The Bioscan 8(4): 1521-1528, 2013 (Supplement on Genetics & Plant Breeding)
AN INTERNATIONAL QUARTERLY JOURNAL OF LIFE SCIENCES
www.thebioscan.in

COMBINING ABILITY, GENE ACTION AND HETEROSIS USING CMS LINES IN HYBRID RICE (ORYZA SATIVA L.).

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KEYWORDS
CMS lines
Gene action
Hybrid vigour and New rice hybrids

Received on :
17.08.2013

Accepted on :
28.11.2013

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ABSTRACT
Combining ability and heterosis studies for grain yield and its component traits in aromatic and non-aromatic rice. Combining ability revealed higher specific combining ability variance than their respective general combining ability variances indicating the predominance of non-additive gene effects indicated relevance of heterosis breeding for improving the yield and yield contributing attributes. Among the lines IR 58025A (1.31) and IR 79156A (0.41); among testers Narendra Usar 3 (7.16), Swarna (6.99), Usar 1 (6.37), Pankaj (4.19), Pusa Sugandha 3 (2.94) and Taraori Basmati (0.82) were emerged as good general combiners for yield along with other related components, thus these were utilize as potential donor. Among these Narendra Usar 3 showed good GCA for majority of the yield enhancing traits except L:B ratio (-0.08) and spikelet per panicle (-4.81). Out of 51 hybrids, eight hybrids were identified to exploit heterosis in positive direction with desirable SCA effects and high *per se* performance for yield and other traits. Among aforesaid crosses one cross "IR 79156 A × Swarna" and one cross "IR 80555 A × Pusa Sugandha 3" were found significantly desirable cross combination for heterosis breeding in non-aromatic and aromatic rice group, based on SCA performance and heterosis over better parent and standard variety for yield and its components.

INTRODUCTION

Rice is life and generally known as prince among the cereals. More than half of the world's population depends on rice for calories and protein, especially among the developing countries 90 per cent of the rice is grown and consumed in Asia, also known as rice bowl of the world, where 60 percent of the earth's people and two third of world's poor live (Khush and Virk, 2000). The world population expected to reach eight billion by 2030 and rice production must increase by 50 per cent in order to meet the growing demand (Khush and Brar, 2002). Thus to full-fill the demand of increasing population, developing new high yielding hybrids and improved lines/varieties along with stable performance in different agro climatic is a big challenge. Genetic improvement depends on the availability high magnitude of genetic variability in germplasm. The most common, easy and effective means for developing/identifying new hybrids or line is by utilizing cytoplasmic genetic male sterility (CMS) technique in the hybrid breeding programme is fruitful. The development and use of hybrid rice varieties on commercial scale utilizing CMS - fertility restoration system has now proved to be one of the plausible milestones in the history of rice improvement. The hybrid rice technology now in operation, aims at yield augmentation through higher exploitable heterosis levels. With the moto of increasing interest in exploitation of heterosis in rice, there is an urgent need to make available various CMS lines and good restoration capability lines for combining ability tests. The knowledge of combining ability is useful to assess nicking ability in self-pollinated crops and at the same time elucidate the nature and magnitude of gene actions involved, provides to the breeder about insight of nature and relative magnitude of fixable and non-fixable genetic variances ie. due to dominance or epistatic components. Thus combining ability analysis is one of the reliable and most prominent tools available to estimate the combining ability effects and foreground selection for desirable parents in hybrid breeding programme. Hence, this study provides useful information for the selection of donor parents for effective breeding programme. Such informations are required to design efficient breeding programmes for rapid dynamic and strategic crop improvement for quantitative along with qualitative nature of traits.

MATERIALS AND METHODS

The parental material for the present study comprised 51 F_1s of rice, three CMS lines (viz., IR 58025A, IR 79156A and IR 80555A) and 17 diverse elite and good restorer lines (testers) derived by line × tester mating design during *kharif*, 2008. The resultant 51 F_1s and 20 parents were evaluated in randomized complete block design (RCBD) with three replications during *kharif*, 2009 at Genetics and Plant Breeding Research Farm of Narendra Deva University of Agriculture and Technology, Kumarganj Faizabad, India. The 7-10 days old seedlings were transplanted in earthen pots for their normal growth, while male lines were direct seeded in fully prepared nursery beds at three different dates to coincide the flowering dates with CMS lines for crossing purpose. 7 to 10 days old seedlings were transplanted with one seedling per hill adopting recommended spacing of 20 x 15 cm and each entry was planted in five rows of 3.0 m length. All the recommended cultural practices and pacakeges were applied for growing healthy and good crop. In each entry, ten plants were randomly selected from each replication and following observations were recorded for Panicle length (PL), Spikelets panicle^{-1} (SP^{-1}), Spikelets fertility (SF), 1000 grain weight (TW), Biological yield hill^{-1} (BYH^{-1}), grain yield hill^{-1} (GYH^{-1}), Harvest-index (HI), Kernel length (Kl), Kernel breadth (KB) and L:B ratio (LBR). The mean data of different traits were subjected to analyze by standard statistical and biometrical method for combining ability by Kempthorne (1957), heterobeltiosis and standard heterosis over (Pusa Basmati 1 and Sarjoo 52) by Fonseca and Patterson (1968).

RESULTS AND DISCUSSION

Analysis of variance

ANOVA for combining ability (Table 1) revealed that mean square due to lines were significant for PL, SF and BYH^{-1}. The magnitude of variance due to line × tester was highly significant for all the traits under study (Saleem *et al*., 2010). The mean squares due to testers were found non-significant only for SP^{-1} and HI. The aforesaid findings suggested the importance of both additive and non-additive gene effects represented by general and specific combining ability variances respectively, for majority of the traits. Combining ability analysis revealed that both GCA and SCA variances were important for inheritance of various studied traits.with additive and non-additive nature of gene action. The SCA variances were higher than the corresponding GCA variances for almost all the traits (Saidaiah *et al*., 2010), indicated preponderance of non-additive gene effects. The estimates of average degree of dominance varied from greater to unity and emphasized predominance of non-additive gene effects. The lesser than unity value of predictability ratio also suggested prevalence of non-additive gene effects. The importance of additive as well as non-additive gene effects with predominance of non-additive gene effects in inheritance of grain yield and yield components of rice were agreement with earlier findings of Saleem *et al*. (2010), Saidaiah *et al*. (2010), Rashid *et al*. (2007), Saravanan *et al*. (2006), Kumar *et al*. (2004) and Vanaja *et al*. (2003).

Proportional contribution

The proportional contribution of lines, testers and their interaction for ten traits is presented in Table 2. It was evident from the finding that testers played very important role for all the traits indicated dominance of parental influence for the traits. Lines were more important but their contribution was not too high, revealed low influence of maternal effect for all traits. The contribution of maternal and paternal interaction (line x tester) was low to high for all the traits under study. These results were confirmity with Saleem *et al*. (2010) and Rashid *et al*. (2007).

General Combining ability

The significant and positive GCA effects for GYH^{-1} were exhibited only by 6 testers namely, Narendra Usar 3 (7.16),

Table 1: Mean square of various treatments components including estimates of components of variances for different traits in aromatic and non aromatic rice

Sources of variation	df	PL	SP-1	SF	TW	BYH-1	GYH-1	HI	KL	KB	LBR
Replications	2	8.941**	452.886	10.099	10.130**	26.69**	16.733**	16.674**	0.0001	0.0002	0.0002
Lines	2	50.187*	3721.3	2056.464**	24.645	1214.786*	122.863	49.9	0.137	0.027	0.088
Testers	16	16.722**	798.451	1221.788**	153.438**	494.275*	156.789**	181	4.022**	0.649**	3.249**
Lines × Testers	32	14.177**	1237.608**	269.858**	36.950**	247.880**	58.295**	125.360**	0.167**	0.073**	0.192**
Error	100	1.666	209.873	5.062	1.365	2.301	0.885	1.98	0.001	0.0003	0.001
gca variance ($\sigma^2 g$)		0.643	34.076	45.642	1.736	20.222	2.718	-	0.064	0.009	0.049
sca variance ($\sigma^2 s$)		4.184	354.367	88.53	11.884	81.71	19.11	40.9	0.056	0.024	0.064
$\sqrt{\sigma^2 s/2\sigma^2 g}$		1.804	2.28	0.985	1.85	1.421	1.875	7.89	0.66	1.173	0.805
$2\sigma^2 g/2\sigma^2 g+\sigma^2 s)$		0.235	0.161	0.508	0.226	0.331	0.222	-	0.696	0.429	0.605
$\sigma^2 A$		1.285	68.151	91.285	3.473	40.443	5.435	-	0.128	0.018	0.098
$\sigma^2 D$		4.184	354.367	88.53	11.884	81.71	19.11	40.9	0.056	0.024	0.064
h2n (%)		21.382	14.178	50.367	21.994	32.862	21.858	@	69.579	42.02	60.614
Ga (%)		3.872	4.261	21.599	9.506	14.078	11.205	-	10.028	8.485	17.447

*, ** Significant at 5% and 1 % probability levels, respectively ; - Negative estimates, @ h^2n value not calculated due to negative estimate of $\sigma^2 g$ i.e. $\sigma^2 A$ = Zero

Table 2: Proportional contribution of lines, testers and their interactions to total variance in a set of line × tester crosses in aromatic and non aromatic rice

Contribution (%)	PL	SP^{-1}	SF	TW	BYH^{-1}	GYH^{-1}	HI	KL	KB	LBR
Lines	12.22	12.44	12.74	1.34	13.29	5.32	1.43	0.392	0.417	0.302
Testers	32.57	21.36	60.53	66.59	43.29	54.3	41.34	91.96	81.28	89.17
Lines × Testers	55.22	66.2	26.74	32.07	43.42	40.38	57.24	7.65	18.3	10.53

Table 3: Estimates of general combining ability (GCA) effects of parents (lines and testers) for 10 traits in aromatic and non aromatic rice

Testers	PL	SP^{-1}	SF	TW	BYH^{-1}	GYH^{-1}	HI	KL	KB	LBR
Sarjoo 52	-1.36**	-2.82	1.06	4.88	-8.68**	-3.91**	-1.10	0.45**	0.25**	-0.18**
Taraori Basmati	-0.61	12.04**	-3.58**	1.13**	4.44**	0.82*	-1.43*	0.95**	-0.34**	0.97**
Kasturi	1.25**	-4.76	0.64	-0.07	1.51**	0.28	-0.45	0.91**	-0.27**	0.81**
CSR 30	-0.15	-0.046	-5.09**	1.64**	-5.17**	-5.39**	-6.65**	0.27**	0.17**	-0.17**
Usar 1	-0.65	9.32*	17.40**	4.23**	7.58**	6.37**	4.90**	-0.59**	0.59**	-0.91**
Pakistani Basmati	-0.51	-26.68**	6.44**	2.69**	-2.50**	-0.90**	-0.09	0.90**	-0.26**	0.81**
NDRK 50012	-1.51**	2.71	-15.85**	0.292**	-2.78**	-4.55**	-4.82**	-0.57**	0.04**	-0.38**
T 3	-2.13**	-8.99*	5.36**	0.04**	-8.49**	-4.13**	-1.88**	0.51**	-0.26**	0.59**
IR 65192-2B-8-1	0.21	-7.84	-3.20**	-7.07**	-5.30**	-1.19**	1.46**	-0.65**	-0.05**	-0.31**
Pokkali	1.12**	4.57	-2.44**	-0.68**	1.02	-1.30**	-1.83**	-0.99**	0.21**	-0.74**
Lalpari	1.31**	3.22	-14.13**	-10.33**	-17.49**	-4.53**	6.92**	-0.49**	-0.28**	0.09**
Swarna	-2.62**	3.74	7.00**	3.69**	6.91**	6.99**	6.98**	-0.85**	0.18**	-0.58**
Narendra Usar 3	1.34**	-4.81	31.77**	4.23**	5.65**	7.16**	8.45**	0.07**	0.03**	-0.08**
Pusa Sugandha 3	1.60**	8.19	-10.63**	-0.47**	9.13**	2.94**	-1.35*	0.64**	-0.08**	0.39**
Pankaj	0.29	-2.41	-5.65**	2.69**	10.01**	4.19**	-0.47	-0.15*	0.12**	-0.27**
IR 61920-3B-22-2-1	0.47	2.38	-9.40**	-3.54**	3.55**	-2.01**	-6.62**	-0.70**	0.30**	-0.71**
Raghuvansi 4	1.98**	12.19**	0.30	-3.33**	0.62	-0.84*	-2.05**	0.29**	-0.35**	0.65**
SE (gi) testers	0.84	8.74	1.37	0.75	1.10	0.65	1.09	0.02	0.01	0.02
SE(gi – gj)	1.19	12.36	1.93	1.07	1.55	0.92	1.55	0.03	0.01	0.03
Lines										
IR 80555 A	-0.89**	8.79**	7.25**	-0.80**	-5.51**	-1.72**	1.13**	-0.01**	0.03**	-0.03**
IR 58025 A	-0.19	-0.52	-2.69**	0.39**	3.78**	1.31**	-0.41	0.06**	-0.01**	0.05**
IR 79156 A	1.07**	-8.27**	-4.57**	0.41**	1.73**	0.41**	-0.72**	-0.05**	-0.02**	-0.02**
SE(gi) lines	0.35	3.67	0.57	0.32	0.46	0.27	0.46	0.01	0.01	0.01
SE(gi – gj)	0.50	5.19	0.81	0.45	0.65	0.39	0.65	0.01	0.01	0.01

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

Swarna (6.99), Usar 1 (6.37), Pankaj (4.19), Pusa Sugandha 3 (2.94) and Taraori Basmati (0.82), and by 2 lines, IR 58025 A (1.31) and IR 79156 A (0.41), and also showed positive and significant GCA effects for other important traits as mentioned in table 3, and may also serve as valuable donors for hybridization programme or multiple crossing programmes for obtaining high yielding hybrid varieties or in selection of transgressive segregants for developing pure line varieties of aromatic and non-aromatic rice through background selection. Hence, simultaneous improvement for yield, yield component and other associated traits is possible and also very important for enhancing yield potential in rice. The additive gene effects were fixable nature for grain yield and most of other yield component traits suggested that these traits are amenable to improvement through background selection in early generations. The considerable improvement in status of grain yield and important yield attributes in rice can still be achieved by following conventional breeding procedures by the used of suitable donor with superior restorer parents in autogamous crops leading to development of high yielding varieties.

Specific combining ability effects

The specific combining ability (SCA) effects, which are supposed to be manifestation of non-additive components of genetic variance, were highly valuable for discrimination of crosses for their genetic worth as breeding materials. Several crosses exhibited significant and desirable SCA effects for one or more studied traits but none of them emerged as good specific combiner for more than seven traits. Out of 51 F_1s, eighteen crosses namely, IR 79156 A × Swarna, IR 79156 A × IR 65192-2B-8-1, IR 80555 A × IR 61920-3B-22-2-1, IR 58025 A × Pankaj, IR 58025 A × Usar 1, IR 58025 A × Pusa Sugandha 3, IR 79156 A × Narendra Usar 3, IR 80555 A × Pusa Sugandha 3, IR 58025 A × Taraori Basmati, IR 80555 A × Sarjoo 52, IR 80555 A × Pankaj, IR 80555 A × T 3, IR 79156 A × Usar 1, IR 79156 A × Raghuvansi 4, IR 79156 A × Kasturi, IR 58025 A × Raghuvansi 4, IR79156 A × Pokkali and IR 80555 A × CSR 30 showed significant and positive SCA effects for GYH^{-1} along with BYH^{-1}, TW, HI, SF, KL, KB and LBR (Table 4). The cross combinations IR 79156 A × Swarna (7.14) and IR 58025 A × Pusa Sugandha 3 (4.45) were the best specific combiner for grain yield per hill in non-aromatic and aromatic rice, respectively. Hence, these two crosses may be used for exploitation of heterosis for yield and yield contributing traits in rice (Satheesh *et al.*, 2010). The predominance of non-additive gene effects represented non-fixable dominance and epistatic components of genetic variance indicated that maintenance of heterozygocity would be highly fruitful for improving the traits. Hence, the suitable breeding strategy for attaining high yield would be the full or partial exploitation of hybrid vigour through development of fully extended hybrid, synthetic or composite cultivars.

In general, the crosses showing significant and desirable SCA

Table 4: Estimates of specific combining ability (SCA) effects of crosses for 10 traits in aromatic and non aromatic rice hybrids

Crosses	PL	SP-1	SF	TW	BYH-1	GYH-1	HI	KL	KB	LBR
IR 80555 A ×Sarjoo 52	2.32**	38.56**	4.05**	-3.21**	1.58	3.14**	6.13**	0.08**	-0.07**	0.11**
IR 58025 A× Sarjoo 52	-0.47	-14.74	-0.75	0.27	1.24	-1.10	-3.54**	-0.30**	0.05**	-0.19**
IR 79156× A Sarjoo 52	-1.85*	-23.82**	-3.29**	2.94**	-2.82**	-2.04**	-2.59**	0.23**	0.02*	0.09**
IR 80555 A ×Taraori Basmati	2.64**	-3.83	0.09	1.78**	-4.21**	0.01	2.67**	-0.14**	-0.03**	-0.04**
IR 58025 A ×Taraori Basmati	-1.59*	-0.33	-15.59**	-3.08**	-0.28	3.24**	5.45**	-0.01	-0.02	0.04**
IR79156 A ×Taraori Basmati	-1.05	4.16	15.50	1.31*	4.44**	-3.25**	-8.12**	0.15**	0.05**	0.02
IR 80555 ×A Kasturi	2.11**	5.50	0.07	2.91**	-7.21**	-1.81**	1.94*	-0.13**	-0.03**	-0.05**
IR 58025 A × Kasturi	-2.35**	-0.09	12.24**	-2.38**	3.54**	-0.15	-2.77**	0.03	-0.02**	0.06**
IR 79156 A × Kasturi	0.24	-5.41	-12.30**	-0.53	3.67**	1.96**	0.83	0.10**	0.05**	-0.01
IR 80555 A × CSR 30	-1.61*	-25.75**	-3.80**	3.07**	-4.66**	1.22*	5.66**	-0.09**	0.04	-0.05**
IR 58025 A ×CSR 30	0.02	10.06	3.83**	-0.47	5.35**	-1.49*	-6.17**	0.20**	0.05**	0.02
IR 79156 A × CSR 30	1.59*	15.69*	-0.03	-2.60**	-0.69	0.26	0.52	-0.11**	-0.05**	0.04*
IR 80555 A × Usar 1	-2.43**	12.56	5.89**	-0.47	-6.25**	-7.14**	-8.06**	0.03	0.07**	-0.03**
IR 58025 A × Usar 1	0.66	-14.71	0.25	2.12**	5.96**	4.71**	3.48**	-0.19**	0.01	-0.09**
IR 79156 A × Usar 1	1.77*	2.15	-6.14**	-1.65*	0.29	2.42**	4.58**	0.16**	-0.08**	0.13**
IR 80555 A × Pakistani Basmati	-4.38**	-44.09**	-7.32**	-0.60	2.55**	-0.87	-4.23**	0.09**	-0.08**	0.17**
IR58025 A × Pakistani Basmati	2.22**	23.44**	-2.16	-0.67	-3.67**	0.88	4.91**	-0.16**	-0.09**	0.09**
IR79156 A × Pakistani Basmati	2.16**	20.64**	9.48**	1.27	1.12	-0.02	-0.68	0.07**	0.17**	-0.25**
IR 80555 A × NDRK 50012	-1.28	-17.57*	9.73**	-4.81**	-1.26	0.71	-0.91	-0.01	-0.12**	0.14**
IR 58025 A × NDRK 50012	2.77**	27.87**	-11.82**	2.62**	15.71**	-1.18*	-11.22**	0.54**	0.09**	0.11**
IR 79156 A × NDRK 50012	-1.49	-10.30	2.09	2.19**	-14.45**	0.48	12.13**	-0.54**	0.03**	-0.25**
IR 80555 A × T 3	0.02	-9.80	-3.69**	-5.72**	6.54**	2.44**	-0.60	0.02	0.01	-0.03*
IR 58025 A × T 3	-2.79**	-11.79	10.84**	-0.09	0.39	-1.46*	-3.52**	0.16**	-0.04**	0.15**
IR 79156 A × T 3	2.77**	21.59**	-7.16**	5.81**	-6.92**	-0.98	4.13**	-0.18**	0.03**	-0.12**
IR 80555 A × IR 65192-2B-8-1	-0.61	7.38	7.09**	0.45	-4.46**	-3.05**	-2.75**	0.06**	-0.03**	0.06**
IR58025 A × IR 65192-2B-8-1	-0.17	-15.22*	-3.08*	-2.56**	-9.64**	-3.6**	0.82	0.01	0.02*	-0.03
IR79156 A × IR 65192-2B-8-1	0.78	7.84	-4.02**	2.12**	14.11**	6.69**	1.94*	-0.07**	0.01	-0.03*
IR 80555 A × Pokkali	-0.37	-9.69	-19.43**	-3.53**	-12.57**	-1.01	8.35**	0.23**	-0.02*	0.11**
IR 5858025 A × Pokkali	0.86	10.26	13.55**	2.37**	4.64**	-0.38	-4.75**	-0.24**	0.15**	-0.25**
IR 79156 A × Pokkali	-0.49	-0.57	5.88**	1.15	7.93**	1.39*	-3.61**	0.01	-0.13**	0.14**
IR 80555 A × Lalpari	-0.64	33.66**	7.46**	0.69	1.54	0.19	-0.23	0.09**	0.01	0.01
IR 58025 A × Lalpari	1.80*	-15.81*	-3.73**	-0.53	0.64	-0.18	-2.15*	-0.09**	-0.03**	-0.01
IR 79156 A × Lalpari	-1.16	-17.85*	-3.73**	-0.17	-2.17*	-0.02	2.38*	0.01	0.02*	-0.01
IR 80555 A × Swarna	0.185	-13.37	-7.64**	-1.16	-4.41**	-2.46**	-0.03	-0.16**	0.24**	-0.34**
IR 58025 A × Swarna	1.70*	4.11	1.92	2.97**	-6.81**	-4.67**	-2.99**	0.29**	-0.47**	0.66**
IR 79156 A × Swarna	-1.89*	9.26	5.72**	-1.80**	11.22**	7.14**	3.03**	-0.14**	0.23**	-0.32**
IR 80555 A × Narendra Usar 3	-0.99	-6.21	-7.91**	-4.55**	-0.38	-1.68*	-2.20*	-0.04**	-0.01	-0.03
IR 58025 A × Narendra Usar 3	0.01	1.46	3.14**	2.25**	-7.16**	-2.69**	0.92	-0.01	0.01	-0.03
IR 79156 A × Narendra Usar 3	0.99	4.75	4.77**	2.30**	7.54**	4.37**	1.29	0.05**	-0.01	0.06**
IR 80555 A × Pusa Sungandha3	2.88**	-5.55	14.91**	8.04**	3.37**	3.28**	5.07**	0.12**	-0.24**	0.40**
IR 58025 A × Pusa Sungandha3	-2.69**	-0.39	-7.44**	-4.14**	-1.00	4.45**	6.09**	-033**	0.35**	-0.67**
IR 79156 A × Pusa Sungandha3	-0.19	5.95	-7.48**	-3.90**	-2.37*	-7.74**	-11.19**	0.21**	-0.11**	0.27**
IR 80555 A × Pankaj	0.31	3.04	5.49**	1.34*	7.44**	3.06**	0.46	-0.35**	0.22**	-0.39**
IR 58025 A × Pankaj	-1.18	-9.96	-3.42**	0.86	9.82**	5.99**	3.66**	0.24**	-0.11**	0.21**
IR 79156 A × Pankaj	0.87	6.92	-2.06	-2.20**	-17.26**	-9.06**	-4.12**	0.12**	-0.11**	0.19**
IR 80555 A × IR 61920-3B-22-2-1	0.31	10.83	0.29	3.73**	15.61**	6.54**	1.36	-0.06**	0.05**	-0.07**
IR 58025 A × IR 61920-3B-22-2-1	2.46**	-0.93	-2.98*	-0.055	-10.92**	-2.59**	2.77**	0.10**	0.11**	-0.08**
IR 79156 A × IR 61920-3B-22-2-1	-2.77**	-9.91	2.69*	-3.68**	-4.69**	-3.95**	-4.13**	-0.04**	-0.15**	0.15**
IR 80555 A × Raghuvansi 4	1.55*	24.32**	-5.27**	2.05**	6.77**	-3.75**	-12.62**	0.27**	0.04**	0.04**
IR 58025 A × Raghuvansi 4	-1.24	6.79	5.19**	0.51	-7.79**	1.43*	9.03**	-0.24**	-0.07**	0.01
IR 79156 A × Raghuvansi 4	-0.306	-31.11**	0.08	-2.56**	1.02	2.32**	3.58	-0.02	0.04**	-0.06**
SE (S_{ij})	1.46	15.13	2.37	1.31	1.90	1.13	1.89	0.03	0.02	003
SE ($S_{ij} - S_{kl}$)	2.07	21.40	3.35	1.84	2.69	1.59	2.68	0.04	0.03	0.04

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

effects were associated with better *per se* performance for respective traits, but in sometimes this association did not showed in desirable direction (Table 5). Thus, the SCA effect of the crosses may not be directly related to their *per se* performance. This may be attributed to the fact that *per se* performance is a realized value, whereas SCA effect is an estimate of F_1 performance over parental value. Therefore, both *per se* performance along with SCA effects should be considered for evaluating the superiority of a cross, if development of hybrids is the ultimate objective.

Heterosis

The estimates of heterosis over better-parent and standard varieties - SV_1 (Pusa Basmati 1) and SV_2 (Sarjoo 52), for 51 F_1's to assess their genetic potential as breeding material. A wide range of heterobeltiosis varied from -55.18% (IR 80555 A ×

Table 5: Most promising cross combinations for different traits along with their mean performance and gca effects of parents in aromatic and non aromatic rice

Traits	Crosses with significant effects	Mean performance of crosses	gca effects of parents
Panicle length	IR 80555 A × Pusa Sugandha 3	2.88	H×L
	IR 79156 A × T 3	2.77	L×H
	IR 58025 A × NDRK 50012	2.77	L×A
	IR 80555 A × Taraori Basmati	2.64	A×L
	IR 58025 A × IR 69120-3B-22-2-1	2.46	A×A
Spikelets/panicle	IR 80555 A × Sarjoo 52	38.56	A×H
	IR 80555 A × Lalpari	33.66	A×H
	IR 58025 A × NDRK50012	27.87	A×A
	IR 80555 A × Raghuvansi 4	24.32	H×H
	IR 58025 A × Pakistani Basmati	23.44	L×A
Spikelet fertility	IR 80555 A × Pusa Sugandha 3	14.92	L×H
	IR 58025 A × Pokkali	13.55	L×L
	IR 58025 A × Kasturi	12.24	A×L
	IR 58025 A × T 3	10.84	H×L
	IR 80555 A × NDRK 50012	9.73	L×H
1000-grain weight	IR 80555 A × Pusa Sugandha 3	8.04	L×L
	IR 79156 A × T 3	5.81	H×H
	IR 80555 A ×IR 61920-3B-22-2-1	3.73	L×L
	IR 80555 A × CSR 30	3.07	H×L
	IR 58025 A × Swarna	2.97	H×H
Biological yield/hill	IR 58025 A × NDRK 50012	15.71	L×H
	IR 80555 A × IR 9120-3B-22-2-1	15.61	H×L
	IR 79156 A × IR 65192-2B-8-1	14.11	L×H
	IR 79156 A × Swarna	11.22	H×H
	IR 58025 A × Pankaj	9.82	H×H
Grain yield/hill	IR 79156 A × Swarna	7.14	H×H
	IR 79156 A × IR 65192-2B-8-1	6.69	L×H
	IR 80555 A × IR 61920-3B-22-2-1	6.54	L×L
	IR 58025 A × Pankaj	5.99	H×H
	IR 58025 A × Usar 1	4.71	H×H
Harvest-index	IR 79156 A × NDRK 50012	12.13	L×L
	IR 79156 A × Raghuvansi 4	9.03	L×L
	IR 80555 A × Pokkali	8.35	L×H
	IR 80555 A × Sarjoo 52	6.13	A×H
	IR 58025 A × Pusa Sugandha 3	6.09	L×A
Kernel length	IR 58025 A × NDRK 50012	0.54	L×H
	IR 58025 A × Swarna	0.29	L×H
	IR 80555 A × Raghuvansi 4	0.27	H×L
	IR 58025 A × Pankaj	0.24	L×H
	IR 79156 A × Sarjoo 52	0.23	H×L
Kernel breadth	IR 58025 A × Pusa Sugandha 3	0.35	L×L
	IR 80555 A × Swarna	0.24	H×H
	IR 79156 A × Swarna	0.23	H×L
	IR 80555 A × Pankaj	0.22	H×H
	IR 79156 A × Pakistani Basmati	0.17	L×L
L:B ratio	IR 58025 A × Swarna	0.66	L×H
	IR 80555 A × Pusa Sugandha 3	0.40	H×L
	IR 79156 A × Pusa Sugandha 3	0.27	H×L

H = High (significant and positive); L = Low (significant and negative); A = Average (non-significant)

Pokkali) to 60.19% (IR 79156 A × Swarna) and standard heterosis varied from -50.35% (IR 80555 A × IR 61920-3B-22-2-1) to 35.22% (IR 79156 A × Swarna) over SV_1 and from -57.82% (IR 80555 A × Raghuvansi 4) to 6.57% (IR 79156 A × Swarna) over SV_2 for grain yield per hill (Table 6). The existence of wide spectrum of heterosis in positive direction with expression of high degree of desirable heterosis by some crosses for all the characters observed in present study was in conformity with the earlier reports Janardanam *et al.*, 2001; Bhanumathi *et al.*, 2003; Punitha *et al.*, 2004; Singh *et al.*, 2007 and Roy *et al.*, 2009.

Out of fifty one cross combinations 13 crosses showed positive and significant heterobeltiosis for grain yield per hill (Table 7). Six crosses showed positive and significant standard heterosis over SV_1 and only one cross i.e. IR 79156 A × Swarna possessed significant and positive standard heterosis over SV_2 for grain yield per hill and some other important yield contributing component traits (Table 8). Besides yield, substantial heterosis over better-parent and standard varieties was also observed in negative as well as positive direction for remaining characters. The eight most desirable crosses showing high mean performance along with high and significant heterosis for grain yield per hill were, IR 79156 A × Swarna, IR 58025 A × Usar 1, IR 79156 A × Narendra Usar

Table 6: Extent of per cent heterosis 13 F_1's out of 51 F_1's over better parent (BP) and two standard varieties (SV1 and SV2) for 10 characters in aromatic and non aromatic rice hybrids

Crosses	Panicle length			Spikelets per panicle			Spikelet fertility			1000-grain wt.			Biological yield per hill		
	BP	SV1	SV2	BP	SV1	SV2	BP	SV1	SV2	BP	SV1	SV2	BP	SV1	SV2
IR 58025 A × Taraori Basmati	-2.88	-15.31**	-5.52	-22.27**	17.40*	0.31	-59.38**	-58.52**	-60.66**	33.30**	2.93	-36.60**	23.98**	-7.74**	-25.03**
IR 80555 A × Usar 1	4.19	-20.56**	-11.37**	57.27**	31.60**	12.45**	-0.13	-1.25	-6.34**	10.81*	28.51**	-20.85**	-25.77**	-26.73**	-40.46**
IR 58025 A × Usar 1	17.28**	-7.99*	2.65	-30.58**	4.91	-10.36	-17.35**	-18.27**	-22.48**	29.33**	49.99**	-7.62*	8.39**	6.98**	-13.07**
IR 79156 A × Usar 1	18.28**	-0.13	11.42**	24.55**	11.55	-4.68	-26.49**	-27.31**	-31.06**	10.96*	28.68**	-20.74**	-6.48**	-5.14**	-22.92**
IR79156 A × IR 65192-2B-8-1	-20.52**	-0.53	10.98**	-17.65**	3.19	-11.82	-47.21**	-47.50**	-50.20**	-22.55**	-14.03**	-47.05**	-5.02*	-3.67	-21.72**
IR 58025 A × Swarna	2.14	-11.08**	-0.79	-24.14**	14.57	-2.10	-32.32**	-27.81**	-31.53**	24.59**	51.71**	-6.56*	-16.57**	-14.10**	-30.20**
IR 79156 A × Swarna	-6.74	-18.80**	-9.41*	-3.85	12.67	-3.72	-30.35**	-25.71**	-29.54**	2.45	24.75**	-23.16**	7.74**	10.93**	-9.86**
IR 80555 A × Pusa Sungandha 3	9.20*	4.53	16.62**	18.48*	18.57*	0.46	-17.61**	-22.01**	-26.04**	47.50**	50.08**	-7.56**	4.76	-9.23**	-26.24**
IR 58025 A × Pusa Sungandha 3	-7.73*	-11.69**	-1.47	-24.17**	14.53	-2.13	-54.91**	-57.32**	-59.52**	-13.60*	-12.08*	-45.85**	15.33**	1.53	-19.98**
IR 79156 A × Pusa Sungandha 3	5.35	0.84	12.51**	14.39	13.50	-3.01	-57.12**	-59.41**	-61.50**	-12.24	-10.70*	-45.00**	-8.19**	-6.88**	-24.33**
IR 80555 A × Raghuvansi 4	3.50	1.36	13.09**	31.53**	42.28**	21.58**	-21.87**	-32.13**	-35.64**	-4.08	-0.40	-38.43**	-4.47	-17.23**	-32.74**
IR 58025 A × Raghuvansi 4	-3.59	-5.59	5.33	-18.76**	22.70**	4.84	-21.20**	-31.56**	-35.09**	-5.92	-1.96	-39.62**	-1.80	-25.50**	-39.46**
IR 79156 A × Raghuvansi 4	3.85	1.70	13.47**	-17.37*	-10.62	-23.63**	-30.00**	-39.20**	-42.34**	-22.55**	-19.29**	-50.29**	-16.11**	-14.91**	-30.85**
Mean heterosis (%) of 51 crosses	-2.23	-7.40	3.31	-10.47	9.22	-6.67	-33.87	-34.62	-38.00	3.77	11.76	-31.16	-18.65	-20.19	-35.14
Range of heterosis	-29.42-21.15	-26.59-4.53	-18.10-16.62	-40.98-57.27	-36.01-42.55	-45.32-21.80	-66.71-2.92	-67.80-0.61	-69.46--4.59	-49.12-82.43	-47.50-58.35	-69.66--2.47	-57.49-23.98	-53.83-16.81	-62.48--5.08

Table 6: Cont.........

Crosses	Grain yield per plant			Harvest index			Kernel length			Kernel breadth			L:B ratio		
	BP	SV1	SV2	BP	SV1	SV2	BP	SV1	SV2	BP	SV1	SV2	BP	SV1	SV2
IR 58025 A × Taraori Basmati	9.84*	-20.31**	-21.74**	4.07	77.07**	4.38	3.08**	1.94**	14.52**	0.55	0.00	-16.64**	2.54**	1.93**	37.37**
IR 80555 A × Usar 1	21.60**	-31.49**	-46.00**	86.61**	53.82**	-9.32**	0.06	-20.04**	-10.17**	17.35**	57.33**	31.51**	-14.67**	-49.16**	-31.48**
IR 58025 A × Usar 1	43.16**	26.82**	-0.04	81.63**	49.71**	-11.76**	-2.54**	-22.11**	-12.50**	13.52**	52.20**	26.87**	-14.10**	-48.82**	-31.03**
IR 79156 A × Usar 1	29.08**	14.35**	-9.88**	90.61**	57.12**	-7.46*	1.62**	-18.79**	-8.77**	9.84**	47.25**	22.75**	-7.48**	-44.87**	-25.71**
IR79156 A × IR 65192-2B-8-1	33.09**	1.41	-20.07**	14.32**	73.17**	2.09	-3.57**	-22.58**	-13.02**	7.58**	17.03**	-2.44**	-10.36**	-33.87**	-10.87**
IR 58025 A × Swarna	9.49*	-7.57*	-27.16**	31.16**	76.89**	4.28	8.33**	-18.98**	-8.97**	-25.85**	3.30**	-13.89**	45.03**	-21.51**	5.78**
IR 79156 A × Swarna	60.19**	35.22**	6.57**	48.61**	83.99**	18.15**	-1.48**	-26.32**	-17.22**	2.65**	41.76**	18.17**	-3.88**	-47.98**	-29.90**
IR 80555 A × Pusa Sungandha3	24.42**	0.51	-20.79**	16.88**	82.11**	7.36*	-3.80**	-1.71**	10.43**	0.35	4.03**	-13.28**	-4.09**	-5.46**	27.41**
IR 58025 A × Pusa Sungandha3	33.40**	7.76*	-15.07**	15.51**	79.98**	6.10	-8.95**	-6.97**	4.51**	29.33**	34.07**	11.76**	-29.58**	-30.59**	-6.46**
IR 79156 A × Pusa Sungandha3	24.13**	0.24	-51.89**	-30.85**	7.74	-36.49**	-3.03**	-0.92**	11.31**	4.59**	8.42**	-9.62**	-7.33**	-8.66**	23.10**
IR 80555 A × Raghuvansi 4	37.26**	-7.26*	-57.82**	-27.45**	6.49	-37.23**	1.62**	-4.43**	7.37**	0.00	3.85**	-13.44**	1.76**	-7.90**	24.12**
IR 58025 A × Raghuvansi 4	26.97**	-14.31**	-32.47**	28.94**	89.25**	11.56**	-4.91**	-10.57**	0.47	-7.58**	-4.03**	-20.00**	2.97**	-6.81**	25.59**
IR 79156 A × Raghuvansi 4	26.71**	-14.35**	-32.51**	12.78**	65.53**	-2.42	10.84**	-8.91**	2.33**	-2.12**	1.65*	-15.27**	-0.93	-10.34**	20.84**
Mean heterosis (%) of 51 crosses	-14.55	27.09	-38.34	1.78	59.36	-5.87	-2.30	-12.02	-1.16	1.23	19.88	-0.07	-2.75	-24.76	1.41
Range of heterosis	-55.18-60.19	-50.35-35.22	-57.82-6.57	-50.51-90.61	-5.49-97.49	-44.28 -18.15	-15.57 -10.84	-28.35 -2.54	-19.50-15.20	-25.85 -29.33	-4.03 -57.33	-20.00 -31.51	-29.58 -45.03	-49.16 -1.93	-31.48-37.37

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

Table 7: Relationship of positive heterobeltiosis for grain yield per plant with desirable heterobeltiosis of other characters in aromatic and non aromatic rice hybrids

CharactersCrosses	Seed yield per hill	Panicle length	Spikelets per panicle	Spikelets fertility	1000-seed weight	Biological yield per hill	Harvest -index	Kernel length	Kernel with	L:B ratio
IR 79156A × Swarna	60.19%	0	0	-	0	+	+	+	+	-
IR 58025 A × Usar 1	43.16%	+	-	-	+	+	+	+	+	-
IR 80555 A × Raghuvansi 4	37.26%	0	+	-	0	0	-	-	0	+
IR 58025 A × Pusa Sugandha 3	33.40%	-	-	-	-	+	+	+	+	-
IR 79156 A × IR 65192-4B-8-1	33.06%	-	-	-	-	-	+	+	+	-
IR 79156 A × Usar 1	29.08%	+	+	-	+	-	+	+	+	-
IR 58025 A × Raghuvansi 4	26.97%	0	-	-	0	0	+	-	-	+
IR 79156 A × Raghuvansi 4	26.71%	0	-	-	-	-	+	+	-	0
IR 80555A × Pusa Sugandha 3	24.42%	+	+	-	+	0	+	-	0	-
IR79156 A × Pusa Sugandha 3	24.13%	0	0	-	0	-	-	-	+	-
IR 80555 A × Usar 1	21.60%	0	+	0	+	-	-	-	-	0
IR 58025 A × Taraori Basmati	9.84%	0	-	-	+	+	0	+	0	+
IR 58025 A × Swarna	9.49%	0	-	-	+	-	+	+	-	+

+ = Significant and positive heterosis; - = Significant and negative heterosis; 0 = Non-significant heterosis.

Table 8: Relationship of positive and significant standard heterosis over SV_1 (Pusa Basmati 1) and SV_2 (Sarjoo 52) for grain yield per plant with standard heterosis for other characters

CharactersCrosses	Grain yield per hill	Panicle length	Spikelets per panicle	Spikelets fertility	1000-seed weight	Biological yield per hill	Harvest-index	Kernel length	Kernel Breadth	L:B ratio
			SV_1							
IR 79156 A × Swarna	35.22%	-	0	-	+	+	+	-	+	-
IR 58025 A × Usar 1	26.82%	-	0	-	+	+	+	-	+	-
IR 79156 A × Narendra Usar 3	25.06%	-	0	0	+	0	+	-	+	-
IR 58025 A × Pankaj	23.29%	-	0	-	+	+	+	-	+	-
IR 79156 A × Usar 1	14.35%	0	0	-	+	-	+	-	+	-
IR 58025 A × Pusa Sugandha 3	7.76%	-	0	-	+	0	+	-	+	-
SV_2										
IR 79156 A × Swarna	6.57%	-	0	-	-	-	+	-	+	-

+ = Significant and positive heterosis; - = Significant and negative heterosis; 0 = Non-significant heterosis.

3, IR 58025 A × Pankaj and IR 79156 A × Usar 1 for non-aromatic rice and IR 58025 A × Pusa Sugandha 3, IR 80555 A × Pusa Sugandha 3 and IR 79156 A × Pusa Sugandha 3 for aromatic rice. The cross, IR 79156 A × Swarna, showed highest mean performance (34.48 g), heterobeltiosis (60.19%), standard heterosis over SV_1 (35.22%) and SV_2 (6.57%) for grain yield per hill, while the best cross involving the aromatic parent, IR 58025 A × Pusa Sugandha 3, produced high mean grain yield per hill (27.48 g) with significant heterobeltiosis (33.40%) and standard heterosis over SV_1 (7.76%). These eight crosses merit further testing and evaluation in adaptive trails to find out their feasibility for recommendation as hybrid cultivars for their respective groups. Based on the above discussion; two crosses one in aromatic and other in non-aromatic rice group (IR 58025 A × Pusa Sugandha 3 and IR 79156 A × Swarna, respectively) emerged as most desirable cross combinations on the basis of their gca, sca and heterosis performance in reference to yield and other related traits.

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