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Combining ability studies using different CMS sources in rice

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ABSTRACT

Combining ability analysis was carried out involving 125 crosses for grain yield, its components and some of the quality characters in Line x Tester crosses. The magnitudes of specific combining ability (SCA) variances were higher than the general combining ability (GCA) variances for all the characters except productive tillers plant^{-1} which indicated preponderance of non-additive gene action in the inheritance of these traits. The SCA variances were significant for all the characters except days to 50 % flowering, head rice recovery, 1000-grain weight, kernel length, kernel L : B ratio, protein content (%) and amylose content (%). Among females, RTN-3B and RTN-2B and among males IR-63879-195-195-2-2-3-2, NVSR-20, BL-184AR, GR-7 and IR-8866 were observed to be good general combiner for yield and most of the yield contributing characters. The cross combinations, RTN-3A X BL-184AR, RTN-13A X GR-7 and RTN-2A X NVSR-20 crosses exhibited positive significance SCA effects for grain yield plant^{-1} and some associated characters. Among these, RTN-3A X BL-184AR was found to be the best combination involving good x good general combiner parents and also exhibited significant highest SCA effects, significant heterobeltiosis and standard heterosis for grain yield plant^{-1}.

Key words : *rice, combining ability, GCA, SCA effects, heterotic combinations*

Selection of parents for hybridization assumes greater importance in heterosis breeding programme. Combining ability analysis is a powerful tool to choose appropriate parental material to produce specific combining hybrids. It also gives the information about the nature of gene effects involved in the inheritance of various traits. Additive and non-additive gene action in the parent, estimated through combining ability analysis, is useful in determining the possibility for commercial exploitation of heterosis. Hence the present study was undertaken to study combining ability effects and type of gene action governing for grain yield and its contributing traits of diverse five CMS lines of five different sources, twenty five restorers and their combinations.

MATERIALS AND METHODS

One hundred twenty five crosses were made in line x tester mating design by using five CMS lines from different CMS sources (KJTCMS-6A - WA sources, RTN 2A -ARC source, RTN 3A - Mutant of IR 62829B source, RTN 13A -Gambiaca source and RTN 17A - Dissi source) and twenty five males by hand pollination at National Agricultural Research Project Farm, Navsari during dry season 2007-2008. Before pollination, sterility of female plants was checked and insured to have 100 per cent pollen sterility. The 125 F_1s, were evaluated in Randomized Block Design (RBD), replicated thrice in the three different locations *viz.,* Navsari (Loc-I), Bardoli (Loc-II) and Vyara (loc-III) by planting a single row plot of 30 plants, placed at 20 x 15 cm during wet season 2008. All the agronomical practices and plant protection measures were followed as per recommendations. The observations were recorded on five randomly selected plants in each replication for 125 hybrids, their respective parents and three checks viz., Jaya (coarse variety check, SC-I), Sahyadri (hybrid check, SC-II) and GR-11 (fine variety check, SC-III) on seventeen characters viz., days to 50 % flowering, productive tillers plant^{-1}, plant height, panicle length, number of filled spikelets panicle^{-1}, grain yield plant^{-1}, straw yield plant^{-1}, harvest index, pollen fertility, spikelet fertility, milling, head rice recovery,

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1000-grain weight, kernel length, L:B ratio, protein content and amylose content. For the estimation of general and specific combining ability variances, the line x tester analysis as outlined by Kempthorne (1957) was followed.

RESULTS AND DISCUSSION

The analysis of variance for combining ability analysis over environments revealed that mean squares due to females x males interaction were significant for all the characters (Table 1). The combining ability variance over pooled environments were found significant for the traits viz., productive tillers plant^{-1}, plant height (cm), number of filled spikelets panicle^{-1}, grain yield plant^{-1} (g), straw yield plant^{-1} (g), 1000-grain weight (g), kernel length (mm), kernel L : B ratio, protein content (%) for female and plant height (cm), panicle length (cm), number of filled spikelets panicle^{-1}, grain yield plant^{-1} (g) and 1000-grain weight (g) for males. The magnitude of SCA variances were higher than the GCA variances for all the characters except productive tillers plant^{-1} which indicated preponderance of non-additive gene action in the inheritance of these traits, while preponderance of additive type of gene action in productive tillers plant^{-1}. This was further supported by low magnitude of σ^2GCA : σ^2SCA ratios. Preponderance of non-additive variance in the expression of different traits in rice have also been reported by Ram *et al*. (1991), Banumathy and Prasad (1991), Ramalingam *et al*. (1993), Singh *et al*. (1996), Shunmagavalli *et al*. (1999), Annadurai and Nadarajan (2001) and Khirsagar (2002). Preponderance of additive gene action for productive tillers plant^{-1} was also reported by Rao *et al*. (1980), Manuel and Palanisamy (1989), Ghosh (1993), Chakraborty *et al*. (1994), Singh *et al*. (1996) and Lavanya (2000). The SCA variances were more sensitive to environmental fluctuations as evident by the significance of mean squares due to females x males x locations interaction for all the characters except days to 50 % flowering, head rice recovery (%), 1000-grain weight (g), kernel length (mm), kernel L : B ratio, protein content (%) and amylose content (%).

The parents were characterized for their ability to transmit desirable genes to their progenies (Table 2). Female RTN-3B was found to be good general combiner for all the traits except days to 50 % flowering and among males, IR-63879-195-195-2-2-3-2 was found to be good general combiner for most of the characters except 50 % flowering whereas average performance in plant height (cm), panicle length (cm) and head rice recovery (%). The male parent, NVSR-20, which was found good combiner for most of the traits except plant height (cm) and protein content (%) while it was average combiner for productive tillers plant^{-1} and pollen fertility (%). Male parent, BL-184AR was found good general combiner for days to 50 % flowering, productive tillers hill^{-1}, panicle length (cm), number of filled spikelets panicle^{-1}, grain yield plant^{-1} (g), straw yield plant^{-1} (g), harvest index (%), milling (%), kernel L : B ratio, amylose content (%) and average combiner for pollen and spikelet fertility (%) and head rice recovery (%). Among females, RTN-3B and RTN-2B and among males IR-63879-195-195-2-2-3-2, NVSR-20, BL-184AR, GR-7 and IR-8866 were observed good general combiner for yield and most of the yield contributing characters.

The crosses exhibiting higher *per se* performance, high heterosis and significant desirable SCA effects for various traits involved in all possible combinations viz., good x good, good x average, good x poor, average x good, average x average, average x poor, poor x good, poor x average and poor x poor combining parents. Thus, crosses exhibiting high SCA effects did not always involve parents with high GCA effects. It may be suggested that interallelic interactions were also important for these characters. Similar results have been reported by Chakraborty *et al*. (1994), Mohan Rao *et al*. (1996), Annadurai and Nadarajan (2001), Khirsagar (2002) Narasimman *et al.* (2007) and Sharma and Mani (2008).

The performance of some selected crosses (best three crosses for each characters) in related parameters are presented in Table 4. The cross, RTN-3A X BL-184AR exhibited highest positive significance SCA effects for grain yield plant^{-1} followed by RTN-13A X GR-7 and RTN-2A X NVSR-20 crosses. These three crosses were found to be the best combinations involving good x good general combiner parents and also exhibited high mean performance and high heterotic potential for grain yield plant^{-1}. The cross, RTN-3A X BL-184AR was observed to be the best combination for straw yield plant^{-1} followed by the cross combinations, RTN-13A X GR-7 and RTN-2A X

Table 1. Analysis of variance for combining ability pooled over three environments

Source	df	Days to 50 % flowering	Productive tillers $plant^{-1}$	Plant height (cm)	Panicle length (cm)	No. of filled spikelets $panicle^{-1}$	Grain yield $plant^{-1}$ (g)	Straw yield $plant^{-1}$ (g)	Harvest index (%)	Pollen fertility (%)	Spikelet fertility (%)
Replications	6	18.98	0.86	44.83	1.15	94.42	18.35	16.48	3.21	2.87	23.45
Locations (l)	2	1109.31**	145.77**	8340.81**	43.34**	19580.57**	7311.06**	23765.41**	322.41**	0.28	265.28**
Females (f)	4	732.59	140.64**	2516.02**	7.33	22630.39**	984.97*	710.50**	46.97	226.00	155.99
Males (m)	24	355.20	25.95	792.06**	19.16**	8767.67*	505.97*	255.70	68.52	188.62	204.71
Females x Males (fxm)	96	302.42**	22.68**	339.70**	7.48**	4806.95**	296.81**	174.63**	50.71**	152.78**	146.49**
Females x Locations (fxl)	8	461.72**	34.14	715.69**	25.71*	2705.37	105.34	132.01	59.96*	165.03	163.06
Males x Locations (mxl)	48	223.41*	10.26	279.49	8.20	2334.19	61.23	114.14	21.44	75.29	63.72
Females x Males x Locations (fxmxl)	192	144.69	21.80**	220.49**	7.47**	1962.59**	68.44**	120.21**	29.54**	111.22**	102.59**
Pooled error	744	11.73	0.51	22.19	0.97	56.67	10.56	22.15	7.91	9.71	11.97
Estimates											
σ^2l		1.22	0.26*	16.27**	0.04	35.49*	15.51**	50.83**	0.58*	-0.28	0.30
σ^2f		0.50	0.47*	7.47	-0.08	75.91*	2.89*	2.33*	-0.15	0.09	-0.23
σ^2m		-0.58	0.33*	8.74*	0.24*	79.76*	4.80*	1.94	0.58	1.59	2.16*
σ^2gca		0.323	0.446	7.68**	0.276	76.555*	3.214*	2.264*	-0.031	0.338	0.171
σ^2sca		17.525**	0.098	13.246**	1.2**	316.040**	25.374**	6.046**	2.352**	4.618*	4.877*
σ^2gca / σ^2sca		0.018	4.530	0.580	0.23	0.242	0.127	0.374	0.013	0.073	0.035
σ^2fxl		4.23**	0.16	6.60**	0.24**	9.90	0.49	0.16	0.41*	0.72	0.80
σ^2mxl		5.25*	-0.77	3.93	0.05	24.77	-0.48	-0.41	-0.54	-2.40	-2.59
σ^2gcaxl		4.40*	0.009	6.16*	0.21*	12.38	0.33	0.06	0.25	0.20	0.24
σ^2scaxl		44.32**	7.10**	66.10**	2.17**	635.31**	19.29**	32.70**	7.21**	33.84**	30.21**
σ^2gcaxl/σ^2scaxl		0.099	0.001	0.093	0.097	0.019	0.017	0.002	0.035	0.006	0.008

*, ** Significant at 5 and 1 per cent probability levels, respectively

Table 1 contd…

Source	df	Milling (%)	Head rice recovery (%)	1000-grain weight (g)	Kernel length (mm)	L:B ratio	Protein content (%)	Amylose content (%)
Replications	6	6.39	4.36	0.26	0.017	0.001	0.155	0.736
Locations (l)	2	210.85**	19.65**	5.56**	0.357**	0.067*	4.063**	74.372**
Females (f)	4	367.04	145.92	285.80**	9.811*	5.75**	147.627**	53.530
Males (m)	24	497.54	561.61	118.62*	4.342	1.485	31.652	29.002
Females x Males (fxm)	96	314.55**	466.77**	61.44**	3.269**	1.55**	30.779**	54.472**
Females x Locations (fxl)	8	13.45	2.67	0.09	0.022	0.00004*	0.039	1.727**
Males x Locations (mxl)	48	9.50	1.88	0.21**	0.026	0.00001	0.048	0.281
Females x Males x								
Locations (fxmxl)	192	11.01**	1.96	0.10	0.024	0.00001	0.041	0.403
Pooled error	744	5.49	2.32	0.59	0.023	0.015	0.070	0.406
Estimates								
σ^2l		0.43**	0.04*	0.01**	0.001*	0.0001*	0.009**	0.16**
σ^2f		0.22	-1.43	0.99**	0.03*	0.02**	0.52**	-0.01
σ^2m		4.10	2.11	1.26*	0.02	-0.002	0.02	-0.56
σ^2gca		0.869	-0.839	1.042*	0.0282*	0.0153*	0.4360*	-0.1023
σ^2sca		33.726**	51.645**	6.81**	0.3605**	0.1726**	3.4154**	6.007**
σ^2gca / σ^2sca		0.026	-0.016	0.153	0.0782	0.089	0.128	-0.017
σ^2fxl		0.03	0.01	0.00	0.00	0.0001*	0.00	0.0017
σ^2mxl		-1.10	-0.006	0.007**	0.0001	0.00	0.001	-0.008
σ^2gcaxl		0.01	0.007	0.001	0.00	0.00	0.0001	0.0001
σ^2scaxl		1.84	-0.12	-0.16	0.0001	-0.005	-0.01	-0.001
σ^2gcaxl/σ^2scaxl		0.005	-0.058	-0.006	0.000	0.000	-0.010	-0.100

*, ** Significant at 5 and 1 percent probability levels, respectively

NVSR-20. All these three crosses were found to be the best combinations involving good x good general combiner parents and also exhibited high mean performance and high heterotic potential for straw yield plant^{-1}. The cross, RTN-2A X KJT-3-2-861-25-15-5 exhibited highest positive significance SCA effects for harvest index followed by the cross combinations, RTN-3A X BL-184AR. The cross, RTN-2A X IR-54742-22-19-3 exhibited significant and highest SCA effects for days to 50 % flowering, RTN-2A X IR-63879-195-195-2-2-3-2 for productive tillers plant^{-1}, RTN-3A X GR-3 for plant height, RTN-3A X IR-8866 for panicle length, RTN-3A X BL-184AR for number of filled spikelets panicle^{-1}, RTN-13A X Phule Radha for pollen fertility and RTN-3A X GR-3 for spikelet fertility. The cross, RTN-17A X RDN-97-3-2-37-14 exhibited highest SCA effects for milling, RTN-2A X PKV-Makarand for head rice recovery, RTN-17A X GR-11 for 1000-grain weight, RTN-3A X GR-11 for kernel length, KJTCMS-6A X PR-116 for L:B ratio, RTN-2A X PR-115 for protein content and cross, RTN-3A X IR-22273 was observed to be the best for amylose content. Similar results have been reported by Chakraborty *et al*. (1994), Mohan Rao *et al*. (1996), Annadurai and Nadarajan (2001), Khirsagar (2002) Narasimman *et al.* (2007) and Sharma and Mani (2008).

The crosses with high sca effects were in general combinations of parents with good x good and good x poor or good x average gca effects. This was represented in best three hybrids for grain yield plant^{-1} viz., RTN-3A X BL-184AR (good x good), RTN-2A X

Table 2. General combining ability (GCA) effects of parents for different characters

Parent	Grain yield plant^{-1} (g)	Straw yield plant^{-1} (g)	Harvest index (%)	Milling (%)	Head rice recovery (%)	1000-grain weight (g)	Kernel length (mm)	L:B ratio	Protein content (%)	Amylose content (%)
Females										
KJTCMS- 6B	-2.22**	-2.41**	-0.21	-0.87**	-0.03	-1.34**	-0.24**	-0.05**	-0.32**	-0.47**
RTN-2B	1.43**	1.08**	0.35	2.12**	0.74**	-0.42**	-0.17**	-0.21**	0.02	0.54**
RTN-3B	2.89**	2.25**	0.59**	0.26	0.71**	0.55**	0.26**	0.22**	0.61**	0.45**
RTN-13B	-1.12**	-0.19	-0.52**	-0.96**	-1.22**	1.62**	0.14**	-0.04**	0.67**	-0.48**
RTN-17B	-0.98**	-0.74*	-0.21	-0.56**	-0.20*	-0.41**	0.02	0.09**	-1.18**	-0.04
S.E. (gi) ±	0.22	0.31	0.19	0.16	0.10	0.05	0.01	0.01	0.02	0.04
Males										
IR-8866	2.08**	0.51	1.06*	-0.92**	-0.20	-0.09	-0.28**	-0.26**	0.81**	-0.52**
IR-22273	-1.96**	-4.39**	1.00*	0.52	0.09	1.56**	0.27**	-0.09**	-0.27**	0.55**
BL-184AR	7.06**	6.07**	1.19**	1.18**	-0.13	-3.55**	-0.38**	0.05**	-1.67**	1.22**
IET-13840-RP-66-67	-2.00**	1.45*	-1.76**	0.17	-1.42**	-1.76**	-0.05*	0.04*	0.18**	0.11
KJT-11-1-26-5-11	-2.94**	1.26	-2.10**	-4.59**	-3.07**	-0.04	0.09**	-0.08**	-0.03	-0.59**
KJT-3-2-861-25-15-5	-0.89	-0.50	-0.51	-1.81**	2.95**	-2.17**	-0.39**	-0.12**	1.08**	-0.23*
RDN-97-3-2-37-14	4.12**	1.86**	1.48**	0.14	-2.02**	-0.16	0.18**	0.03	0.14**	0.37**
GR-3	-4.78**	-1.07	-2.43**	2.68**	1.73**	0.66**	0.14**	0.15**	-0.50**	-1.04**
PR-115	-2.33**	-1.72*	-0.50	3.42**	1.95**	-1.96**	-0.48**	-0.33**	0.07	-1.07**
PKV-Makarand	0.38	0.16	0.18	1.37**	3.71**	-3.95**	-0.78**	-0.22**	0.08*	0.96**
GR-7	0.98*	1.67*	-0.51	1.48**	1.02**	0.97**	-0.10**	0.14**	1.68**	1.24**
IR-54742-22-19-3	2.04**	0.52	1.15**	5.31**	6.86**	0.59**	0.09*	-0.05**	0.08*	-0.64**
Pusa Sugandh-5	-1.90**	-1.19	-0.73	0.98**	1.18**	1.39**	0.14**	0.04	-1.14**	-0.85**
Super Basmati	0.56	-1.02	0.79	-3.14**	-2.89**	-1.54**	-0.27**	-0.02	-0.81**	-0.19*
PR-114	-1.56**	-0.63	-0.76	1.24**	3.29**	1.43**	0.52**	0.53**	0.37**	-0.61**
PR-116	-2.75**	-3.27**	0.11	-8.45**	-10.19**	1.25**	0.15**	0.14**	0.78**	0.88**
NVSR-20	8.83**	3.68**	3.05**	8.68**	5.49**	1.32**	0.36**	0.09**	-0.34**	0.56**
CR-57-MR-1523	-3.94**	-3.66**	-0.60	-3.91**	-4.24**	2.21**	0.16**	-0.03	2.09**	-1.05**
IR-63879-195-195-2-2-3-2	4.59**	3.25**	1.06*	0.98**	-0.02	0.68**	0.37**	0.24**	0.08*	0.27**
Dandi	2.10**	0.99	0.91*	-1.38**	0.43	-0.10	-0.36**	-0.28**	-0.58**	-0.17
RP-BIO-226	-0.70	1.45*	-0.73	-1.48**	3.75**	-0.23*	0.13**	-0.07**	-0.78**	1.33**
INP-19	-2.27**	-0.54	-0.97*	1.25**	-1.78**	0.67**	0.25**	0.045*	-0.01	-1.42**
GR-11	-1.58**	-2.87**	0.34	-0.56	-3.30**	0.64**	0.8**	-0.08**	-0.36**	0.61**
Phule Radha	2.47**	-1.55*	-0.51	-1.02**	-1.15**	1.72**	0.22**	0.15**	-0.11**	0.39**
PKV-Ganesh	-0.66	-0.48	-0.21	-2.17**	-2.06**	0.46**	-0.06*	-0.02	-0.89**	-0.09
S.E. (g_j) ±	0.48	0.70	0.42	0.35	0.23	0.11	0.02	0.02	0.04	0.09

*, ** Significant at 5 and 1 per cent probability levels, respectively

Table 2 contd..

Parent	Milling (%)	Head rice recovery (%)	1000-grain weight (g)	Kernel length (mm)	L:B ratio	Protein content (%)	Amylose content (%)
Females							
KJTCMS- 6B	-0.87**	-0.03	-1.34**	-0.24**	-0.05**	-0.32**	-0.47**
RTN-2B	2.12**	0.74**	-0.42**	-0.17**	-0.21**	0.02	0.54**
RTN-3B	0.26	0.71**	0.55**	0.26**	0.22**	0.61**	0.45**
RTN-13B	-0.96**	-1.22**	1.62**	0.14**	-0.04**	0.67**	-0.48**
RTN-17B	-0.56**	-0.20*	-0.41**	0.02	0.09**	-1.18**	-0.04
S.E. (gi) ±	0.16	0.10	0.05	0.01	0.01	0.02	0.04
Males							
IR-8866	-0.92**	-0.20	-0.09	-0.28**	-0.26**	0.81**	-0.52**
IR-22273	0.52	0.09	1.56**	0.27**	-0.09**	-0.27**	0.55**
BL-184AR	1.18**	-0.13	-3.55**	-0.38**	0.05**	-1.67**	1.22**
IET-13840-RP-66-67	0.17	-1.42**	-1.76**	-0.05*	0.04*	0.18**	0.11
KJT-11-1-26-5-11	-4.59**	-3.07**	-0.04	0.09**	-0.08**	-0.03	-0.59**
KJT-3-2-861-25-15-5	-1.81**	2.95**	-2.17**	-0.39**	-0.12**	1.08**	-0.23*
RDN-97-3-2-37-14	0.14	-2.02**	-0.16	0.18**	0.03	0.14**	0.37**
GR-3	2.68**	1.73**	0.66**	0.14**	0.15**	-0.50**	-1.04**
PR-115	3.42**	1.95**	-1.96**	-0.48**	-0.33**	0.07	-1.07**
PKV-Makarand	1.37**	3.71**	-3.95**	-0.78**	-0.22**	0.08*	0.96**
GR-7	1.48**	1.02**	0.97**	-0.10**	0.14**	1.68**	1.24**
IR-54742-22-19-3	5.31**	6.86**	0.59**	0.09*	-0.05**	0.08*	-0.64**
Pusa Sugandh-5	0.98**	1.18**	1.39**	0.14**	0.04	-1.14**	-0.85**
Super Basmati	-3.14**	-2.89**	-1.54**	-0.27**	-0.02	-0.81**	-0.19*
PR-114	1.24**	3.29**	1.43**	0.52**	0.53**	0.37**	-0.61**
PR-116	-8.45**	-10.19**	1.25**	0.15**	0.14**	0.78**	0.88**
NVSR-20	8.68**	5.49**	1.32**	0.36**	0.09**	-0.34**	0.56**
CR-57-MR-1523	-3.91**	-4.24**	2.21**	0.16**	-0.03	2.09**	-1.05**
IR-63879-195-195-2-2-3-2	0.98**	-0.02	0.68**	0.37**	0.24**	0.08*	0.27**
Dandi	-1.38**	0.43	-0.10	-0.36**	-0.28**	-0.58**	-0.17
RP-BIO-226	-1.48**	3.75**	-0.23*	0.13**	-0.07**	-0.78**	1.33**
INP-19	1.25**	-1.78**	0.67**	0.25**	0.045*	-0.01	-1.42**
GR-11	-0.56	-3.30**	0.64**	0.8**	-0.08**	-0.36**	0.61**
Phule Radha	-1.02**	-1.15**	1.72**	0.22**	0.15**	-0.11**	0.39**
PKV-Ganesh	-2.17**	-2.06**	0.46**	-0.06*	-0.02	-0.89**	-0.09
S.E. (g_j) ±	0.35	0.23	0.11	0.02	0.02	0.04	0.09

*, ** Significant at 5 and 1 per cent probability levels, respectively

Table 3. Correlation between the parental mean and GCA effects and hybrid mean performance with SCA effects in rice

Characters	Correlation between the parental mean and gca effects ('r' values)				Correlation between hybrid mean performance with sca effects ('r' values)			
	LOC-I	LOC-II	LOC-III	Pooled	LOC-I	LOC-II	LOC-III	Pooled
Days to 50 % flowering	-0.5248	0.0067	0.3130	0.2618	-0.5268**	0.3875**	0.4299**	0.4268**
Productive tillers plant^{-1}	6.9611**	0.0995	-0.4405*	-0.4718**	0.5347**	0.2539**	0.4848**	0.2866**
Plant height	-0.9761**	-0.3878*	0.0526	-0.0384	0.3985**	0.6964**	0.5165**	0.4154**
Panicle length	0.2829	0.0902	0.1287	0.6221**	0.5023**	0.1715	0.4726**	0.3414**
No. of filled spikelets panicle^{-1}	0.0145	-0.9996**	-0.8190**	-0.8214**	0.2565**	-0.2154*	0.0284	0.2379**
Grain yield plant^{-1}	0.0627	0.0337	0.7847**	0.2029	0.4003**	0.3060**	0.4403**	0.2924**
Straw yield plant^{-1}	-0.1545	-0.2764	-0.2818	-0.2884	0.7622**	0.6084**	0.6699**	0.4775**
Harvest index	-0.2222	0.0658	-0.2282	-0.1769	0.7203**	0.7626**	0.7445**	0.5584**
Pollen fertility	0.5454**	-0.1736	0.5617**	0.7442**	0.5637**	0.1510	0.4161**	0.6116**
Spikelet fertility	0.0338	-0.1732	-0.2442	0.6552**	0.6687**	0.1202	0.5171**	0.5850**
Milling	0.0173	0.1112	0.3203	-0.7026**	0.5263**	0.2445**	0.5247**	0.3741**
Head rice recovery	-0.0809	0.5798**	0.4054*	0.4717**	0.1961**	0.2779**	0.3778**	0.2888*
1000-grain weight	0.7144**	0.3693*	0.3173	0.9838**	0.0279	0.0729	0.1320	0.3645**
Kernel length	0.3767*	0.1967	0.2262	0.6644	0.4007**	0.4764**	0.3474**	0.2293*
L:B ratio	0.6983**	0.6516**	0.4475**	0.8304**	0.1638	0.2716**	0.2641**	0.1821*
Protein content	-0.1105	-0.4163**	-0.5752**	0.0025	0.0754	0.1243	0.2524**	0.1974*
Amylose content	-0.3446	-0.2515	0.0426	0.0170	0.5839**	0.3992**	0.4161**	0.6681**

*, ** Significant at 5 and 1 per cent probability levels, respectively.

NVSR-20 (good x good) and RTN-13A X GR-7 (poor x good) had significant desired sca effects and significant desired heterotic response over better parent as well as both standard checks. The frequency of good x good was more. Among top 10 hybrids, five hybrids viz., RTN-3A X BL-184AR, RTN-2A X NVSR-20, RTN-3A X NVSR-20, RTN-3A X RDN-97-3-2-37-14 and RTN-2A X IR-8866 exhibited both of their parents found to be good combiners.

Correlation studies indicated (Table-3) the comparison of mean performance of hybrids and their sca effects showed higher performance of crosses was associated with their sca effects for all most all the characters while close association between mean performance of parents and their gca effects was observed only for the traits viz., productive tillers plant^{-1}, panicle length, number of filled spikelets panicle^{-1}, pollen fertility, spikelet fertility, milling, head rice recovery, 1000-grain weight and L:B ratio. The ranking of crosses on the basis of SCA effects and heterotic response was different. Crosses showing highest SCA effects need not show high heterotic response. This means that selection of the crosses based on SCA effects would be realistic than on the basis of heterotic response. Similar results have been reported earlier by Acharya and Pandey (2000); Bidan Roy and Mandal (2001); Krishnaveni and Shobha Rani (2003); Manonmani and Fazlullah Khan (2003); Mohan Rao *et al*. (1996), Narasimman *et al.* (2007) and Sharma and Mani (2008).

Thus, in the present investigation non-additive genes appeared to play a significant role in controlling the expression of all the traits except productive tillers plant^{-1}. This suggests that there is scope for improvement for these characters by using hybrid breeding programme for exploitation of the non additive gene action. Similar results have been reported earlier by Chakraborty *et al*. (1994), Mohan Rao *et al*. (1996), Annadurai and Nadarajan (2001), Khirsagar (2002), Narasimman *et al.* (2007) and Sharma and Mani (2008).

Table 4. Best performing cross combinations along with their SCA effects and estimates of heterobeltiosis and standard heterosis for various traits

Character	Best performing hybrids	GCA effects		SCA effects	Heterobeltiosis	Standard heterosis over		
		P_1	P_2		(%)	SC-I	SC-II	SC-III
Days to 50 % flowering	KJTCMS-6A X NVSR-20	G	G	-7.91**	-8.70**	-10.87**	-11.74**	-11.39**
	RTN-2A X IR-54742-22-19-3	P	P	-12.19**	-12.19**	-10.65**	-11.52**	-11.18**
	RTN-17A X IR-8866	G	G	-6.40**	-0.72	-10.55**	-11.41**	-11.07**
Productive tillers plant^{-1}	RTN-2A X IR-63879-195-195-2-2-3-2	G	G	3.22**	70.41**	67.53**	26.64**	69.30**
	RTN-2A X PR-116	G	G	1.75**	24.94**	60.40**	21.25**	62.09**
	RTN-13A X PR-116	G	G	2.25**	21.29**	55.71**	17.71**	57.36**
Plant height (cm)	RTN-3A X GR-3	G	G	-16.65**	-16.15**	-26.17**	-30.85**	-21.12**
	RTN-3A X PR-115	G	G	-7.01**	-0.53	-16.86**	-22.13**	-11.18**
	KJTCMS-6A X GR-11	G	G	-7.23**	1.66	-14.47**	-19.89**	-8.62**
Panicle length (cm)	RTN-3A X IR-8866	G	G	1.66**	6.39**	17.72**	8.63**	33.89**
	RTN-17A X NVSR-20	A	G	0.32	11.12**	15.34**	6.43**	31.19**
	RTN-3A X NVSR-20	G	G	0.07	10.88**	15.09**	6.20**	30.90**
No. of filled spikelets panicle^{-1}	RTN-3A X BL-184AR	G	G	35.56**	45.73**	48.44**	25.04**	39.30**
	RTN-3A X RDN-97-3-2-37-14	G	G	24.84**	37.51**	43.45**	20.84**	34.62**
	RTN-3A X NVSR-20	G	G	26.17	40.64**	43.26**	20.68**	34.44**
Grain yield plant^{-1} (g)	RTN-3A X BL-184AR	G	G	18.39**	66.85**	86.60**	58.03**	102.65**
	RTN-2A X NVSR-20	G	G	14.08**	77.75**	75.48**	48.61**	90.57**
	RTN-13A X GR-7	G	G	17.23**	66.31**	55.33**	31.54**	68.68**
Straw yield plant^{-1} (g)	RTN-3A X BL-184AR	G	G	13.42**	28.96**	51.00**	47.40**	61.80**
	RTN-2A X NVSR-20	G	G	10.65**	29.73**	37.80**	34.52**	47.65**
	RTN-13A X GR-7	G	G	10.95**	18.18**	31.58**	28.44**	40.98**
Harvest index (%)	RTN-2A X NVSR-20	A	G	2.09*	14.64**	13.63**	5.25	14.45**
	RTN-2A X KJT-3-2-861-25-15-5	A	A	5.39**	9.51**	13.02**	4.69	13.84**
	RTN-3A X BL-184AR	G	G	2.99**	14.41**	11.95**	3.70	12.76**
Pollen fertility (%)	RTN-3A X GR-3	G	G	6.58**	7.44**	16.65**	12.40**	15.35**
	RTN-13A X IR-54742-22-19-3	P	G	7.35**	6.25**	14.45**	10.29**	13.18**
	RTN-13A X Phule Radha	P	A	8.96**	9.29**	13.45**	9.32*	12.19**
Spikelet fertility (%)	RTN-3A X GR-3	G	G	4.76**	4.88*	16.31**	7.42**	13.74**
	KJTCMS-6A X Pusa Sugandh-5	A	G	3.29**	6.80**	15.94**	7.08**	13.37**
	RTN-3A X Pusa Sugandh-5	G	G	2.77**	4.15*	15.50**	6.67**	12.94**

Table 5. Contd.

Character	Best performing hybrids	GCA effects		SCA effects	Heterobeltiosis	Standard heterosis over		
		P_1	P_2		(%)	SC-I	SC-II	SC-III
Millng (%)	RTN-3A X NVSR-20	A	G	5.55**	20.08**	20.35**	15.90**	14.37**
	RTN-17A X RDN-97-3-2-37-14	P	A	14.54**	12.53**	19.80**	15.38**	13.85**
	RTN-2A X Pusa Sugandh-5	G	G	8.15**	10.04**	15.77**	11.50**	10.03**
Head Rice Recovery (%)	RTN-2A X PKV-Makarand	G	G	15.51**	24.63**	33.28**	32.15**	17.62**
	RTN-3A X IR-54742-22-19-3	G	G	11.37**	20.15**	31.52**	30.40**	16.06**
	RTN-2A X Pusa Sugandh-5	G	G	15.03**	19.79**	28.10**	27.01**	13.04**
1000-grain weight (g)	RTN-13A X GR-7	G	G	3.29**	19.65**	2.28	-3.63**	82.33**
	RTN-17A X GR-11	P	G	5.67**	40.85**	2.26	-3.64**	82.31**
	RTN-13A X NVSR-20	G	G	2.34**	3.29*	0.05	-5.73**	78.36**
Kernel length (mm)	RTN-3A X GR-11	G	G	1.31**	2.61**	37.18**	25.90**	38.73**
	RTN-13A X Phule Radha	G	G	1.18**	12.37**	35.63**	24.47**	37.16**
	RTN-3A X Pusa Sugandh-5	G	G	1.07**	-8.43**	34.28**	23.24**	35.80**
L:B ratio	RTN-3A X PR-114	G	G	-0.46**	14.93**	67.00**	46.53**	41.95**
	KJTCMS-6A X PR-116	P	G	1.06**	22.47**	64.54**	44.37**	39.86**
	RTN-13A X Phule Radha	P	G	0.94**	16.15**	60.68**	40.98**	36.57**
Protein content (%)	RTN-3A X PR-114	G	G	4.15**	54.68**	40.27**	19.05**	79.36**
	RTN-2A X GR-7	A	G	3.35**	95.25**	39.48**	18.38**	78.35**
	RTN-2A X PR-115	A	A	4.78**	72.20**	37.50**	16.69**	75.82**
Amylose Content (%)	RTN-3A X IR-22273	G	G	3.45**	12.83**	10.53**	1.19	11.69**
	RTN-2A X RP-BIO-226	G	G	2.53**	15.86**	21.28**	11.03**	22.55**
	RTN-17A X GR-7	A	G	3.02**	19.71**	20.40**	10.23**	21.66**

*, ** Significant at 5 and 1 per cent probability levels, respectively; G = Good parent having significant GCA effect in desired direction; A = Average parent having either positive or negative but non-significant GCA effects; P = Poor parent having significant GCA effects in undesired direction; SC-I- Jaya; SC-II- Sahyadri; SC-III- GR-11

The cross combination, RTN-3A X BL-184AR exhibited significant highest SCA effects, significant heterobeltiosis and standard heterosis for grain yield and most of the traits under the investigations. This cross combination could well be utilized for commercial cultivation after extensive testing in state and national trials.

REFERENCES

Acharya B and Pandey K 2000. Combining ability studies for grain yield and related characters in lowland rice. Oryza 37: 190-194.

Annadurai A and Nadarajan N 2001. Combining ability for yield component and physiological traits in hybrid rice. Madras Agric. J. 88 (4-6) : 300-303.

Banumathy S and Prasad M N 1991. Studies of combining ability for development of new hybrids in rice. Oryza 28 : 439-442.

Bidhan Roy and. Mandal A B 2001. Combining ability of some quantitative traits in rice. Indian J. Genet. 61: 162-164.

Chakraborty S, Hazarika M H and Hazarika G N 1994. Combining ability analysis in rice. Oryza 31 : 281-283.

Ghosh A 1993. Combining ability for yield and its related traits in upland rice. Oryza 30 : 275-279.

Kemthorne O 1985. An introduction to genetical Statistics. John Wiley and Sons, Inc., New York.

Krishnaveni B and Shobha Rani N 2003. Heterosis and combining ability for yield and yield components in rice. J. Res. ANGARU. 31: 44-51.

Kshirsagar R M 2002. Genetic analysis of yield and its components in rice. M.Sc. (Agri.) thesis (unpublished) submitted to Gujarat Agricultural University, Navsari.

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

Manonmani S and Faziuah Khan A K 2003. Studies on combining ability and heterosis in rice. Madras Agric. J. 90: 228-231

Manuel W W and Palanisamy S 1989. Line x tester analysis of combining ability in rice. Oryza 26 : 27-32.

Mohan Rao A, Ramesh S S, Kulkarni Savithramma D L and Madhusudan K 1996. Heterosis and combining ability in rice. (*Oryza sativa* L.) Crop Improvement 23 (1) : 53-56.

Narasimman R, Thirugananakumar S R, Eswarn S, Praveen Sampathkumar and Anandkumar A. 2007. Combining ability and heterosis for grain yield and its component characters in rice (*Oryza sativa* L.). Crop Improvement, 34 (1) : 16-18.

Ram T, Singh J and Singh R M 1991. Genetic analysis of yield and components in rice. *Oryza*, 28 : 447-450.

Ramalingam J, Vivekanandan P and Subramanian M 1993. Combining ability in rice. Oryza 30 : 33-37.

Rao A V, Krishna S T and Prasad A S R 1980. Combining ability analysis in rice. Indian J. Agric. Sci. 50 (3) : 193-197.

Sharma R K and Mani S C 2008. Analysis of gene action and combining ability for yield and its component characters in rice. Oryza 45 (2) : 94-97.

Shunmugavalli N, Kingshlin M and Ravindran G R 1999. Combining ability in early rice cultivars. Crop Res. 18 (3) : 419-422.

Singh P K, Thakur R, Chaudhary V K and Singh N B 1996. Combining ability for grain yield and its components in relation to rice breeding. Crop Res. 11 (1) : 62-66.