 5% and 1% levels, respectively.

General Combining ability effects

The gca effects of parent have been presented in Table 4. It is noted that top two males, NDRK 5095 and NDRK 5013 proved the best general combiner for seedling height and number of leaves seedling^{-1}; Sarjoo 52 and NDRK 5056 for days to 50% flowering (earliness); 92-H 51-4 and IR 61920-3B-22-2-1 for flag leaf area; CST 7-1 and Sarjoo 52 for plant height (dwarf stature); Sarjoo 52 and IR 72048-B-R-2-2-2-1-B for panicle bearing tillers plant^{-1}; IR 72048-B-R-2-2-2-1-B and NDRK 5095 for panicle length; Narendra Usar 3 and NDR 9830119 for spikelets panicle^{-1}; NDR 9830119 and NDRK 5094 for spikelet fertility; NDRK 5013 and NDRK 5094 for test weight; Sarjoo 52 and NDR 9830119 for biological yield; Sarjoo 52 and Narendra Usar 3 for harvest index and grain yield plant^{-1}. Similar findings are also reported by Rosamma and Vijayakumar (2005) [12], Priyanka *et al* (2014) [11], and Dorosti and Monajjem (2014) [14].

Among the female parental lines, IR 58025 was observed as a good general combiner only for seedling height, panicle length, spikelets panicle^{-1}, test weight, biological yield palnt^{-1}. Whereas, IR 688897 A was good combiner for panicle bearing tillers plant-^{1} and harvest index. These findings are supported by Patial *et al.* (2016) [9] and Prasad *et al.* (2013) [10] also reported IR 58025 A as good general combiner for seedling vigour.

Table 4: Estimates of general combining ability effects (gca) of parent (males and females) for 13 characters in rice

Parental lines	Seedling height (cm)	Number of leaves per seedling	Days to 50% flowering	Flag leaf area (cm^2)	Plant height (cm)	Panicle bearing tillers per plant
Male						
IR 70023-4B-R-12-3-1-1-B	1.204**	-0.266*	1.189	1.811**	7.465**	-1.607**
IR 61920-3B-22-2-1	-2.885**	0.423**	-0.478	5.231**	5.088**	-1.118**
PNL 1-8-5-17-2	3.571**	0.090	3.522**	1.778**	-3.963**	0.326
NDRK 5095	8.604**	0.446**	-0.033	-0.044	3.465**	-0.363
NDRK 5056	-1.896**	-0.243	-4.256**	-1.233**	-2.624**	0.859**
NDRK 5086	2.004**	0.134	-1.033	-0.722	-1.079*	0.882**
NDR 9830119	-2.418**	-0.310*	-1.033	3.400**	2.099**	-0741*
NDRK 5013	5.648**	0.312*	-1.033	-1.122**	2.432**	-2.918**
CST 7-1	-1.374**	0.112	-0.033	2.311**	-11.190**	-0.629
21-2-5-B-1-1	-0.174	0.290*	-1.811	2.836**	5.965**	0.259
IR 64	-1.385**	0.001	0.744	-3.756**	-3.924**	-1.918**
NDR 9830148	2.671**	0.290*	-0.589	-2.867**	7.699**	-2.529**
CSRC(S) 14-1-4-0	-4.363**	-0.354**	-1.922	0.200	9.354**	-1.896**
PNL 5-8-1-7-21	-1.574**	-0.110	-1.478	-0.911*	-6.657**	0.548
IR 72048-B-R-2-2-2-1-B	0.204	-0.354**	2.078*	-1.328**	0.332	1.726**
IR 71829-3R-73-1-2-B	-4.485**	-0.332*	2.856**	-3.933**	-2.213**	1.348**
NDRK 5094	1.537**	0.134	3.967**	2.300**	-2.668**	-1.163**
92-H 51-4	-0.074	-0.177	1.300	6.789**	2.376**	-0.518
Narendra Usar 3	-0.152	-0.154	3.078**	0.360	-3.613**	1.171**
Sarjoo 52	-4.663	0.068	-5.033**	-6.478**	-8.346	8.282**
SE (gi)	0.3145	0.1290	1.0066	0.3923	0.4974	0.3202
SE (gi-gj)	0.4448	0.1825	1.4235	0.5548	0.7034	0.4528
CD (1%)	0.8234	0.3378	2.6354	1.0272	1.3022	0.8383
CD (5%)	0.6228	0.2555	1.9933	0.7769	0.9850	0.6341
Female						
IR 688897A	-2.379**	0.088	-2.239**	-1.449**	-4.410**	1.036**
IR 58025 A	4.174**	-0.156**	0.611	3.276**	10.444**	-0.646**
PUSA 6A	-1.794**	0.068	1.628**	-1.827**	-6.304**	-0.389**
SE (gj)	0.1218	0.0500	0.3899	0.1519	0.1926	0.1240
SE (gi-gj)	0.1723	0.0707	0.5513	0.2149	0.2724	0.1754
CD (1%)	0.3189	0.1308	1.0207	0.3978	0.7133	0.3247
CD (5%)	0.2412	0.0990	0.7720	0.3009	0.5395	0.2456

Parental lines	Panicle length (cm)	Spikelets per panicle	Spikelet fertility (%)	Test weight (g)	Biological yield per plant (g)	Harvest index (%)	Grain yield per plant (g)
Male							
IR 70023-4B-R-12-3-1-1-B	2.271**	-39.333**	2.212*	-3.181**	-35.216**	-7.287**	-18.016**
IR 61920-3B-22-2-1	-0.507	-13.667**	-1.922*	-3.081**	22.084**	-5.045**	-14.907**
PNL 1-8-5-17-2	-3.129**	-6.089	3.167**	0.053	-23.612**	5.736**	-0.601
NDRK 5095	3.226**	-22.889**	0.812	1.408**	-14.350**	0.049	-4.512**
NDRK 5056	-0.318	16.669**	7.189**	-2.003**	3.128	2.126*	5.401**
NDRK 5086	-2.085**	-0.889	-9.499**	-0.503*	4.306*	-6.025**	-7.232**
NDR 9830119	1.759**	28.111**	9.045**	-1.459**	38.306**	-5.230**	3.079*
NDRK 5013	-0.341	-18.311**	-17.788**	3.108**	-33.850**	-8.081**	-18.872**
CST 7-1	-1.318**	-5.356	3.734**	0.630**	4.750*	0.800	1.479
21-2-5-B-1-1	-0.141	22.111**	3.123**	1.408**	3.573	6.673**	14.093**
IR 64	-3.041**	-4.622	8.545**	-0.347	-23.794**	0.937	-5.503**
NDR 9830148	1.193**	-17.533**	-5.855**	0.130	-32.672**	-7.074**	-17.194**
CSRC(S) 14-1-4-0	-0.052	6.667	-3.799**	1.303**	2.850	-2.415*	--6.092**
PNL 5-8-1-7-21	-1.429**	2.667	6.223**	0.253	-2.627	5.296**	6.735**
IR 72048-B-R-2-2-2-1-B	3.782**	7.155	1.712	-0.322	9.517**	3.707**	7.975**
IR 71829-3R-73-1-2-B	-0.274	2.444	-5.944**	-1.807**	-9.261**	-1.682	-1.327
NDRK 5094	-0.496	-2.311	8.556**	2.453**	-13.841**	6.743**	4.673**
92-H 51-4	-0.274	10.044*	-14.688**	-0.081	38.028**	-6.353**	--4.079**
Narendra Usar 3	0.204	37.355**	7.656**	-0.403*	15.862**	6.999**	18.410**
Sarjoo 52	0.971**	-2.222	-2.477**	2.441**	46.817**	10.128**	36.490**
SE (gi)	0.3497	4.9879	0.8664	0.1996	1.8941	0.9988	
SE (gi-gj)	0.4945	7.0539	1.2253	0.2822	2.6786	1.4125	
CD (1%)	0.9155	13.0590	2.2685	0.5225	4.9589	2.6150	
CD (5%)	0.6925	9.8774	1.7158	0.3952	3.7508	1.9779	
Female							
IR 688897A	-0.839***	-12.472***	0.541	-0.340***	-17.209***	3.153***	-0.385
IR 58025 A	1.546***	8.161***	-2.189***	0.308***	27.975***	-4.738***	0.958
PUSA 6A	-0.706***	4.311*	1.649***	0.032	-10.765***	1.585***	-0.574
SE (gj)	0.1354	1.9318	0.3356	0.0773	0.7336	0.3868	05593
SE (gi-gj)	0.1915	2.7320	0.4746	0.1093	1.0374	0.5471	0.7909
CD (1%)	0.3546	5.0577	08786	0.2023	1.9206	1.0128	1.4642
CD (5%)	0.2682	3.8255	06645	0.1530	1.4527	07660	1.1075

Significant at 5% and 1% levels, respectively.

Specific combining ability effects

In the present investigation, none of the 40 hybrids manifested consistently high sca effects for all the characters. The sca effects of parent have been presented in Table 5. The present findings reveled that cross IR 58025 A X 21-2-5-B-1-1, IR 58025 A X IR 71829-3R-73-1-2-B, IR 58025 A X CST 7-1, IR 58025 A X Narendra Usar 3 and IR 688897A X Sarjoo52 exhibited high sca effects for grain yield plant^{-1}. The effect of IR 58025 A X CST 7-1 for grain yield was due to desirable sca effect of seedling height, plant height, spikelets panicle^{-1}, test weight and biological yield plant^{-1}. The common crosses based on *per se* performance and sca effects for all the characters (Table 4) were also in close correspondence. Similar pattern of association between sca effects for grain yield plant^{-1} with other yield attributing traits were reported by Hasan *et al* (2013) [6], Adilakshmi and Reddy (2012) [1] have suggested that about 20-30% standard heterosis may be considered sufficient to offset the extra cost of hybrid seeds. The favourable *per se* performances and higher significant positive sca effects in related to grain yield plant^{-1} were found in hybrid IR 688897A X Sarjoo52, IR 58025 A X 21-2-5-B-1-1, IR 58025 A X Narendra Usar 3 and IR 58025 A X IR 71829-3R-73-1-2-B. These combinations proved to be good hybrids based on CMS system in rice.

Table 5: Estimates of specific combining ability effects (sca) of hybrids for 13 characters in rice

Hybrids	Seedling height (cm)	Number of leaves seedling^{-1}	Days to 50% flowering	Flag leaf length (cm)	Plant height (cm)	Panicle bearing tillers plant^{-1}
IR 688897A X IR 70023-4B-R-12-3-1-1-B	-0.987	0.446*	-2.206	-1.151	-6.804**	-0.991
IR 688897A X IR 61920-3B-22-2-1	0.835	0.290	-5.872**	-4.011**	-6.693**	-1.213*
IR 688897A X PNL 1-8-5-17-2	-1.821**	0.223	-6.539**	1.016	0.273	-0.191
IR 688897A X NDRK 5095	-3.454**	-0.466*	-0.650	1.171	-0.804	0.031
IR 688897A X NDRK 5056	0.779	0.223	0.239	1.527*	3.151**	-0.924
IR 688897A X NDRK 5086	1.479**	0.046	0.017	0.649	-1.893*	-0347
IR 688897A X NDR 9830119	-0.698	0.223	1.017	-2.307**	-3.671**	0.742
IR 688897A X NDRK 5013	3.502**	-0.199	-3.983*	1.416*	-6.071**	-0.080
IR 688897A X CST 7-1	-6.809**	-0.332	1.017	0.871	7.551**	-0.302
IR 688897A X 21-2-5-B-1-1	-2.143**	0.157	1.461	-1.235	-1.938*	-1.458**
IR 688897A X IR 64	-6.798**	-0.488*	-1.428	-1.051	6.284**	1.587**
IR 688897A X NDR 9830148	0.146	-0.557*	4.906**	1.660*	-3.338**	1.631**
IR 688897A X CSRC(S) 14-1-4-0	5.179**	0.601**	-0.094	-1.840**	-1.027	1.431*
IR 688897A X PNL 5-8-1-7-21	-0.676	-0.310	-1.206	1.771*	5.018**	0.053
IR 688897A X IR 72048-B-R-2-2-2-1-B	7.546**	0.001	3.572*	3.271**	3.662**	0.209
IR 688897A X IR 71829-3R-73-1-2-B	0.235	-0.021	2.461	0.827	-2.093*	0.187
IR 688897A X NDRK 5094	-0.787	-0.021	4.683**	-2.540**	3.862**	-0.436
IR 688897A X 92-H 51-4	1.091*	-0.043	3.550	-2.362**	-4.016**	0.053
IR 688897A X Narendra Usar 3	-1.032	-0.399	-3.094	0.447	3.307**	0.631
IR 688897A X Sarjoo 52	4.413**	0.446*	2.350	1.871	5.240**	-0.613
IR 58025 A X IR 70023-4B-R-12-3-1-1-B	-2.141**	-0.178	-0.389	1.424*	7.678**	0.491
IR 58025 A X IR 61920-3B-22-2-1	-1.252*	-0.867**	6.278**	8.204**	10.256**	1.668**
IR 58025 A X PNL 1-8-5-17-2	3.159**	0.600**	7.611**	-3.476**	-5.828**	-0.909
IR 58025 A X NDRK 5095	0.859	0.578*	-3.500*	-1.921**	6.745**	-0.554
IR 58025 A X NDRK 5056	-0.907	-0.133	-1.944	-0.798	-7.300**	1.957**
IR 58025 A X NDRK 5086	0.326	-0.178	-5.833**	-0.976	7.289**	1.935**
IR 58025 A X NDR 9830119	-3.918**	-0.333	-2.833	5.902**	3.245**	-1.176*
IR 58025 A X NDRK 5013	4.948**	1.044**	4.500*	-3.576**	7.978**	-1.732**
IR 58025 A X CST 7-1	8.971**	-0.022	-3.500*	-2.987**	-10.266**	1.379*
IR 58025 A X 21-2-5-B-1-1	5.771**	0.200	-2.389	1.366*	4.378**	2.357**
IR 58025 A X IR 64	11.215**	0.889**	-0.278	1.124	-8.733**	-2.598**
IR 58025 A X NDR 9830148	2.326**	0.067	-1.278	-1.432*	5.511**	-2.521**
IR 58025 A X CSRC(S) 14-1-4-0	-10.707**	-1.156**	0.722	4.168**	2.456**	-1.554**
IR 58025 A X PNL 5-8-1-7-21	3.571**	0.467*	0.611	-3.721**	-11.200**	-1.265*
IR 58025 A X IR 72048-B-R-2-2-2-1-B	-8.541**	-0.422	4.389*	-2.437**	-5.855**	-0.509
IR 58025 A X IR 71829-3R-73-1-2-B	1.082*	-0.044	0.278	-2.565**	4.356**	2.068**
IR 58025 A X NDRK 5094	-1.874**	0.022	0.500	4.335**	-5055**	-0.421
IR 58025 A X 92-H 51-4	-1.329*	0.067	-3.167	4.446**	8.900**	0.268
IR 58025 A X Narendra Usar 3	-2.318**	-0.222	3.389	-4.125**	-6.444**	0.846
IR 58025 A X Sarjoo 52	-9.241**	-0.378	-5.167**	-2.954**	-8.111**	0.268
PUSA 6A X IR 70023-4B-R-12-3-1-1-B	3.128**	-0.268	2.594	-0.273	-0.874	0.501
PUSA 6A X IR 61920-3B-22-2-1	0.417	0.577*	-0.406	-4.193**	-3.563**	-0.455
PUSA 6A X PNL 1-8-5-17-2	-1.339**	-0.823**	-1.072	2.460**	5.554**	1.101*
PUSA 6A X NDRK 5095	2.594**	-0.112	4.150*	0.749	-5.940**	0.523
PUSA 6A X NDRK 5056	0.128	-0.290	1.706	-0.728	4.149**	-1.033
PUSA 6A X NDRK 5086	-1.806**	0.132	5.817**	0.327	-5.396**	-1.588**
PUSA 6A X NDR 9830119	4.617**	0.110	1.817	-3.595**	0.426	0.434**
PUSA 6A X NDRK 5013	-8.450**	-0.846**	0.517	2.160**	-1.907*	1.812**
PUSA 6A X CST 7-1	-2.161**	0.354	2.483	2.116**	2.715**	-1.077
PUSA 6A X 21-2-5-B-1-1	-3.628**	-0.357	0.978	-0.131	-2.440**	-0.899
PUSA 6A X IR 64	-4.417**	-0.401	1.706	-0.073	2.449**	1.012
PUSA 6A X NDR 9830148	-2.472**	0.510*	-3.628*	-0.228	-2.174*	0.889
PUSA 6A X CSRC(S) 14-1-4-0	5.528**	0.554*	-0.628	-2.328**	-1.429	0.123
PUSA 6A X PNL 5-8-1-7-21	-2.894**	-0.157	0.594	1.949**	6.182**	1.212*

PUSA 6A X IR 72048-B-R-2-2-2-1-B	0.994	0.421	-7.661**	-0.834	2.193*	0.301
PUSA 6A X IR 71829-3R-73-1-2-B	-1.317*	0.066	-2.739	1.738*	-2.263**	-2.255**
PUSA 6A X NDRK 5094	2.661**	-0.001	-7.183**	-1.795**	1.193	0.856
PUSA 6A X 92-H 51-4	0.239	-0.023	-0.183	-2.084**	-4.885**	-0.322
PUSA 6A X Narendra Usar 3	3.350**	0.621**	-0.294	3.678**	3.138**	-1.477**
PUSA 6A X Sarjoo 52	4.828**	-0.068	-2.817	1.083	2.871**	0.345
SE (Sij)	0.545	0.224	1.744	0.680	0.862	0.555
SE (Sij-Skl)	0.7704	0.3160	2.4656	0.9610	1.2183	0.7843
CD (1%)	2.0169	0.8274	6.4554	2.5161	3.1898	2.0534
CD (5%)	1.5255	0.6258	4.8827	1.9031	2.4126	1.5531

Hybrids	Panicle length (cm)	Spikelets per panicle	Spikelet fertility (%)	Test weight (g)	Biological yield per plant (g)	Harvest index (%)	Grain yield per plant (g)
IR 688897A X IR 70023-4B-R-12-3-1-1-B	-0.394	43.583**	7.248**	1.329**	18.254**	6.545**	10.283**
IR 688897A X IR 61920-3B-22-2-1	1.151	32.583**	4.515**	1.962**	-46.713**	7.803**	8.167**
IR 688897A X PNL 1-8-5-17-2	1.206*	22.339*	4.259**	-1.471**	27.263**	-2.098	5.874*
IR 688897A X NDRK 5095	0.384	10.139	4.048**	-1.026**	5.087	1.952	2.732
IR 688897A X NDRK 5056	0.695	-31.752**	1.471	-1.582**	0.743	-8.821**	-12.995**
IR 688897A X NDRK 5086	-1.072	6.139	2.559	-2.115**	-15.535**	4.140*	0.305
IR 688897A X NDR 9830119	-0.449	-19.528*	-1.318	-0.726*	-26.502**	2.628	-2.760
IR 688897A X NDRK 5013	-1.616**	15.561	0.782	-0.360	9.587**	2.129	3.605
IR 688897A X CST 7-1	-1.772**	-28.728**	-8.341**	-1.882**	-46.746**	-0.795	-17.553**
IR 688897A X 21-2-5-B-1-1	-1.583*	-20.194*	-4.129**	-1.626**	-10.635**	-9.539**	-20.446**
IR 688897A X IR 64	0.251	-14.128	1.782	3.596**	27.865**	4.665**	13.363**
IR 688897A X NDR 9830148	-0.616	27.450**	-1.418	0.318	21.776**	6.462**	11.927**
IR 688897A X CSRC(S) 14-1-4-0	0.295	-8.417	2.826	-0.554	-11.746**	5.800**	5.992*
IR 688897A X PNL 5-8-1-7-21	-0.294	-11.417	6.863**	0.496	0.698	-3.364	-5.575*
IR 688897A X IR 72048-B-R-2-2-2-1-B	1.462*	-16.239	-12.385**	0.070	-18.346**	-3.699*	-11.802**
IR 688897A X IR 71829-3R-73-1-2-B	0.751	1.806	-15.729**	-3.644**	-7.668*	-10.803**	-18.400**
IR 688897A X NDRK 5094	-0.627	-0.772	-1.563	1.096**	12.645***	-1.442	0.614
IR 688897A X 92-H 51-4	3.351**	-9.128	18.715**	3.829**	1.876	2.141	11.438**
IR 688897A X Narendra Usar 3	-0427	-8.439	-2.596	-0.815*	11.543**	-3.671	-3.637
IR 688897A X Sarjoo 52	-0.694	9.139	6.137**	3.107**	46.554**	-0.033	18.869**
IR 58025 A X IR 70023-4B-R-12-3-1-1-B	1.054	-52.384**	-8.622**	-2.919**	-32.563**	-8.138**	-15.014**
IR 58025 A X IR 61920-3B-22-2-1	0.199	-30.717**	-5.355**	-4.952**	109.470**	-17.616**	-12.730**
IR 58025 A X PNL 1-8-5-17-2	-2.479**	-19.228*	7.823**	1.114**	-42.168**	8.547**	-2.483
IR 58025 A X NDRK 5095	0.899	-22.161*	-9.155**	1.025**	-14.763**	-7.207**	-12.038**
IR 58025 A X NDRK 5056	-0.157	-0.046	3.801*	2.170**	-21.508**	13.643**	14.108**
IR 58025 A X NDRK 5086	1.270*	-24.161**	-18.044**	3.817**	-26.419**	-0.002	-6.285*
IR 58025 A X NDR 9830119	0.699	13.505	2.678	1.359**	16.848**	-0.978	0.950
IR 58025 A X NDRK 5013	1.932**	-21.006*	3.512*	0.659	-40.597**	1.297	-7.212**
IR 58025 A X CST 7-1	1.843**	33.905**	7.256**	3.270**	76.737**	0.452	26.717**
IR 58025 A X 21-2-5-B-1-1	3.532**	35.172**	8.401**	2.625**	26.314**	13.512**	35.624**
IR 58025 A X IR 64	-2.434**	29.372**	2.712	-7.152**	-33.052**	-9.604**	-18.747**
IR 58025 A X NDR 9830148	1.266*	-24.117**	18.378**	-1.164**	-27.908**	-2.250	-8.503**
IR 58025 A X CSRC(S) 14-1-4-0	-1.823**	6.616	-8.544**	0.998**	29.777**	-11.699**	-10.665**
IR 58025 A X PNL 5-8-1-7-21	-1.552*	25.283**	5.167**	-0.286	-2.286	-0.363	1.375
IR 58025 A X IR 72048-B-R-2-2-2-1-B	-1.657**	26.261**	10.345**	1.199**	37.570**	-0.428	14.062**
IR 58025 A X IR 71829-3R-73-1-2-B	0.599	-5.495	17.067**	6.394**	13.481**	18.674**	33.050**
IR 58025 A X NDRK 5094	2.554**	31.994**	3.234*	-0.286	-15.846**	6.656**	6.084*
IR 58025 A X 92-H 51-4	-5.534**	-14.628	-40.322**	-6.086**	27.525**	-17.804**	-31.112**
IR 58025 A X Narendra Usar 3	-0.079	32.661**	4.267**	2.970**	-2.241	12.590**	22.293**
IR 58025 A X Sarjoo 52	-0.179	-20.828*	-4.599**	-4.808**	-78.363**	0.718	-29.474**
PUSA 6A X IR 70023-4B-R-12-3-1-1-B	-0.661	8.800	1.373	1.590**	14.310**	1.593	4.731
PUSA 6A X IR 61920-3B-22-2-1	-1.349*	-1.867	0.840	2.990**	-62.757**	9.812**	4.562
PUSA 6A X PNL 1-8-5-17-2	1.273*	-3.111	-12.082**	0.357	14.905**	-6.449**	-3.391
PUSA 6A X NDRK 5095	-1.283*	12.022	5.107**	0.001	9.676**	5.254**	9.307**
PUSA 6A X NDRK 5056	-0.538	31.798**	-5.271**	-0.588	20.765**	-4.822**	-1.113
PUSA 6A X NDRK 5086	-0.205	18.022*	15.484**	-1.755**	41.954**	-4.138*	5.980*
PUSA 6A X NDR 9830119	-0.249	6.022	-1.360	-0.632	9.654**	-1.650	1.809
PUSA 6A X NDRK 5013	-0.316	5.445	-4.293**	-0.299	31.010**	-3.426	3.607
PUSA 6A X CST 7-1	-0.072	-5.178	1.084	-1.388**	-29.990**	-0.343	-9.164**
PUSA 6A X 21-2-5-B-1-1	-1.949**	-14.978	-4.271**	-0.999**	-15.679**	-3.973*	-15.178**
PUSA 6A X IR 64	2.184**	-15.244	-4.493**	3.557**	5.187	4.940**	5.385*
PUSA 6A X NDR 9830148	-0.649	-3.333	-16.960**	0.846*	6.132	-4.212*	-3.424
PUSA 6A X CSRC(S) 14-1-4-0	1.528*	1.800	5.718**	-0443	-18.024**	5.899**	4.674
PUSA 6A X PNL 5-8-1-7-21	1.806**	-13.867	1.696	-0.210	1.587	3.728*	4.200
PUSA 6A X IR 72048-B-R-2-2-2-1-B	0.195	-10.022	2.040	-1.269**	-19.224**	4.127*	-2.260
PUSA 6A X IR 71829-3R-73-1-2-B	-1.349*	3.689	-1.338	-2.750**	-5.813	-7.871**	-14.651**
PUSA 6A X NDRK 5094	-1.927**	-31.222**	-1.671	-0.810*	3.201	-5.213**	-6.698**
PUSA 6A X 92-H 51-4	2.184**	23.756**	21.607**	2.257**	-29.402**	15.663**	19.674**
PUSA 6A X Narendra Usar 3	0.506	-24.222	-1.671	-2.155**	-9.302**	-8.919**	-18.665**
PUSA 6A X Sarjoo 52	0.873	11.689	-1.538	1.701**	31.810**	-0.685	10.605**

SE (Sij)	0.606	8.639	1.500	0.346	3.281	1.730	2.501
SE (Sij-Skl)	0.8566	12.2177	2.1223	0.4888	4.6395	2.4465	3.5371
CD (1%)	2.2426	31.9878	5.5566	1.2798	12.1468	6.4053	9.2605
CD (5%)	1.6962	24.1945	4.2028	0.9680	9.1874	4.8448	7.0044

*, ** significant at 5% and 1% levels, respectively.

References

1. Adilakshmi D, Reddy PR. Combining ability analysis for yield components and physiological traits in rice. International J Plant Sci. 2012; **7**:295-300.
2. Ahmed EA, Ibn Oaf HS, El Jack AE. Combining ability and heterosis in Line x tester crosses of summer squash (*Cucurbita pepo* L.). Cucurbit Genetics Cooperative Report. 2003; 26:54-56.
3. Arunachalam V. The fallacy behind the use of modified line x tester design. Indian J Genet. 1974; 34(2):200-207.
4. Dorosti H, Monajjem S. Gene action and combining ability for grain yield and yield related traits in rice (*Oryza sativa* L.). The Journal of Agricultural Sciences, 2014; 9:100-108.
5. Ghara AG, Nematzadeh G, Bagheri N, Oladi M, Bagheri A. Heritability and heterosis of Agronomic traits in rice lines. Intl. J Farm & Alli. Sci. 2014; 3(1):66-70.
6. Hasan MJ, Kulsum UK, Lipi LF, Shamsuddin AKM. Combining ability studies for developing new rice hybrids in Bangladesh. Bangladesh J Bot. 2013; 42(2):215-222.
7. Kempthorne O. An Introduction to Genetical Statistics (Ed.) John Wiley and Sons, Inc. New York, USA, 1957.
8. Manivannan N, Ganesan J. Line x tester analysis in sesame (*Sesamum indicum* L). Ind. J Agric. Res. 2001; 35(2): 90-94.
9. Patial M, Pal D, Kumar J. Combining ability and gene action studies for grain yield and its component traits in barley (*Hordeum vulgare* L.) Sabrao J Breed. Genet. 2016; 48(1):90-96.
10. Prasad S, Verma OP, Treepathi N, Ashish, Yadav PK. Combining Ability for Yield and its Contributing Traits in Rice (*Oryza sativa* L.) under Salt Affected Soil. International Journal of Science and Research. 2013; 6:1050-1054.
11. Priyanka K, Jaiswal HK, Waza SA. Combining ability and heterosis for yield, its component traits and some grain quality parameters in rice (*Oryza sativa* L.). Journal of Applied and Natural Science. 2014; 6(2):495-506.
12. Rosamma CA, Vijayakumar NK. Heterosis and combining ability in rice (*Oryza sativa* L.). Indian J Genet. 2005; 65(2):119-120.
13. Roy B, Mandal AB. Combining ability of some quantitative traits in rice. Ind. J Genet. 2001; 61(2):162-164.
14. Sarker U, Biswas PS, Prasad B, Khaleque Mian MA. Heterosis and genetic analysis in rice hybrids. Pak. J Biol. Sci. 2002; 5(1):1-5.
15. Singh NK, Kumar A. Combining ability analysis to identify suitable parents for heterotic rice hybrid breeding. IRRN, 2004; 29(1):21-22.
16. Zhang R, Ming JS, Xu CW, Yang LS, Bai YS, CQ Sun, Wanc XK. Heterosis and combining ability of hybrid rice and its relation to Japonica-index of parents, 2002. http://143.48.220.116/newsletter/rice genetics/rgn 14/V14p34.html.