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HETEROSIS AND COMBINING ABILITY ANALYSIS FOR GRAIN YIELD AND ITS COMPONENT TRAITS FOR THE DEVELOPMENT OF RED RICE (*ORYZA SATIVA* L.) HYBRIDS

Yogita Shrivas *et al.*,

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YOGITA SHRIVAS*, PARMESHWAR SAHU, DEEPAK SHARMA AND NIDHI KUJUR
Department of Genetics and Plant Breeding,
Indira Gandhi Krishi Vishwavidyalaya, Raipur - 492 012 (C.G.)
e-mail: yogita.shrivas30@gmail.com

ABSTRACT

The nature and magnitude of heterosis and combining ability on grain yield and its component traits were studied in 24 red rice hybrids involving three CMS lines, eight testers and thirteen characters using line × tester analysis at Research cum Instructional Farm, College of Agriculture, Indira Gandhi Krishi Vishwavidyalaya, Raipur (C.G.), India, during Kharif 2014. Analysis of variance revealed that variance due to the line x tester was significant for almost all the characters. Combining ability analysis revealed presence of non-additive gene action for most of the characters. The line, CRMS 32A and the testers, Pavizham and Krishna arjuna were identified as good general combiner (on the basis of GCA effects) and the hybrids IR 79156A/Bharda, CRMS 32A/Makom, CRMS 31A/Pavizham, IR 79156A/Revathy, IR 79156A/Karishma, CRMS 32A/Pavizham, CRMS 31A/Karishma and CRMS 32A/Revathy were identified as good combinations (on the basis of SCA effects) for grain yield per plant and other related traits. Three crosses viz., CRMS 31A/Krishna arjuna, CRMS 32A/Krishna arjuna and CRMS 32A/Pavizham showed significant heterosis (over mid parents) for grain yield and many yield attributing traits. These findings could be used for exploitation of heterosis in hybrid breeding program.

***Corresponding author**

INTRODUCTION

Rice has been one of the world's most important food crops, feeding more than half of the world's population (Khush, 1997). In the Asia and Pacific region, rice is the main staple food and the most important source of employment and income for rural people (Hossain, 1998). Future food security of major rice growing countries lies in the development of hybrid rice varieties which have potential to increase production and productivity with good quality. To achieve targeted food production of increasing population as well as decreasing cultivated area, hybrid rice technology is very useful.

Even though red rice has been around for centuries, it started being used in the 1970s in the united states has a natural healing remedy for different health ailments ranging from digestive problems, circulatory problems to high cholesterol levels. It contains monacolins, which are naturally occurring statins. These statins are known to limit cholesterol synthesis. One of the most potent monacolins is lovastatin, which has been used in pharmaceutical drugs (Gordon, 2009).

A defining feature of red rice is the dark pigmented pericarp (bran). The vast majority of modern domesticated rice varieties lack proanthocyanidin pigment in the pericarp; this domestication trait arose through human selection for loss-of-function mutation at the *Rc* locus, which encodes a "*bHLH*" regulatory protein in the proanthocyanidin synthesis pathway. Red rice germplasms are often inferior to commercial cultivars because of several agronomically undesirable features such as poor plant type, spreading habit, high grain shattering, long awn, purple pericarp and/or red kernel and low yield. But they can serve as a good source of resistance against several; biotic and abiotic stresses like drought and insect pest and diseases along with high nutritive value *viz*., high iron and zinc content which is very useful particularly for anemic women. Development of hybrids of red rice can transfer desirable features of these agronomically undesirable genotypes to the agronomically desirable genotypes. Thus hybrid rice technology is one of the best options to develop high yielding red rice hybrid to overcome malnutrition problem of tribal people where rice is major food grain (Gross *et al*., 2010).

Similar work has been done by many researchers *viz*., Bagheri and Jelodar (2010), Mirarab *et al*. (2011), Amudha and Thiyagarajan (2011), Hussain and Sanghera (2012), Padmavathi *et al*. (2012), Latha *et al*. (2013), Pratap *et al*. (2013), Ghara *et al*. (2014), Bhati *et al*. (2015) and Singh *et al*. (2015) to study the combining ability and heterosis for the development of hybrid rice varieties.

Breeding strategies for developing the hybrids with high yield potential and better grain quality require the expected level of heterosis and combining ability. Several methods like *per se* performance, genetic diversity, combining ability, have been attempted to select the parents. Among them combining ability analysis offers a powerful tool for estimating the value of a parent to produce superior hybrid. The combining ability analysis also provides information on additive and dominance variance. Its role is important to decide parents, crosses and appropriate breeding procedure to be followed to select desirable segregants (Salgotra *et al*. 2009). The success of future hybrid rice programme depends upon identification of parents having good combining ability with higher magnitude of heterosis. Line × tester technique (Kempthorne, 1957) is useful in deciding the relative ability of female and male lines to produce desirable hybrid combinations. It also provides information on genetic components and enables the breeders to choose appropriate breeding methods for hybrid variety or cultivar development programmes.

The present investigation work was therefore carried out with the objective to assess combining ability based on mean performance, genetic components and heterosis controlling some economic traits in red rice.

MATERIALS AND METHODS

The present study entitled was conducted at the Uni-versity Research cum Instructional Farm, Department of Genetics and Plant Breeding, College of Agriculture, Indira Gandhi Kirshi Vishwavidyalaya, Raipur (Chhattisgarh) during *Kharif* 2013 and *Kharif* 2014. It is situated at 21°16′ N Latitude and 81°36′ E longitude at an altitude of 289.60 meters above mean sea level. It comes under sub-humid region receiving an average rainfall of 1400 mm annually, of which about 92 percent is received during rainy season between June to September and remaining 8 percent during winter season between October to March. The experimental material comprised of three CMS lines ('IR 79156A', 'CRMS 31A' and 'CRMS 32A') used as females which have cytoplasm derived from a WA and Kalinga cytoplasmic source and eight testers ('Bharda', 'Pavizham', 'Aruna', 'Makom', 'Panchami', 'Revathy', 'Karishma' and 'Krishna arjuna') used as males and resulting 24 F_1 hybrids obtained from line × tester mating design (Kempthorne, 1957). The crosses were made during *Kharif* 2013. Three checks *viz*. Jyoti, Indira Sona and Bagdi dhan were also included to evaluate the standard heterosis. The twenty one days old seedlings of 24 F_1 hybrids along with their parents were transplanted in the main field during *Kharif* 2014 at Research farm, Indira Gandhi Krishi Vishwavidyala, Raipur, Chhattisgarh. The experiment was conducted as randomized complete block design with two replications with inter-row and intra-row spacing of 20 cm having a plot size of 5 m x 1 m^2. All recommended agronomical practices were followed to raise the ideal crop stand. Observations were recorded on thirteen agro-morphological characters such as days to 50 per cent flowering, plant height (cm), number of productive tillers per plant, panicle length (cm), pollen fertility (%), number of fertile spikelets per panicle, number of sterile spikelets per panicle, total number of spikelets per panicle, spikelet fertility (%), 100 grain weight (g)/seed index, grain yield per plant (g), biological yield per plant (g) and harvest index (%). The mean data were recorded on five randomly selected plants from parents and F_1's from each replication. Heterosis was estimated from mean values according to the Fehr (1987).

Heterosis for each trait was worked out by utilizing the overall mean of each hybrid over replication for each trait.

Relative heterosis was estimated as per cent deviation of hybrid value from its mid parental value. The formula used for estimating relative heterosis is under:

$$di = (\overline{F1} - \overline{MP}/\overline{MP}) \times 100$$

Where,

di = Heterosis over mid parental value (relative heterosis)

F_1 = Mean hybrid performance

$\overline{MP}$ = Mid parental value *i.e.,* the arithmetic mean of two parents involved in the respective cross combination.

Heterobeltosis was calculated as the deviation of hybrid from the better parent as under:

$$dii = (\overline{F1} - \overline{BP}/\overline{BP}) \times 100$$

Where,

dii = Heterobeltosis *i.e.*, heterosis over better parent

$\overline{F1}$ = Mean hybrid performance

$\overline{BP}$ = Average performance of better parent in the respective cross combination.

Standard heterosis was calculated as the deviation of hybrid from the standard variety as under:

$$diii = (\overline{F1} - \overline{SV}/\overline{SV}) \times 100$$

Where,

diii = Heterosis over standarad variety *i.e.,* standard heterosis

$\overline{FI}$ = Mean hybrid performance,

$\overline{SV}$ = Average performance of standarad variety.

The significance of different types of heterosis was carried out by adopting 't test' as suggested by Nadarajan and Gunasekaran (2005) as given below:

$$t(\text{relativeheterosis}) = \frac{\overline{Fij} - \overline{MPij}}{SE} \times 100$$

$$t(\text{heterobeltiosis}) = \frac{\overline{Fij} - \overline{BPij}}{SE} \times 100$$

$$t(\text{s tan ard}) = \frac{\overline{Fij} - \overline{SV}}{SE} \times 100$$

Where,

Fij = Mean of ijth cross

MPij = Mid parental value for i, jth cross

BPij = Better parental value of i, jth cross

SV = Standarad variety value

SE = Standard error of heterosis

Standard error:

$$\text{Relative heterosis} = \sqrt{\frac{3Me}{2r}}$$

$$\text{Heterobeltiosis and Standard heterosis} = \sqrt{\frac{2Me}{2r}}$$

However, combining ability analysis was done using line × tester method (Kempthorne, 1957). The variances for general combining ability (GCA) and specific com-bining ability (SCA) were tested against their respective error variances derived from ANOVA reduced to mean level. Significance test for GCA and SCA effects were performed using t-test.

Significance of GCA effects of lines is tested as:

$$t = \frac{g_i}{SE(g_i)}$$

Signicance of GCA effects of testers is tested as:

$$t = \frac{g_j}{SE(g_j)}$$

Significance of SCA effects of hybrids is tested as:

$$t = \frac{s_{ij}}{SE(s_j)}$$

RESULTS AND DISCUSSION

Analysis of variance:

The analysis of variance for combining ability of all the traits under study has been presented in the Table 1. The variance due to treatments was highly significant for all the characters under study. The variance due to parents was highly significant for all the characters. The variance due to hybrids was also found highly significant for all the characters except seed index (100 grain weight). The variance due to parent vs. hybrids was also found highly significant for most of the characters except productive tiller per plant, seed index, biological yield per plant. The variance due to lines was found non significant for all the traits under study due to less number of entries except days to 50% flowering, productive tiller per plant, fertile spikelets per panicle and total spikelets per panicle. The variance due to testers was found highly significant for nine characters *viz*., days to 50% flowering, panicle length, fertile spikelets per panicle, sterile spikelets per panicle, pollen fertility percentage, spikelet fertility percentage, grain yield per plant, biological yield per plant, harvest index. The variance due to line x tester was recorded highly significant for all the characters except panicle length and seed index. This finding suggested that sufficient variability is available in the material used for study which indicated that they are suitable for genetic studies as reported by Singh *et al*. (2015). Similar finding have been also reported by Akter *et al*. (2010) for treatment, crosses, parent vs. crosses, Line x Tester interaction, parents except for grain yield per plant, and testers except for panicle length, spikelets fertility and grain yield, Mirarab *et al*. (2011) for treatments, parents, crosses except for seed index, lines except for tiller per plant, fertile spikelets per panicle, total spikelets per panicle, testers except for fertile spikelets per panicle, grain yield per plant, line x tester interaction, and parents vs. crosses except for tiller per plant, Sharma *et al*. (2012) for lines except for days to 50% flowering, seed index, grain yield per plant, testers except for plant height, tiller per plant, total spikelets per panicle, seed index, and line x tester interactions except for panicle length and seed index. Similar findings were reported by Ghara *et al*. (2014) for genotypes, crosses, lines, testers and line x tester interactions for tiller number, plant height, days to 50% flowering, panicle length, number of spikelets per panicle, spikelets fertility and grain yield traits.

GCA and SCA variance

Table 1: Analysis of variance for line × tester and combining ability for grain yield and component traits in red rice

Sources	DF	1	2	3	4	5	6	7	8	9	10	11	12	13
Replication	1.00	2.54	3.83	7.44	-0.26	313.10	808.83	2128.17	16.88	10.70	0.04	8.38	1.38	57.14
Treatment	34.00	55.51**	79.44**	8.90**	9.05**	5098.50**	10826.04**	5179.09**	2276.61**	1743.52**	0.06**	48.71**	176.99**	423.81**
Parent	10.00	71.75**	94.88**	5.36**	13.50**	729.01**	492.54*	1835.46**	3343.18**	102.70**	0.13**	20.95**	152.88**	76.98**
Crosses	23.00	47.60**	75.49**	10.84**	6.13**	6186.50**	8052.13**	3747.11**	1374.58**	1285.01**	0.03	33.45**	195.05**	368.29**
Parent vs Hybrid	1.00	75.23**	17.33*	0.04	31.64**	23769.53**	179956.70**	71551.25**	12357.49**	28987.42**	0.02	677.39**	2.56	5169.00**
Line Effect	2.00	152.06**	71.34	27.74*	8.24	6301.26*	8089.88	17861.50**	504.64	670.18	0.02	1.51	103.62	39.48
Tester Effect	7.00	66.02*	117.97	14.64	11.53**	15099.45**	18078.04**	1982.58	3786.49**	3510.52**	0.04	75.56**	389.94**	982.09**
Line × Tester Eff.	14.00	23.47**	54.84**	6.53**	3.13	1713.63**	3033.78**	2613.03**	292.90**	260.09**	0.03	16.96**	110.67**	108.37**
Error	34.00	4.16	3.11	1.31	1.89	81.48	223.87	418.83	2.70	2.07	0.02	1.49	5.60	10.04
Total	69.00	29.41	40.72	5.10	5.40	2564.63	5456.68	2806.31	1123.42	860.33	0.04	24.82	89.99	214.44
Variance GCA		7.78	3.62	1.33	0.61	816.79	913.65	664.46	168.42	166.39	0.00	1.96	12.37	36.58
variance SCA		9.65	25.87	5.88	2.19	816.07	1404.96	2403.62	108.68	125.65	0.00	7.73	107.86	103.35
Variance GCA/SCA		0.81	0.14	0.23	0.28	1.00	0.65	0.28	1.54	1.30	0.00	0.25	0.11	0.35

*Significant at p=0.05% level, **Significant at p=0.01% level. 1: Days to 50% flowering, 2: Plant height (cm), 3: Productive tiller per plant, 4: Panicle length (cm), 5: Fertile spikelet per panicle, 6: Sterile spikelet per panicle, 7: Total spikelet per panicle, 8: Pollen fertility (%), 9: Spikelet fertility (%), 10: Seed index (g), 11: Grain yield per plant (g), 12: Biological yield per plant (g), 13: Harvest index (%)

Table 2: General combining ability (GCA) effects and mean performance of different parents for different characters under study

Parent/Character	1	2	3	4	5	6	7	8	9	10	11	12	13
Lines													
IR 79156A	-3.50**	1.97**	1.07**	-0.32	-19.73**	-18.25**	-37.98**	-4.56**	-4.06**	0.02	-0.34	-0.50	0.30
	86.00	81.42	12.45	27.31	99.35	62.10	161.45	0.02	61.48	2.09	13.02	43.26	30.16
CRMS 31 A	2.31**	-2.23**	.39	-0.50	-0.24	25.12**	24.88**	-1.72**	-3.40**	0.02	0.09	2.76**	-1.70**
	93.00	85.90	8.60	26.50	132.11	49.40	181.50	0.02	72.86	1.87	16.23	47.10	34.46
CRMS 32 A	1.19**	0.25	-1.47**	0.82*	19.96**	-6.87*	13.09**	6.27**	7.46**	-0.04	0.25	-2.26**	1.40**
	100.00	84.20	9.55	25.31	127.42	55.69	183.10	0.01	69.59	1.83	14.06	40.68	34.54
SE (Lines)	0.34	0.30	0.20	0.25	0.98	2.97	3.60	0.28	0.26	0.02	0.19	0.41	0.43
Testers													
Bharda	6.35**	-1.5*	2.78**	-0.14	-40.84**	50.96**	10.12	-19.54**	-20.43**	-0.10*	-3.32**	17.53**	-13.50**
	97.50	88.30	9.75	19.85	72.42	16.24	88.66	89.45	81.60	1.61	13.68	31.36	43.88
Pavizham	-2.81**	2.63**	-1.72**	0.91	58.10**	-81.68**	-23.58**	34.98**	33.32**	-0.07	5.07**	-6.96**	19.64**
	93.50	91.90	8.10	20.70	97.80	17.16	114.96	89.35	85.07	1.93	10.29	22.95	45.12
Aruna	-3.98**	0.03	-0.34	0.93	12.83**	-11.01	1.82	3.48**	4.50**	0.14**	-0.41	-5.98**	0.32
	97.00	93.00	7.25	24.53	102.82	24.78	127.61	91.02	80.61	2.39	7.69	25.71	29.90
Makom	-1.65*	-4.02**	1.73**	0.39	-28.35**	34.85**	6.50	-13.87**	-12.81**	0.01	-1.36**	1.08	-4.74**
	87.00	85.50	9.10	22.67	104.81	44.79	149.60	85.93	70.05	2.27	15.79	36.16	43.67
Panchami	0.19	-7.97**	-0.22	-1.06*	-55.35**	46.19**	-9.16	-27.29**	-26.14**	-0.07	-3.97**	-1.48	-12.97**
	94.50	89.60	7.40	21.30	92.65	23.29	115.94	86.42	79.84	2.40	8.35	25.06	33.37
Revathy	-1.81*	3.41**	-1.21**	-2.9**	-25.08**	2.03	-23.06**	-8.95**	-8.29**	0.05	-1.29**	-4.58**	-3.81**
	103.00	103.50	6.20	19.78	94.08	29.28	123.36	85.88	76.33	2.29	8.64	26.36	32.94
Karishma	1.85*	5.9**	0.29	1.35*	-9.72**	40.55**	30.83**	-9.86**	-9.41**	-0.01	-0.38	4.62**	-3.85**
	105.50	99.50	9.30	22.39	109.11	45.14	154.26	81.35	70.89	2.28	9.40	35.43	26.49
Krishna arjuna	1.85*	1.53*	-1.31**	0.51	88.41**	-81.88**	6.53	41.05**	39.27**	0.04	5.64**	-4.22**	18.91**
	94.00	97.10	8.60	22.75	136.41	28.64	165.06	89.55	82.56	2.09	15.39	45.05	34.30
SE (Testers)	0.64	0.57	0.38	0.46	1.83	5.56	6.73	0.53	0.49	0.04	0.36	0.77	0.81

*Significant at p = 0.05% level, **Significant at p = 0.01% level. 1: Days to 50% flowering, 2: Plant height (cm), 3: Productive tiller per plant, 4: Panicle length (cm), 5: Fertile spikelet per panicle, 6: Sterile spikelet per panicle, 7: Total spikelet per panicle, 8: Pollen fertility (%), 9: Spikelet fertility (%), 10: Seed index (g), 11: Grain yield per plant (g), 12: Biological yield per plant (g), 13: Harvest index (%)

A comparison of the magnitude of variance components due to GCA and SCA combined the nature of gene action in controlling the expression of the traits was also reported by Bhadru *et al.* (2013) and Malik and Singh (2013). The value of variance of general combining ability (variance GCA) was less than variance of specific combining ability (variance SCA) for all traits except fertile spikelets per panicle, pollen fertility percentage, spikelet fertility percentage which indicated the presence of non-additive gene action in the inheritance of concerned traits. Therefore, the hybrid breeding programme will be more useful for improvement of these traits. Similar finding (SCA > GCA) has been reported by Amudha and Thiyagarajan (2011) for days to 50% flowering, productive tillers per plant, spikelets fertility percentage and grain yield, Padmavathi *et al.* (2012) for days to 50% flowering, plant height, productive tiller per plant, panicle length, number of filled grains per panicle, spikelet fertility, test weight and grain yield, Veeresha *et al.* (2013) for days to 50% flowering, plant height, number of grain per panicle, test weight, grain yield per plant, Ghara *et al.* (2014) for days to 50% flowering, spikelets fertility %, tiller per plant, plant height, panicle length, sterile spikelets per panicle and grain yield per plant and Singh *et al.* (2015) for plant height, productive tillers, spikelets per panicle, fertile spikelets per panicle, sterile spikelets per panicle, spikelet fertility percentage, pollen fertility percentage, biological yield, grain yield, and harvest index (%).

Identification of parents based on General combining ability (GCA) effects and mean performance

GCA effects and mean performance of the parents have been given in Table 2. Significant and positive mean performance and GCA effects are preferable for almost all traits. It is evident that assessment of parents on the basis of mean performance and GCA effects separately, however, mean performance of the parents with nature of combining ability provides the criteria to select the parents for hybridization as suggested by Harer and Bapat (1982). On this basis, those parents who perform better for both mean performance and GCA effects are the good general combiner.

The results revealed that none of the parents showed significant GCA effects simultaneously in the desired direction for all the traits studied (Table 2). However, to determine the appropriate parent for subsequent hybrid red rice development, variation in GCA effects was estimated among lines and testers for all traits. Negative GCA effects were desirable for days to 50 percent flowering, plant height and sterile spikelets per panicle while in other traits, positive GCA effects were desirable. Character wise estimation of GCA effects of lines (Table 2) revealed that among the 3 lines, CRMS 32A was identified as a good general combiner for red rice varieties. This line exhibited positive GCA effect for grain yield per plant and positive and significant GCA effect for panicle length, fertile spikelets per panicle, total spikelets per panicle, pollen fertility (%), spikelet fertility (%), and harvest index (%). IR 79156A was identified to be a good combiner for days to 50 percent flowering, productive tiller per plant and CRMS 31A is a good combiner for plant height, total spikelets per panicle, biological yield per plant. Among the testers, Pavizham and Krishna arjuna were found to be good combiner for grain yield per plant and component traits. These results are similar to the findings of Salgotra *et al.* (2009), Latha *et al.* (2013) and Singh *et al.* (2015). Investigation of GCA effects revealed the good general combiner among lines and testers for grain yield and other traits. Hence, these good general combiners of males and females may be extensively used in future for hybrid red rice breeding programme.

Table 3: Specific combining ability (SCA) effects and mean performance of different hybrids for different characters under study

Hybrids/Characters	1	2	3	4	5	6	7	8	9	10	11	12	13
IR 79156A													
Bharda	-5.17**	3.66**	2.54**	0.25	15.14**	10.56	25.71*	2.62**	2.80**	0.04	3.28**	13.15**	3.97**
	91.00	96.10	15.20	24.25	21.15	187.89	209.04	13.45	10.01	2.10	4.97	65.06	7.61
Pavizham	1.50	1.28	-2.46**	0.09	-28.43**	14.83	-13.60	-4.45**	-4.66**	0.01	-4.58**	-10.50**	-4.62**
	88.50	97.83	5.73	25.14	76.53	59.51	136.03	60.90	56.31	2.09	5.50	16.92	32.16
Aruna	0.67	6.28**	0.26	0.29	-17.34**	17.17*	-0.17	-7.75**	-7.80**	-0.01	-0.30	1.96	-3.41**
	86.50	100.25	9.80	25.36	42.35	132.52	174.86	26.09	24.34	2.29	4.30	30.35	14.05
Makom	-1.67	-0.62	1.14*	-0.76	-11.71**	-13.56	-25.27*	-10.12**	-10.51**	-0.01	-2.77**	1.63	-10.06**
	86.50	89.30	12.75	23.77	6.80	147.64	154.44	6.38	4.32	2.16	0.88	37.09	2.34
Panchami	-2.50*	-0.97	0.89	-1.86**	18.30**	-32.07**	-13.77	5.77**	5.00**	-0.01	0.10	1.35	-0.78
	87.50	85.00	10.55	21.22	9.80	140.48	150.28	8.85	6.50	2.08	1.14	34.25	3.39
Revathy	2.50*	-5.76**	-0.92	2.02**	26.87**	-36.33**	-9.46	15.40**	15.28**	0.07	2.49**	-1.78	8.99**
	90.50	91.60	7.75	23.26	48.64	92.05	140.69	36.82	34.63	2.28	6.21	28.02	22.32
Karishma	5.33**	1.56	-1.22*	0.17	29.82**	7.29	37.11**	9.26**	9.58**	-0.05	2.28**	-4.45**	6.76**
	97.00	101.40	8.95	25.66	66.95	174.20	241.15	29.77	27.81	2.10	6.92	34.55	20.05
Krishna arjuna	-0.67	-5.42**	-0.22	-0.20	-32.65**	32.11**	-0.54	-10.73**	-9.68**	-0.05	-0.50	-1.36	-0.86
	91.00	90.05	8.35	24.45	102.61	76.59	179.20	60.69	57.23	2.14	10.15	28.79	35.20
CRMS 31A													
Bharda	1.52	-7.09**	-1.58**	0.56	-9.58**	-30.71**	-40.29**	1.52	-0.20	-0.07	-1.71**	-8.10**	-0.80
	103.50	81.15	10.40	24.37	15.92	189.99	205.90	15.19	7.67	1.98	0.41	47.06	0.84
Pavizham	1.69	1.53	1.57**	-0.51	45.60**	-32.02**	13.57	15.46**	13.60**	-0.10	2.57**	5.74**	0.99
	94.50	93.90	9.05	24.35	170.04	56.02	226.06	83.65	75.23	1.98	13.08	36.42	35.77
Aruna	-1.65	0.38	-0.11	-0.38	9.80**	-19.88*	-10.08	6.82**	6.18**	-0.11*	0.81	1.64	1.95
	90.00	90.15	8.75	24.50	88.98	138.84	227.81	43.50	38.98	2.19	5.84	33.29	17.41
Makom	4.52**	4.13**	1.72**	0.40	-3.16	83.25**	80.09**	-6.86**	-4.87**	-0.04	-0.93	1.66	-2.63*
	98.50	89.85	12.65	24.75	34.83	287.82	322.65	12.47	10.62	2.12	3.15	40.38	7.77
Panchami	0.69	2.93**	0.27	-0.56	5.80*	3.98	9.79	3.03**	4.80**	0.00	0.93	7.53**	3.32**
	96.50	84.70	9.25	22.34	16.79	219.90	236.69	8.94	6.96	2.08	2.40	43.68	5.49
Revathy	-1.81	-2.66**	-0.14	-0.14	-26.44**	23.26**	-3.17	-14.37**	-12.94**	0.14**	-3.91**	-6.56**	-10.43**
	92.00	90.50	7.85	20.92	14.82	195.02	209.84	9.89	7.07	2.35	0.24	26.49	0.90
Karishma	-3.48**	0.21	-1.19*	-0.42	-47.77**	-6.18	-53.95**	-14.74**	-14.70**	0.18**	1.46**	-0.02	4.08**
	94.00	95.85	8.30	24.89	8.86	204.10	212.95	8.61	4.19	2.32	6.52	42.24	15.37
Krishna arjuna	-1.48	0.58	-0.54	1.03	25.74**	-21.70*	4.05	9.13**	8.12**	0.00	0.79	-1.90	3.54**
	96.00	91.85	7.35	25.49	180.50	66.15	246.65	83.39	73.19	2.19	11.87	31.51	37.60
CRMS 32A													
Bharda	3.65**	3.43**	-0.96	-0.81	-5.56*	20.15*	14.58	-4.14**	-2.60**	0.03	-1.57**	-5.06**	-3.16*
	104.50	94.15	9.15	24.32	40.14	208.85	248.98	17.52	16.13	2.03	0.72	45.09	1.56
Pavizham	-3.19**	-2.80**	0.89	0.42	-17.17**	17.19*	0.03	-11.01**	-8.94**	0.09	2.01**	4.76**	3.63**
	88.50	92.05	6.50	26.61	127.47	73.25	200.72	65.17	63.55	2.11	12.69	30.42	41.51
Aruna	0.98	-6.65**	-0.15	0.09	7.54**	2.71	10.25	0.93	1.62*	0.11*	-0.50	-3.60**	1.46
	91.50	85.60	6.85	26.29	106.92	129.44	236.35	45.60	45.28	2.35	4.69	23.03	20.02
Makom	-2.85**	-3.50**	-2.86**	0.36	14.87**	-69.68**	-54.82**	16.98**	15.38**	0.05	3.70**	-3.29**	12.69**
	90.00	84.70	6.20	26.03	73.06	102.90	175.96	44.31	41.74	2.16	7.95	30.41	26.19
Panchami	1.81	-1.95*	-1.16*	2.42**	-24.10**	28.08**	3.98	-8.80**	-9.80**	0.01	-1.03*	-8.88**	-2.54*
	96.50	82.30	5.95	26.64	7.09	212.01	219.10	5.10	3.22	2.05	0.60	22.26	2.73
Revathy	-0.69	8.41**	1.07	-1.88**	-0.43	13.07	12.64	-1.02	-2.34**	-0.22**	1.42**	8.33**	1.44
	92.00	104.05	7.20	20.50	61.03	152.84	213.86	31.23	28.53	1.93	5.74	36.37	15.88
Karishma	-1.85	-1.77*	2.42**	0.25	17.95**	-1.11	16.84	5.48**	5.12**	-0.13*	-3.75**	4.47**	-10.84**
	94.50	96.35	10.05	26.88	94.77	177.19	271.96	36.81	34.87	1.96	1.48	41.71	3.55
Krishna arjuna	2.15*	4.85**	0.77	-0.83	6.91*	-10.41	-3.50	1.60*	1.57*	0.05	-0.29	3.27**	-2.68*
	98.50	98.60	6.80	24.95	181.86	45.45	227.31	83.85	80.01	2.19	10.96	31.66	34.47
SE (Hybrids)	0.90	0.80	0.54	0.65	2.59	7.86	9.52	0.74	0.69	0.05	0.50	1.09	1.14

*Significant at p = 0.05% level, **Significant at p = 0.01% level. 1: Days to 50% flowering, 2: Plant height (cm), 3: Productive tiller per plant, 4: Panicle length (cm), 5: Fertile spikelet per panicle, 6: Sterile spikelet per panicle, 7: Total spikelet per panicle, 8: Pollen fertility (%), 9: Spikelet fertility (%), 10: Seed index (g), 11: Grain yield per plant (g), 12: Biological yield per plant (g), 13: Harvest index (%)

Identification of hybrids based on Specific combining ability (SCA) effects and mean performance

Marilia *et al*. (2001) stated that specific combining ability (SCA) effects of hybrids alone had limited value for parental choice in breeding programme and must be used in combination with other parameters such as hybrid means and GCA of the respective parents. The hybrid combinations with high mean performance, desirable SCA estimates and involving at least one of the parents with high GCA would likely to enhance the concentration of favorable alleles (Kenga *et al*., 2004) and this is what a breeder desires to improve a trait. Similar views have been expressed by various researchers, Gnanasekaran *et al*. (2006), Bhati *et al*. (2015) and Singh *et al*. (2015) in rice. The identification of good specific combiners (hybrids) has been advised on the basis of mean performance, SCA effects estimates (Table 3).

Based on the estimates of SCA effects none of the cross combinations exhibited significant and desirable SCA effect for all the parameters simultaneously (Table 3) indicating that no specific combination was desirable for all traits. These results are in complete agreement with earlier findings (Sanghera and Hussain, 2012, Latha *et al*. 2013). Yield is ultimate goal of a rice breeding and hybrid development programme. Character wise estimation of SCA effects of hybrids (Table 3) revealed that out of 24 hybrids, nine hybrids *viz*., CRMS 31A/Bharda, CRMS 32A/Aruna, IR 79156A/ Revathy,

Table 4: Percent mid parent heterosis, heterobeltiosis and standard heterosis for different characters in red rice

Cross	Days to 50% flowering Mid	Better	Standard Jyoti	Indira sona	Bagdi dhan	Plant height (cm) Mid	Better	Standard Jyoti	Indira sona	Bagdi dhan
IR 79156A										
IR 79156A/Bharda	-0.82	5.81*	17.42**	5.81*	-2.15	13.25**	18.03**	1.48	-12.56**	-38.57**
IR 79156A/Pavizham	-1.39	2.91	14.19**	2.91	-4.84*	12.88**	20.15**	3.30	-10.99**	-37.47**
IR 79156A/Aruna	-5.46**	0.58	11.61**	0.58	-6.99**	14.95**	23.13**	5.86**	-8.78**	-35.92**
IR 79156A/Makom	0.00	0.58	11.61**	0.58	-6.99**	7.00**	9.68**	-5.70**	-18.74**	-42.92**
IR 79156A/Panchami	-3.05	1.74	12.90**	1.74	-5.91**	-0.60	4.40*	-10.24**	-22.66**	-45.67**
IR 79156A/Revathy	-4.23*	5.23*	16.77**	5.23*	-2.69	-0.93	12.50**	-3.27	-16.65**	-41.45**
IR 79156A/Karishma	1.31	12.79**	25.16**	12.79**	4.30	12.09**	24.54**	7.07**	-7.73**	-35.19**
IR 79156A/Krishna arjuna	1.11	5.81*	17.42**	5.81*	-2.15	0.89	10.60**	-4.91*	-18.06**	-42.44**
CRMS 31A										
CRMS 31A/Bharda	8.66**	11.29**	33.55**	20.35**	11.29**	-6.83**	-5.53*	-14.31**	-26.16**	-48.13**
CRMS 31A/Pavizham	1.34	1.61	21.94**	9.88**	1.61	5.62**	9.31**	-0.84	-14.56**	-39.98**
CRMA 31A/Aruna	-5.26**	-3.23	16.13**	4.65	-3.23	0.78	4.95*	-4.80*	-17.97**	-42.38**
CRMA 31A/Makom	9.44**	13.22**	27.10**	14.53**	5.91**	4.84**	5.09*	-5.12**	-18.24**	-42.57**
CRMS 31A/Panchami	2.93	3.76	24.52**	12.21**	3.76	-3.48	-1.40	-10.56**	-22.93**	-45.86**
CRMS 31A/Revathy	-6.12**	-1.08	18.71**	6.98**	-1.08	-4.44**	5.36*	-4.44*	-17.65**	-42.15**
CRMS 31A/Karishma	-5.29**	1.08	21.29**	9.30**	1.08	3.40*	11.58**	1.21	-12.78**	-38.73**
CRMS 31A/Krishna arjuna	2.67	3.23	23.87**	11.63**	3.23	0.38	6.93**	-3.01	-16.42**	-41.29**
CRMS 32A										
CRMS 32A/Bharda	5.82**	7.18**	34.84**	21.51**	12.37**	9.16**	11.82**	-0.58	-14.33**	-39.82**
CRMS 32A/Pavizham	-8.53**	-5.35*	14.19**	2.91	-4.84*	4.54*	9.32**	-2.80	-16.24**	-41.16**
CRMA 32A/Aruna	-7.11**	-5.67**	18.06**	6.40**	-1.61	-3.39	1.66	-9.61**	-22.11**	-45.29**
CRMA 32A/Makom	-3.74	3.45	16.13**	4.65	-3.23	-0.18	0.59	-10.56**	-22.93**	-45.86**
CRMS 32A/Panchami	-0.77	2.12	24.52**	12.21**	3.76	-5.29**	-2.26	-13.09**	-25.11**	-47.40**
CRMS 32A/Revathy	-9.36**	-8.00**	18.71**	6.98**	-1.08	10.87**	23.57**	9.87**	-5.32**	-33.49**
CRMS 32A/Karishma	-8.03**	-5.50**	21.94**	9.88**	1.61	4.90**	14.43**	1.74	-12.33**	-38.41**
CRMS 32A/Krishna arjuna	1.55	4.79*	27.10**	14.53**	5.91**	8.77**	17.10**	4.12*	-10.28**	-36.98**

*Significant at p = 0.01% level, **Significant at p = 0.05% level

Table 4a: Percent mid parent heterosis, heterobeltiosis and standard heterosis for different characters in red rice (Continuous)

Cross	Productive tiller per plant Mid	Better	Standard Jyoti	Indira sona	Bagdi dhan	Panicle length (cm) Mid	Better	Standard Jyoti	Indira sona	Bagdi dhan
IR 79156A										
IR 79156A/Bharda	36.94**	22.09*	100.00**	98.69**	118.71**	2.84	-11.20*	2.32	-11.79*	-3.44
IR 79156A/Pavizham	-44.28**	-54.02**	-24.67	-25.16	-17.63	4.73	-7.95	6.08	-8.55	-1.70
IR 79156A/Aruna	-0.51	-21.29*	28.95	28.10	41.01*	-2.16	-7.14	7.00	-7.75	6.14
IR 79156A/Makom	18.33	2.41	67.76**	66.67**	83.45**	-4.88	-12.96*	0.30	-13.53**	2.33
IR 79156A/Panchami	6.30	-15.26	38.82*	37.91*	51.80**	-12.69*	-22.30**	-10.46	-22.81**	-0.47*
IR 79156A/Revathy	-16.89	-37.75**	1.97	1.31	11.51	-1.21	-14.83**	-1.86	-15.39**	-3.58
IR 79156A/Karishma	-17.70	-28.11**	17.76	16.99	28.78	3.26	-6.04	8.27	-6.66	1.76
IR 79156A/Krishna arjuna	-20.67*	-32.93**	9.87	9.15	20.14	-2.32	-10.47*	3.16	-11.06*	2.50
CRMS 31A										
CRMS 31A/Bharda	13.35	6.67	36.84*	35.95*	49.64**	5.16	-8.04	2.83	-11.35*	-5.10
CRMS 31A/Pavizham	8.38	5.23	19.08	18.30	30.22	3.18	-8.11	2.74	-11.42*	-3.36
CRMA 31A/Aruna	10.41	1.74	15.13	14.38	25.90	-3.98	-7.55	3.38	-10.88*	4.48
CRMA 31A/Makom	42.94**	39.01**	66.45**	65.36**	82.01**	0.67	-6.60	4.43	-9.97	0.68
CRMS 31A/Panchami	15.63	7.56	21.71	20.92	33.09	-6.53	-15.70**	-5.74	-18.73**	-2.13
CRMS 31A/Revathy	6.08	-8.72	3.29	2.61	12.95	-9.59	-21.06**	-11.73*	-23.90**	-5.24*
CRMS 31A/Karishma	-7.26	-10.75	9.21	8.50	19.42	1.82	-6.08	5.02	-9.46	0.10
CRMS 31A/Krishna arjuna	-14.53	-14.53	-3.29	-3.92	5.76	3.51	-3.81	7.55	-7.28	0.84
CRMS 32A										
CRMS 32A/Bharda	-5.18	-6.15	20.39	19.61	31.65	-3.91	-3.91	2.62	-11.53*	3.64
CRMS 32A/Pavizham	-26.35*	-31.94*	-14.47	-15.03	-6.47	17.85**	5.14	12.28*	-3.20	-7.53
CRMA 32A/Aruna	-18.45	-28.27*	-9.87	-10.46	-1.44	14.28**	3.87	10.93	-4.37	-5.79
CRMA 32A/Makom	-33.51**	-35.08**	-18.42	-18.95	-10.79	4.45	2.84	9.83	-5.31	2.05
CRMS 32A/Panchami	-29.79*	-37.70**	-21.71	-22.22	-14.39	11.05*	5.25	12.41*	-3.09	-1.76
CRMS 32A/Revathy	-8.57	-24.61*	-5.26	-5.88	3.60	-12.04*	-19.00**	-13.50*	-25.43**	-4.57**
CRMS 32A/Karishma	6.63	5.24	32.24*	31.37*	44.60**	19.23**	6.20	13.42*	-2.22	-7.68
CRMS 32A/Krishna arjuna	-25.07*	-28.80*	-10.53	-11.11	-2.16	4.61	-1.42	5.27	-9.24	-2.33

IR 79156A/Krishna arjuna, CRMS 32A/Makom, CRMS 32A/Pavizham, CRMS 31A/Revathy, CRMS 32A/Panchami, and CRMS 32A/Karishma have shown the negative significant SCA effects for shortening plant height with mean performance ranged from 81.15 to 96.35 cm. Similarly, for growth duration, five hybrids *viz*., IR 79156A/Bharda, CRMS 31A/Karishma, CRMS 32A/Pavizham, CRMS 32/Makom and IR 79156A/Panchami have shown the negative significant SCA effects with mean performance ranged from 87.50 to 94.00 days, which were desirable for early hybrid. Five hybrids showed positive significant SCA effects for productive tiller per plant. Only two hybrids showed significant positive SCA effects for

Table 4b: Percent mid parent heterosis, heterobeltiosis and standard heterosis for different characters in red rice (Continuous)

Cross	Fertile spikelet per panicle Mid	Better	Standard Jyoti	Indira sona	Bagdi dhan	Mid	Better	Sterile spikelet per panicle Standard Jyoti	Indira sona	Bagdi dhan
IR 79156A										
IR 79156A/Bharda	-69.73**	-78.71**	-76.53**	-85.54**	-84.28**	379.70**	1057.28**	446.65**	535.18**	320.80**
IR 79156A/Pavizham	-21.46**	-22.98*	-15.10	-47.67**	-43.11**	50.16	246.86**	73.12	101.16	33.27
IR 79156A/Aruna	-57.26**	-58.82**	-53.02**	-71.04**	-68.52**	205.05**	434.73**	285.55**	347.99**	196.79**
IR 79156A/Makom	-91.19**	-93.52**	-92.46**	-95.36**	-94.95**	176.26**	229.65**	329.57**	399.13**	230.67**
IR 79156A/Panchami	-88.54**	-90.14**	-89.13**	-93.30**	-92.71**	229.03**	503.18**	308.73**	374.92**	214.62**
IR 79156A/Revathy	-43.34**	-51.04**	-46.03**	-66.74**	-63.84**	101.48**	214.43**	167.82**	211.19**	106.16**
IR 79156A/Karishma	-36.30**	-38.64**	-25.72*	-54.22**	-50.23**	224.88**	285.91**	406.84**	488.91**	290.15**
IR 79156A/Krishnaarjuna	-8.98	-24.78**	13.85	-29.83**	-23.72**	68.81*	167.41**	122.84**	158.92**	71.53*
CRMS 31A										
CRMS 31A/Bharda	-79.62**	-87.95**	-82.34**	-89.12**	-88.17**	478.92**	1070.23**	452.77**	542.28**	325.50**
CRMS 31A/Pavizham	38.17**	28.71**	88.66**	16.28*	26.41**	68.34	226.55*	62.99	89.38	25.46
CRMA 31A/Aruna	-16.87**	-32.65**	-1.28	-39.15**	-33.85**	274.31**	460.24**	303.94**	369.36**	210.94**
CRMA 31A/Makom	-26.97**	-73.64**	-61.36**	-76.18**	-74.11**	511.16**	542.63**	737.42**	873.02**	544.61**
CRMS 31A/Panchami	-75.44**	-87.29**	-81.37**	-88.52**	-87.52**	505.04**	844.18**	539.80**	643.41**	392.50**
CRMS 31A/Revathy	-79.89**	-88.78**	-83.56**	-89.87**	-88.98**	395.75**	566.15**	467.40**	559.28**	336.76**
CRMS 31A/Karishma	-81.79**	-93.30**	-90.18**	-93.95**	-93.42**	331.76**	352.13**	493.81**	589.97**	357.10**
CRMS 31A/Krishnaarjuna	238.33**	32.31**	100.26**	23.43**	34.19**	69.53*	130.96*	92.46*	123.63*	48.15
CRMS 32A										
CRMS 32A/Bharda	-53.01**	-68.50**	-55.47**	-72.56**	-70.16**	480.74**	1186.40**	507.64**	606.04**	367.74**
CRMS 32A/Pavizham	58.63**	0.04	41.43**	-12.83*	-5.23	101.11**	326.99**	113.12*	147.63**	64.05
CRMA 32A/Aruna	-0.63	-16.09*	18.62	-26.89**	-20.52**	221.69**	422.30**	276.59**	337.58**	189.89**
CRMA 32A/Makom	31.87	-42.67**	-18.94	-50.04**	-45.69**	104.82**	129.75**	199.39**	247.87**	130.46**
CRMS 32A/Panchami	-93.91**	-94.44**	-92.13**	-95.15**	-94.73**	436.87**	810.30**	516.85**	616.73**	374.83**
CRMS 32A/Revathy	-32.83**	-52.11**	-32.29**	-58.27**	-54.63**	259.76**	422.07**	344.68**	416.68**	242.30**
CRMS 32A/Karishma	42.47**	-25.62**	5.15	-35.19**	-29.54**	251.45**	292.52**	415.52**	499.00**	296.83**
CRMS 32A/Krishnaarjuna	233.47**	33.31**	101.77**	24.37**	35.20**	7.79	58.69	32.24	53.65	1.79

Table 4c: Percent mid parent heterosis, heterobeltiosis and standard heterosis for different characters in red rice (Continuous)

Cross	Total spikelet per panicle Mid	Better	P Standard Jyoti	Indira sona	Bagdi dhan	ollen fertility (%) Mid	Better	Standard Jyoti	Indira sona	Bagdi dhan
IR 79156A										
IR 79156A/Bharda	67.16**	29.47*	67.89**	18.91	16.68	-69.93**	-84.96**	-83.99**	-84.52**	-85.06**
IR 79156A/Pavizham	-1.58	-15.75	9.25	-22.63	-24.08*	36.29**	-31.84**	-27.52**	-29.90**	-32.33**
IR 79156A/Aruna	20.99	8.31	40.44*	-0.53	-2.40	-42.68**	-71.34**	-68.95**	-69.97**	-71.01**
IR 79156A/Makom	-0.70	-4.34	24.03	-12.15	-13.80	-85.16**	-92.58**	-92.41**	-92.66**	-92.92**
IR 79156A/Panchami	8.35	-6.92	20.70	-14.52	-16.12	-79.53**	-89.76**	-89.47**	-89.82**	-90.17**
IR 79156A/Revathy	-1.20	-12.86	12.99	-19.97	-21.47	-14.28**	-57.13**	-56.19**	-57.62**	-59.09**
IR 79156A/Karishma	52.77**	49.37**	93.68**	37.17**	34.60**	-26.84**	-63.41**	-64.58**	-65.74**	-66.93**
IR 79156A/Krishna arjuna	9.77	8.57	43.92*	1.93	0.02	35.52**	-32.22**	-27.77**	-30.14**	-32.57**
CRMS 31A										
CRMS 31A/Bharda	52.43**	13.44	65.37**	17.12	14.93	-63.86**	-83.02**	-81.93**	-82.52**	-83.13**
CRMS 31A/Pavizham	52.51**	24.55**	81.56**	28.59*	26.17*	92.53**	-6.37**	-0.45	-3.71	-7.06**
CRMA 31A/Aruna	47.40**	25.52*	82.97**	29.58*	27.15*	-3.35	-52.21**	-48.23**	-49.93**	-51.67**
CRMA 31A/Makom	94.90**	77.77**	159.14**	83.53**	80.09**	85.15**	-85.49**	-85.16**	-85.65**	-86.14**
CRMS 31A/Panchami	59.15**	30.41*	90.10**	34.64**	32.11**	-70.67**	-89.66**	-89.37**	-89.72**	-90.07**
CRMS 31A/Revathy	37.66**	15.61	68.53**	19.36	17.12	-24.28*	-88.49**	-88.24**	-88.62**	-89.02**
CRMS 31A/Karishma	26.85*	17.33	71.03**	21.13	18.86	169.12**	-89.42**	-89.76**	-90.09**	-90.44**
CRMS 31A/Krishna arjuna	42.34**	35.89**	98.09**	40.30**	37.67**	1781.22**	-6.88**	-0.76	-4.02*	-7.35**
CRMS 32A										
CRMS 32A/Bharda	83.24**	35.98**	99.97**	41.63**	38.97**	-4.87	-80.41**	-79.15**	-79.83**	-80.53**
CRMS 32A/Pavizham	34.69**	9.62	61.21**	14.18	12.03	337.57**	-27.06**	-22.45**	-24.99**	-27.59**
CRMA 32A/Aruna	52.14**	29.08*	89.82**	34.44**	31.92**	50.22**	-49.90**	-45.73**	-47.51**	-49.33**
CRMA 32A/Makom	5.77	-3.90	41.32*	0.09	-1.79	482.77**	-48.44**	-47.27**	-49.00**	-50.77**
CRMS 32A/Panchami	46.54**	19.66	75.97**	24.63*	22.29	-87.81**	-94.10**	-93.93**	-94.13**	-94.33**
CRMS 32A/Revathy	39.57**	16.80	71.76**	21.65	19.37	43.50**	-63.64**	-62.84**	-64.06**	-65.31**
CRMS 32A/Karishma	61.23**	48.53**	118.42**	54.70**	51.79**	489.43**	-54.75**	-56.19**	-57.63**	-59.10**
CRMS 32A/Krishna arjuna	30.58**	24.15*	82.56**	29.30*	26.88*	1772.59**	-6.37**	-0.21	-3.49	-6.84**

panicle length. For fertile spikelet per panicle, eleven hybrids showed positive significant SCA effects while only three hybrids for total spikelets per panicle. Eleven hybrids for pollen fertility (%) and twelve hybrids for spikelet fertility (%) showed positive significant SCA effects. Eight hybrids *viz*., IR 79156A/Bharda, CRMS 32A/Makom, CRMS 31A/Pavizham, IR 79156A/Revathy, IR 79156A/Karishma, CRMS 31A/Karishma, CRMS 32A/Pavizham and CRMS 32A/Revathy have shown the positive significant SCA effects for grain yield per plant. Seven hybrids for biological yield and eight hybrids for harvest index have shown positive significant SCA effects. Similar results have been reported by Bagheri and Jelodar (2010) and Singh *et al.*

Table 4d: Percent mid parent heterosis, heterobeltiosis and standard heterosis for different characters in red rice (Continuous)

Cross	Spikelet fertility (%) Mid	Better	Standard Jyoti	Indira sona	Bagdi dhan	Seed index (g) Mid	Better	Standard Jyoti	Indira sona	Bagdi dhan
IR 79156A										
IR 79156A/Bharda	-86.01**	-87.73**	-86.16**	-87.98**	-86.66**	13.21*	0.29	-10.04	-11.93*	-5.59
IR 79156A/Pavizham	-23.16**	-33.82**	-22.13**	-32.37**	-24.99**	4.10	0.00	-10.30	-12.18*	-5.86
IR 79156A/Aruna	-65.75**	-69.81**	-66.35**	-70.77**	-67.58**	2.02	-4.30	-2.02	-4.08	2.84
IR 79156A/Makom	-93.44**	-93.84**	-94.03**	-94.82**	-94.25**	-1.14	-4.99	-7.58	-9.52	-3.00
IR 79156A/Panchami	-90.81**	-91.86**	-91.02**	-92.20**	-91.34**	-7.41	-13.33*	-10.86	-12.73*	-6.44
IR 79156A/Revathy	-49.75**	-54.64**	-52.12**	-58.41**	-53.87**	4.01	-0.46	-2.32	-4.37	2.52
IR 79156A/Karishma	-57.99**	-60.78**	-61.55**	-66.60**	-62.96**	-4.08	-8.09	-10.04	-11.93*	-5.59
IR 79156A/Krishna arjuna	-20.54**	-30.68**	-20.85**	-31.26**	-23.75**	2.45	2.37	-8.18	-10.11	-3.63
CRMS 31A										
CRMS 31A/Bharda	-90.07**	-90.60**	-89.39**	-90.79**	-89.78**	-10.45	5.83	-15.06*	-16.85**	-10.86
CRMS 31A/Pavizham	-4.74**	-11.58**	4.03	-9.64**	0.22	-11.80*	2.44	-15.34*	-17.12**	-11.15
CRMA 31A/Aruna	-49.21**	-51.65**	-46.10**	-53.18**	-48.08**	1.38	-8.40	-6.22	-8.19	-1.58
CRMA 31A/Makom	-85.14**	-85.43**	-85.32**	-87.25**	-85.86**	1.05	-6.68	-9.23	-11.13	-4.73
CRMS 31A/Panchami	-90.89**	-91.29**	-90.38**	-91.64**	-90.73**	-0.60	-13.31*	-10.84	-12.71*	-6.42
CRMS 31A/Revathy	-90.53**	-90.74**	-90.23**	-91.51**	-90.59**	7.25	2.56	0.64	-1.47	5.63
CRMS 31A/Karishma	-94.18**	-94.26**	-94.21**	-94.97**	-94.43**	9.25	1.64	-0.52	-2.61	4.41
CRMS 31A/Krishna arjuna	-5.82**	-11.35**	1.22	-12.08**	-2.49	5.04	4.89	-6.07	-8.05	-1.42
CRMS 32A										
CRMS 32A/Bharda	-78.66**	-80.23**	-77.69**	-80.62**	-78.51**	-7.21	10.68	-13.07*	-14.89*	-8.76
CRMS 32A/Pavizham	-17.83**	-25.31**	-12.12**	-23.67**	-15.34**	0.88	9.66	-9.38	-11.28	-4.89
CRMA 32A/Aruna	-39.71**	-43.83**	-37.38**	-45.61**	-39.68**	11.01	-1.59	0.75	-1.37	5.74
CRMA 32A/Makom	-40.23**	-40.42**	-42.28**	-49.87**	-44.40**	6.05	-4.81	-7.40	-9.35	-2.82
CRMS 32A/Panchami	-95.69**	-95.97**	-95.55**	-96.14**	-95.71**	0.55	-14.77*	-12.34*	-14.18*	-8.00
CRMS 32A/Revathy	-60.89**	-62.62**	-60.54**	-65.73**	-61.99**	-9.75	-15.64*	-17.21**	-18.95**	-13.11*
CRMS 32A/Karishma	-50.36**	-50.82**	-51.78**	-58.12**	-53.55**	-6.71	-13.99*	-15.82*	-17.58**	-11.64
CRMS 32A/Krishna arjuna	5.16**	-3.10	10.64**	-3.90*	6.59**	5.12	4.98	-5.99	-7.96	-1.33

Table 4e: Percent mid parent heterosis, heterobeltiosis and standard heterosis for different characters in red rice (Continuous)

Cross	Grain yield per plant (g) Mid	Better	Standard Jyoti	Indira sona	Bagdi dhan	Biological yield per plant (g) Mid	Better	Standard Jyoti	Indira sona	Bagdi dhan
IR 79156A										
IR 79156A/Bharda	-62.79**	-63.69**	-62.17**	-76.92**	-69.45**	74.38**	50.38**	142.20**	67.71**	52.50**
IR 79156A/Pavizham	-52.86**	-57.80**	-58.15**	-74.47**	-66.21**	-48.89**	-60.89**	-37.01**	-56.38**	-60.34**
IR 79156A/Aruna	-58.53**	-67.01**	-67.29**	-80.04**	-73.59**	-11.98	-29.84**	12.99	-21.76**	-28.86**
IR 79156A/Makom	-93.89**	-94.42**	-93.29**	-95.91**	-94.58**	-6.59	-14.26*	38.09**	-4.38	-13.06*
IR 79156A/Panchami	-89.33**	-91.24**	-91.32**	-94.70**	-92.99**	0.26	-20.83**	27.51**	-11.70	-19.71**
IR 79156A/Revathy	-42.67**	-52.31**	-52.71**	-71.15**	-61.81**	-19.52**	-35.24**	4.30	-27.78**	-34.33**
IR 79156A/Karishma	-38.34**	-46.90**	-47.35**	-67.88**	-57.48**	-12.19*	-20.13**	28.63**	-10.93	-19.01**
IR 79156A/Krishna arjuna	-28.55**	-34.06**	-22.69*	-52.83**	-37.57**	-34.80**	-36.09**	7.19	-25.78**	-32.51**
CRMS 31A										
CRMS 31A/Bharda	-96.92**	-97.52**	-96.93**	-98.13**	-97.52**	34.23**	-0.08	75.20**	21.32**	10.31
CRMS 31A/Pavizham	-24.31**	-19.46*	-0.45	-39.26**	-19.61*	-11.24*	-22.69**	35.57**	-6.12	-14.64*
CRMA 31A/Aruna	-60.14**	-64.04**	-55.55**	-72.88**	-64.11**	-22.50**	-29.32**	23.94**	-14.18*	-21.96**
CRMA 31A/Makom	-65.03**	-80.62**	-76.04**	-85.38**	-80.65**	-25.44**	-14.27**	50.34**	4.10	-5.34
CRMS 31A/Panchami	-74.07**	-85.21**	-81.72**	-88.85**	-85.24**	45.16**	-7.26	62.62**	12.61*	2.39
CRMS 31A/Revathy	-97.23**	-98.52**	-98.18**	-98.89**	-98.53**	-28.03**	-43.76**	-1.38	-31.71**	-37.90**
CRMS 31A/Karishma	-6.16	-59.82**	-50.33**	-69.69**	-59.89**	5.13	-10.33*	57.24**	8.88	-1.00
CRMS 31A/Krishna arjuna	67.58**	-26.90**	-9.64	-44.87**	-27.03**	-18.71**	-33.11**	17.29	-18.78**	-26.15**
CRMS 32A										
CRMS 32A/Bharda	-92.60**	-94.94**	-94.58**	-96.70**	-95.63**	26.51**	10.83	67.85**	16.23*	5.68
CRMS 32A/Pavizham	27.30*	-9.77	-3.37	-41.05**	-21.97**	-21.81**	-25.22**	13.25	-21.58**	-28.69**
CRMA 32A/Aruna	-59.51**	-66.64**	-64.28**	-78.20**	-71.15**	-36.07**	-43.39**	-14.26	-40.63**	-46.02**
CRMA 32A/Makom	18.37	-49.70**	-39.49**	-63.08**	-51.14**	-32.67**	-25.26**	13.20	-21.62**	-28.73**
CRMS 32A/Panchami	-95.40**	-95.74**	-95.43**	-97.21**	-96.31**	-44.14**	-45.29**	-17.14	-42.63**	-47.83**
CRMS 32A/Revathy	-39.19**	-59.22**	-56.33**	-73.36**	-64.74**	-4.99	-10.61	35.39**	-6.25	-14.76*
CRMS 32A/Karishma	-81.70**	-89.48**	-88.73**	-93.13**	-90.90**	-0.27	2.52	55.27**	7.51	-2.24
CRMS 32A/Krishna arjuna	42.19**	-28.78**	-16.50	-49.06**	-32.58**	-27.17**	-29.72**	17.87*	-18.38**	-25.79**

(2015). Specific combining ability refers chiefly to dominance variance and epistatic interaction (dominance x dominance, additive x dominance or additive x additive) and is the index to determine the usefulness of particular cross combination in the exploitation of heterosis.

Heterosis

For exploitation of hybrid breeding in red rice it is important to identify the potential restorers and maintainers from the existing red rice germplasm. Percent heterosis for grain yield and yield related traits was calculated over mid parent, better parent and check varieties. The magnitude of heterosis varied from trait to trait and cross to cross and none of the cross

Table 4f: Percent mid parent heterosis, heterobeltiosis and standard heterosis for different characters in red rice (Continuous)

Cross	Harvest index (%) MId	Better	Standard Jyoti	Indira sona	Bagdi dhan
IR 79156A					
IR 79156A/Bharda	-79.45**	-82.67**	-84.36**	-86.33**	-79.99**
IR 79156A/Pavizham	-14.58	-28.74**	-33.91**	-42.22**	-15.41
IR 79156A/Aruna	-53.21**	-53.41**	-71.12**	-74.75**	-63.03**
IR 79156A/Makom	-93.65**	-94.63**	-95.18**	-95.79**	-93.83**
IR 79156A/Panchami	-89.33**	-89.85**	-93.03**	-93.91**	-91.08**
IR 79156A/Revathy	-29.27**	-32.26**	-54.13**	-59.90**	-41.29**
IR 79156A/Karishma	-29.22**	-33.53**	-58.79**	-63.98**	-47.26**
IR 79156A/Krishna arjuna	9.21	2.62	-27.66**	-36.76**	-7.41
CRMS 31A					
CRMS 31A/Bharda	-97.86**	-98.09**	-98.28**	-98.50**	-97.80**
CRMS 31A/Pavizham	-10.11	-20.72**	-26.48**	-35.73**	-5.90
CRMA 31A/Aruna	-45.92**	-49.49**	-64.22**	-68.72**	-54.21**
CRMA 31A/Makom	-80.12**	-82.22**	-84.04**	-86.04**	-79.57**
CRMS 31A/Panchami	-83.81**	-84.07**	-88.71**	-90.13**	-85.56**
CRMS 31A/Revathy	-97.33**	-97.39**	-98.15**	-98.39**	-97.64**
CRMS 31A/Karishma	-49.57**	-55.40**	-68.41**	-72.38**	-59.57**
CRMS 31A/Krishna arjuna	9.36	9.10	-22.72**	-32.44**	-1.09
CRMS 32A					
CRMS 32A/Bharda	-95.98**	-96.41**	-96.76**	-97.17**	-95.86**
CRMS 32A/Pavizham	4.22	-8.00	-14.68*	-25.41**	9.21
CRMA 32A/Aruna	-37.89**	-42.06**	-58.86**	-64.04**	-47.35**
CRMA 32A/Makom	-33.03**	-40.03**	-46.17**	-52.94**	-31.11**
CRMS 32A/Panchami	-91.96**	-92.10**	-94.39**	-95.10**	-92.82**
CRMS 32A/Revathy	-52.96**	-54.05**	-67.37**	-71.48**	-58.24**
CRMS 32A/Karishma	-88.37**	-89.72**	-92.70**	-93.62**	-90.66**
CRMS 32A/Krishna arjuna	0.14	-0.21	-29.15**	-38.06**	-9.32

combination recorded significant heterosis for all the traits simultaneously (Table 4). These results are in agreement with the findings of Bagheri and Jelodar (2010), Hussain and Sanghera (2012) and Latha *et al*. (2013). Heterosis for grain yield along with its components is very important consideration in heterosis breeding. Yield is a complex character and ultimate aim of plant breeding. Three crosses *viz*., CRMS 31A/Krishna arjuna, CRMS 32A/Krishna arjuna and CRMS 32A/Pavizham showed significant heterosis (over mid parents) for grain yield and most of the yield attributing traits. These crosses were identified as promising hybrids based on mean *per se* performance, heterosis estimation, SCA effects and GCA effects (of their corresponding parents) for grain yield per plant. While none of the hybrid showed significant positive better heterosis/heterobeltiosis or standard heterosis for this trait. Similar results have been reported by Pratap *et al*. (2013), Latha *et al*. (2013) and Ghara *et al*. (2014). The hybrids showing positive and significant SCA effects and heterosis can be further tested in observational yield/multi-location yield trials to exploit their heterotic potential and fertility for the development of successful red rice hybrid.

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