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Combining ability and heterosis for yield, its component traits and some grain quality parameters in rice (*Oryza sativa* L.)

Kumari Priyanka, H. K. Jaiswal and Showkat A. Waza*

Department of Genetics and Plant Breeding, IAS, Banaras Hindu University, Varanasi-221005 (U P), INDIA
***Corresponding author. E-mail: sahmad777@gmail.com

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Abstract: The experiment was conducted to estimate combining ability and heterosis for yield, yield attributing traits and few grain quality parameters in rice. The crosses were made among three CMS lines *i.e.,* IR58025A, Pusa6A and IR68897A and seven pollen parents *viz.,* Sarjoo-52, Jaya, Sasyashree, Swetha, HUR 5-2, PR-106 and BPT 5204. Twenty one hybrids were generated in line x tester design. The superior hybrids were identified on the basis of combining ability effect and heterosis. Cross combination IR68897A/Jaya and IR68897A/BPT 5204 exhibited good x good parental GCA effects suggesting that there is additive x additive type of gene action. The cross IR68897A/Jaya showed highest positive SCA effect. The higher magnitude of heterosis for all the yield and quality traits were not expressed in a single hybrid combination. It varied from cross to cross due to diverse genetic background of their parents. The two crosses IR68897A/Jaya and IR68897A/BPT 5204 were found to be heterotic for yield and yield traits as well as the grain quality characteristcs.

Keywords: GCA, Heterosis, Line x Tester, Rice, SCA

INTRODUCTION

Rice is an important cereal crop and food for more than half of the world population. There is a need to increase the rice production to meet the demand of ever growing population. Hybrid rice technology is a feasible and economically sound approach for yield enhancement in rice. The average yield of hybrid rice is at least 20 percent more than that of inbred rice and it has been anticipated that hybrid rice technology will play a key role in ensuring food security worldwide in the future decades (Yuan, 2010).

The choice of appropriate parental lines possessing good combining ability is a prerequisite for commercial exploitation of hybrid rice technology. Hamada (2014) reported the existence of both general and specific combining ability among the crosses between four CMS lines and three rice restorers in line x tester mating design. Similarly, Satheeshkumar and Saravanan (2013) crossed six rice ovule parents with five pollinator parents in line x tester fashion so as to identify suitable general and specific combiners for breeding program. Prasad (2014) reported five rice genotypes which exhibit significant GCA effects for grain yield plant^{-1} among the crosses between 3 genotypes with 12 lines in line x tester design, indicating the involvement of additive gene action for yield and component traits.

The success of hybrid rice programme mainly depends upon good combining ability among parental lines and higher magnitude of heterosis for yield and quality traits. Therefore, in the present study an attempt has been made to identify some restorers that combine well with the CMS line for yield and its component traits along with the better quality.

MATERIALS AND METHODS

Three WA Cytosterile genotypes (Testers) *i.e.,* IR58025A, Pusa6A and IR68897A were crossed with seven Lines *i.e.,* Sarjoo-52, Jaya, Sasyashree, Swetha, HUR 5-2, PR-106 and BPT 5204 during the wet season of 2011.The seed of 21 F_1 hybrids obtained along with their parents were raised during 2012 in Randomized Block Design with three replications to evaluate combining ability and heterotic potential of the crosses.

Twenty one days old seedlings were transplanted in field and standard spacing of 20 x15 cm was followed for the planting. Single seedling per hill was planted and recommended package of practices followed. Observations were recorded on three randomly selected plants in three replications for sixteen traits *viz.,* days to 50% flowering, days to maturity, plant height, panicle per plant, panicle length, seeds per panicle, yield per plant, 100 seed weight, grain length, grain width, brown rice length, brown rice width, brown rice length/width, kernel length, kernel width and kernel length/width. Due to the male sterile nature of three CMS or female lines, their corresponding maintainer lines were used for studying yield and

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quality traits.

Rice varieties, Jaya and PRH-10 were selected as inbred Check and Hybrid check, respectively. Mid parent heterosis, better parent heterosis, standard heterosis and hybrid check heterosis were worked out for the above mentioned sixteen traits. The significance of different types of heterosis was calculated with the help of t-test. Combining ability analysis was carried out by the method suggested by Kempthorne (1957). Character wise estimation of GCA effects of Lines and Testers was done and the significance of GCA (General Combining Ability) and SCA (Specific Combining Ability) effects were tested by t-test.

RESULTS AND DISCUSSION

Combining ability: The analyses of variances for present study have been given in Table 1. Analysis of combining ability for most of the characters revealed significant differences among genotypes, crosses, lines, testers and line x testers. The results indicated sufficient variability existing in material used in the present study. Significance of mean squares of lines and testers suggested the prevalence of additive gene effects.

The results from present study revealed that none of the parents showed significant GCA effects simultaneously in the desired direction for all the traits studied (Table 2). Moreover, none of the crosses exhibited high specific combining ability for all the characters (Table 3). Similar findings have been reported by Tiwari *et al.* (2011) and Latha *et al.* (2013) while studying the nature and magnitude of heterosis, and combining ability in rice.

Among the female parents, IR58025A and Pusa6A showed significant negative GCA effect for days to 50% flowering. Among the seven male lines, four exhibited significant negative GCA effect for the trait. The negative GCA effects indicate their usefulness in breeding for early maturing lines. Among the twenty one hybrids, SCA effect was found to be significant for eighteen hybrids in which nine crosses showed positive SCA effects whereas remaining nine hybrids showed negative SCA effects for days to 50% flowering. The hybrid combination IR68897A/ PR-106 recorded highest significant negative SCA effect (-8.29). The significant negative GCA and SCA are desirable as also reported by Tiwari *et al.* (2011) and Latha *et al.* (2013) while working in line x tester mating design for combining ability analysis in rice.

IR58025A showed highest significant negative GCA effect for maturity among female parents whereas three male parents showed significant negative GCA for the trait days to maturity. Hybrid IR58025A/BPT 5204 showed highest negative SCA effect (-8.35) followed by IR68897A/Sarjoo-52 (-7.68). Negative GCA effect is desirable for days to maturity. The best general combiner for grain yield and most of its

Table 1. Analysis of variance for line X tester in rice.

Source	df	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Replications	2	0.023	1.832	0.823	6.538*	0.101	0.554	86.528	5.365	0.001	0.000	0.080**	0.001	0.042	0.232	0.030	0.107
Crosses	20	0.302***	137.168***	129.464***	449.507***	15.160***	25.587***	4105.051***	101.704***	0.305***	2.737	0.475***	0.247***	0.757***	0.515	0.196***	0.542*
Line effect	2	0.168	17.621	10.626	339.567	38.640	18.896	1051.431	97.468	0.370	3.222	0.066	0.037	0.044	0.861	0.173	0.026
Tester effect	6	0.727***	187.064	181.567	1057.238**	15.707	25.799	4721.527	155.475	0.534	3.425	0.775	0.416	0.803	0.562	0.263	0.503
Line x tester effect	12	0.113***	132.146***	123.219***	163.965***	10.974***	26.597***	4305.750***	75.525***	0.181***	2.313	0.393***	0.197***	0.852***	0.435	0.166***	0.648*
Error	40	0.009	1.071	1.333	1.305	0.362	1.030	63.658	7.808	0.001	0.012	0.014	0.012	0.042	0.514	0.010	0.264
Total	62	0.104	44.998	42.649	146.055	5.127	8.936	1368.071	38.018	0.099	0.891	0.165	0.088	0.272	0.506	0.071	0.349

[df = degrees of freedom; 1= Days to 50% flowering; 2= Days to maturity; 3= Plant height (cm); 4= Panicles per plant; 5= Panicle length (cm); 6= Seeds per panicle; 7= Yield per plant (gm); 8= 100 seed weight (gm); 9=Grain length(mm); 10= Grain width (mm); 11= Brown rice length (mm); 12= Brown rice width(mm); 13= Brown rice length/width ratio; 14= Kernel length(mm); 15=Kernel width (mm); 16=Kernel length/width ratio] (*Significant at 5% level, ** Significant at 1% level, ***Significant at 0.1% level)

Table 2. General combining ability (GCA) of parents for characters under study.

Parents	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Testers																
IR58025B	-0.07 ***	-0.20 ***	-0.87 ***	-0.05 ***	-0.76 ***	-2.19 ***	-1.16 ***	1.00 ***	1.87	-0.42 ***	-0.024 ***	0.030 ***	-0.028 ***	0.125 **	0.060 ***	0.006
Pusa6B	0.15 ***	0.45 ***	-0.09 ***	0.10 ***	0.12	4.64 ***	-0.33 ***	-0.13 ***	-7.82 ***	-1.91 ***	0.064 ***	0.018 ***	-0.025 ***	0.109*	0.045 ***	-0.038 ***
IR68897B	-0.08 ***	-0.25 ***	0.96 ***	-0.06 ***	0.64 **	-2.45 ***	1.49 ***	-0.88 ***	5.96	2.33 ***	-0.040 ***	-0.048 ***	0.053 ***	-0.234 ***	-0.105 ***	0.031
Lines																
Sarjoo52	-0.05 ***	-0.09 ***	-1.25 ***	0.04 ***	-0.18 ***	-2.89 ***	-0.35 ***	1.10 ***	4.98	-5.99 ***	-0.003 ***	-0.201 ***	0.317 ***	0.118 ***	-0.129 ***	0.290 ***
Jaya	0.04 ***	-0.07 ***	-2.11 ***	0.30 ***	-2.53 ***	-2.09 ***	-1.87 ***	-0.57 ***	-10.20 ***	5.80 ***	0.138 ***	0.413 ***	-0.545 ***	0.219*	0.358 ***	-0.436 ***
Sasyashree	0.11 ***	0.16 ***	4.67 ***	0.27 ***	5.12 ***	-1.05 ***	-0.09 ***	0.35	6.87	-2.10 ***	0.068 ***	0.142 ***	-0.202 ***	0.173 ***	0.058 ***	-0.033 ***
SH1wetha	0.03 ***	-0.12 ***	2.00 ***	-0.02 ***	0.79 ***	10.27 ***	-0.4 ***	1.81 ***	41.46 ***	3.10 ***	0.258 ***	-0.011 ***	0.137 ***	-0.191 ***	-0.051 ***	-0.067 ***
HUR 5-2	-0.44 ***	-0.48 ***	-8.66 ***	-0.28 ***	-8.55 ***	-17.25 ***	2.53 ***	-3.21 ***	-34.65 ***	-3.16 ***	-0.560 ***	-0.185 ***	-0.023 ***	-0.449 ***	-0.141 ***	-0.019 ***
PR-106	-0.01 ***	1.26 ***	4.00 ***	0.15 ***	3.12 ***	16.58 ***	-0.21 ***	1.30 ***	-1.36	-0.72 ***	0.282 ***	-0.077 ***	0.276 ***	0.200 ***	-0.060 ***	0.233 ***
BPT 5204	-0.03 ***	-0.64 ***	1.34 ***	-0.47 ***	2.23 ***	-3.57 ***	0.42 ***	-0.69 ***	-7.10 ***	3.08 **	-0.183 ***	-0.081 ***	0.040 ***	-0.071 ***	-0.035 ***	0.032 ***

[1= Days to 50% flowering; 2= Days to maturity; 3= Plant height (cm); 4= Panicles per plant; 5= Panicle length (cm); 6= Seeds per panicle; 7= Yield per plant (gm); 8= 100 seed weight (gm); 9=Grain length(mm); 10= Grain width (mm); 11= Brown rice length (mm); 12= Brown rice width(mm); 13= Brown rice length/width ratio; 14= Kernel length(mm); 15=Kernel width (mm); 16=Kernel length/width ratio] (*Significant at 5% level, ** Significant at 1% level, ***Significant at 0.1% level)

Table 3. Specific combining ability (SCA) effects of hybrids for characters under study.

Hybrids	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
IR58025A/Sarjoo- 52	4.016 ***	4.838 ***	-4.155 ***	-0.582	0.187	-26.459 ***	-0.389	0.179 ***	-0.019	-0.048	0.112	-0.003	0.013	-0.03	0.003	-0.097
IR58025A/Jaya	4.646 ***	5.122 ***	-2.054 **	1.270 **	-0.78	-24.582 ***	-5.740 ***	-0.111 ***	-0.539 ***	0.092	-0.333 ***	0.350 ***	-0.537 ***	-0.375	0.406 ***	-0.724 **
IR58025A/Sasyashree	-3.132 ***	-2.570 ***	-5.829 ***	2.492 ***	-1.201 *	21.541 ***	3.419 *	-0.224 ***	-0.446 ***	0.119 *	0.021	-0.345 ***	0.529 ***	-0.098	-0.237 ***	0.353
IR58025A/Swetha	4.534 ***	4.764 ***	8.611 ***	1.937 ***	-0.761	-22.496 ***	-0.485	0.305 ***	0.175 **	0.196 **	0.257 ***	0.153 *	-0.219 *	0.765 *	0.041	0.286
IR58025A/HUR 5-2	-2.799 ***	-3.236 ***	2.271 **	-1.471 ***	0.469	-11.273 **	1.219	0.126 ***	1.322 ***	-0.293 ***	0.265 ***	-0.075	0.246 *	0.153	-0.085	0.206
IR58025A/PR-106	0.534	-0.57	-1.189	-0.730 *	-1.379 *	58.875 ***	5.712 ***	-0.086 ***	-0.941 ***	0.074	-0.427 ***	0.247 ***	-0.697 ***	-0.346	0.204 ***	-0.643 *
IR58025A/BPT 5204	-7.799 ***	-8.347 ***	2.345 **	-2.915 ***	3.466 ***	4.393	-3.736 *	-0.189 ***	0.449 ***	-0.140 *	0.105	-0.327 ***	0.665 ***	-0.068	-0.331 ***	0.619 *
Pusa6A/Sarjoo-52	4.016 ***	2.843 ***	-7.734 ***	0.037	1.218 *	-37.104 ***	-0.366	0.049 **	0.581 ***	-0.004	0.217 **	0.058	0.026	0.169	-0.013	0.131
Pusa6A/Jaya	-5.466 ***	-6.799 ***	-3.195 ***	0	-2.664 ***	-3.376	-3.373 *	0.019	0.117	0.016	0.189 **	-0.192 **	0.317 **	0.208	-0.089	0.157
Pusa6A/Sasyashree	-2.910 ***	-2.453 ***	3.637 ***	-1.000 **	2.796 ***	0.34	1.441	0.049 **	0.381 ***	-0.240 ***	-0.141 *	0.033	-0.13	-0.175	0.141 *	-0.323
Pusa6A/Swetha	-2.243 ***	-3.120 ***	0.622	-0.556	-0.997	22.970 ***	1.793	-0.303 ***	-1.215 ***	0.137 *	-0.677 ***	0.082	-0.497 ***	-0.092	0.066	-0.15
Pusa6A/HUR 5-2	0.423	1.547 *	-2.652 ***	-0.963 *	2.333 ***	29.748 ***	-0.592	-0.240 ***	-0.265 ***	0.121 *	-0.006	-0.037	0.095	-0.178	-0.084	0.087
Pusa6A/PR-106	7.757 ***	7.547 ***	9.511 ***	1.333 ***	2.596 ***	-5.882	1.889	0.02	0.932 ***	-0.065	0.388 ***	-0.188 **	0.590 ***	-0.013	-0.198 ***	0.4
Pusa6A/BPT 5204	-1.577 **	0.436	-0.189	1.148 **	-5.282 ***	-6.697	-0.792	0.406 ***	-0.531 ***	0.035	0.03	0.245 ***	-0.400 ***	0.081	0.177 **	-0.301
IR68897A/Sarjoo-52	-8.032 ***	-7.681 ***	11.889 ***	0.545	-1.406 *	63.563 ***	0.755	-0.228 ***	-0.562 ***	0.053	-0.329 ***	-0.055	-0.039	-0.139	0.01	-0.033
IR68897A/Jaya	0.82	1.677 *	5.249 ***	-1.270 **	3.445 ***	27.958 ***	9.114 ***	0.092 ***	0.422 ***	-0.107	0.143 *	-0.158 *	0.220 *	0.167	-0.317 ***	0.567 *
IR68897A/Sasyaree	6.042 ***	5.023 ***	2.192 **	-1.492 ***	-1.595 **	-21.882 ***	-4.860 **	0.175 ***	0.065	0.120 *	0.12	0.313 ***	-0.400 ***	0.274	0.097	-0.03
IR68897A/Swetha	-2.291 ***	-1.644 *	-9.234 ***	-1.381 ***	1.757 **	-0.474	-1.309	-0.002	1.040 ***	-0.333 ***	0.420 ***	-0.235 ***	0.717 ***	-0.673	-0.108 *	-0.136
IR68897A/HUR 5-2	2.376 ***	1.690 *	0.381	2.434 ***	-2.802 ***	-18.474 ***	-0.627	0.113 ***	-1.057 ***	0.171 **	-0.259 ***	0.113	-0.341 **	0.025	0.169 **	-0.293
IR68897A/PR-106	-8.291 ***	-6.977 ***	-8.322 ***	-0.603	-1.217 *	-52.993 ***	-7.601 ***	0.066 ***	0.01	-0.009	0.039	-0.058	0.107	0.359	-0.005	0.244
IR68897A/BPT5204	9.376 ***	7.912 ***	-2.156 **	1.767 ***	1.817 **	2.303	4.529 **	-0.217 ***	0.083	0.105	-0.135 *	0.082	- 0.265*	-0.013	0.153 **	-0.318

[1= Days to 50% flowering; 2= Days to maturity; 3= Plant height (cm); 4= Panicles per plant; 5= Panicle length (cm); 6= Seeds per panicle; 7= Yield per plant (gm); 8= 100 seed weight (gm); 9=Grain length(mm); 10= Grain width (mm); 11= Brown rice length (mm); 12= Brown rice width(mm); 13= Brown rice length/width ratio; 14= Kernel length(mm); 15=Kernel width (mm); 16=Kernel length/width ratio] (*Significant at 5% level, ** Significant at 1% level, ***Significant at 0.1% level)

Table 4. Percent heterosis over mid parent (MH), better parent (BH), standard inbred check (SH1) and hybrid check (SH2) for various traits under study

Hybrids	Days to 50% flowering				Days to maturity				Plant Height				Panicles per plant			
	MH	BH	SH1	SH2	MH	BH	SH1	SH2	MH	BH	SH1	SH2	MH	BH	SH1	SH2
IR58025A/Sarjoo- 52	0.23	-5.72 **	3.22 **	-30.23 **	2.49 **	-2.95 **	2.4	8.57 **	-12.33 **	-16.70 **	-17.2 **	-15.86 **	-30.23 **	-40.48 **	-11.1 **	-16.67 **
IR58025A/Jaya	-2.56 **	-5.94 **	2.15	-25.00 **	-1.53 *	-4.52 **	-0.8	6.81 **	-9.91 **	-14.83 **	-13.7 **	-13.05 **	-25.00 **	-38.10 **	0	-13.33 *
IR58025A/Sasyashree	-8.74 **	-10.48 **	1.07	1.45	-5.62 **	-6.67 **	0	6.78 **	-8.03 **	-8.76 **	-17.1 **	-15.70 **	1.45	-16.67 **	33.33 **	16.67 **
IR58025A/Swetha	-6.60 **	-10.81 **	6.45 **	-4.43	-4.44 **	-6.52 **	4 **	9.32 **	12.40 **	5.69 **	7.211 **	9.15 **	-4.43	-23.02 **	22.22 **	7.78
IR58025A/HUR 5-2	-18.59 **	-19.80 **	-12.9 **	-16.96 **	-14.65 **	-15.40 **	-11.2 **	-5.37 **	-8.06 **	-15.88 **	-24.8 **	-23.51 **	-16.96 **	-26.19 **	22.22 **	3.33
IR58025A/PR-106	0	-3.96 **	4.30 **	-31.51 **	-1.56 *	-4.55 **	0.8	6.78 **	5.91 **	-2.81 **	3.985 **	5.79 **	-31.51 **	-40.48 **	-11.1 **	-16.67 **
IR58025A/BPT 5204	-20.37 **	-25.22 **	-7.53 **	-45.29 **	-15.59 **	-19.63 **	-6.4 **	-0.56	-3.13 **	-4.89 **	-11.7 **	-10.24 **	-45.29 **	-51.59 **	-22.2 **	-32.22 **
Pusa6A/Sarjoo-52	-4.95 **	-15.04 **	3.22 **	-16.98 **	-3.05 **	-11.81 **	2.4	7.63 **	-6.01 **	-13.59 **	-14.2 **	-12.72 **	-16.98 **	-28.46 **	0	-2.22
Pusa6A/Jaya	-17.23 **	-24.19 **	-8.6 **	-27.80 **	-14.18 **	-20.14 **	-8.8 **	-2.54 **	-1.03	-9.46 **	-9.51 **	-7.56 **	-27.80 **	-39.84 **	-11.1 **	-17.78 **
Pusa6A/Sasyashree	-12.84 **	-15.93 **	2.15	-20.59 **	-8.96 **	-11.81 **	1.6	7.63 **	12.95 **	8.26 **	-2.13 *	0.02	-20.59 **	-34.15 **	-11.1 **	-10
Pusa6A/Swetha	-16.96 **	-17.70 **	0	-18.00 **	-13.48 **	-15.28 **	-2.4	3.39 **	14.94 **	4.61 **	6.262 **	8.04 **	-18.00 **	-33.33 **	-11.1 **	-8.89
Pusa6A/HUR 5-2	-19.43 **	-24.78 **	-9.68 **	-4.98	-14.25 **	-18.52 **	-6.4 **	-0.56	-2.18 *	-7.53 **	-23.2 **	-21.67 **	-4.98	-14.63 **	11.11 **	16.67 **
Pusa6A/PR-106	1.94 **	-7.08 **	12.9 **	-6.48	0.75	-6.25 **	8 **	14.41 **	26.78 **	12.73 **	21 **	22.69 **	-6.48	-17.89 **	11.11 **	12.22 *
Pusa6A/BPT 5204	-18.42 **	-19.13 **	0	-4.55	-12.41 **	-13.01 **	0.8	7.63 **	4.87 **	-0.5	-7.69 **	-6.10 **	-4.55	-14.63 **	22.22 **	16.67 **
IR68897A/Sarjoo-52	-3.95 **	-4.49 **	-8.6 **	-3.96	-2.09 **	-3.31 **	-7.2 **	-0.85	12.75 **	-1.62	-2.41 *	-0.63	-3.96	-21.01 **	33.33 **	21.11 **
IR68897A/Jaya	2.20 **	-1.06	-1.08	-28.18 **	1.22	0	-1.6	5.08 **	5.72 **	-8.18 **	-7.56 **	-6.26 **	-28.18 **	-42.75 **	-11.1 **	-12.22 *
IR68897A/Sasyashree	8.81 **	0	12.9 **	-15.07 **	5.47 **	0	7.2 **	14.41 **	9.50 **	-0.65	-9.74 **	-8.21 **	-15.07 **	-32.61 **	0	3.33
IR68897A/Swetha	-5.53 **	-15.32 **	0	-15.35 **	-4.25 **	-10.14 **	-0.8	5.08 **	2.72 **	-11.21 **	-9.63 **	-8.30 **	-15.35 **	-34.06 **	11.11 **	1.11
IR68897A/HUR 5-2	-5.38 **	-10.20 **	-6.45 **	28.81 **	-5.85 **	-9.00 **	-6.4 **	0	-1.24	-1.36	-26 **	-25.58 **	28.81 **	10.14 **	10 **	68.89 **
IR68897A/PR-106	-0.55	-3.23 **	-4.3	-13.42 **	-1.22	-2.42 **	-4 **	2.54 **	7.18 **	-9.35 **	-3.23 **	-1.34	-13.42 **	-27.54 **	22.22 **	11.11 *
IR68897A/BPT 5204	3.45 **	-8.70 **	13.98 **	8.09 *	1.12	-7.53 **	8.8 **	14.41 **	0.42	-9.75 **	-16.2 **	-14.83 **	8.09 *	-7.97 *	55.56 **	41.11 **

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Hybrids	Panicle length				Seeds per panicle				Yield per plant				100 seed weight			
	MH	BH	SH1	SH2	MH	BH	SH1	SH2	MH	BH	SH1	SH2	MH	BH	SH1	SH2
IR58025A/Sarjoo- 52	2.13	-0.94	8.73 **	-1.19	2.55	-11.16 **	11.76* *	-0.07	-39.06 **	-42.89 **	-40.5 **	-26.32 **	-15.97 **	-26.15 **	-29.6 **	-10.58 **
IR58025A/Jaya	-7.46 *	-10.73 **	-10.2 **	-10.96 **	-9.11 **	-18.93 **	-2.21	-8.81 *	-20.81 **	-22.81 **	-6.17	-0.42	-13.33 **	-25.48 **	-23.1 **	-4.98 **
IR58025A/Sasyashree	-7.68 **	-8.78 **	0.25	-9.02 **	39.58 **	17.98 **	50 **	32.70 **	-10.3	-18.90 **	-15.6 **	4.63	-26.46 **	-36.28 **	-37.1 **	-20.24 **
IR58025A/Swetha	2.78	-1.49	9.70 **	-1.74	22.17 **	12.46 **	49.26 **	26.50 **	-4.35	-14.85 *	-11.4	9.86	-3.39 **	-11.39 **	-23.4 **	-2.56 **
IR58025A/HUR 5-2	-10.88 **	-16.03 **	-7.97 **	-16.25 **	-18.57 **	-25.44 **	-5.88 **	-16.13 **	-20.88 **	-29.04 **	-26.3 **	-8.45	-14.76 **	-21.72 **	-43.6 **	-28.17 **
IR58025A/PR-106	-5.4	-5.84	3.46 **	-6.08	55.22 **	34.98 **	73.53 **	51.82 **	-1.87	-7.44	-3.57	19.41 *	-22.34 **	-30.10 **	-36.8 **	-19.84 **
IR58025A/BPT 5204	21.87 **	5.12	16.03 **	4.85	9.08 **	-0.19	29.41 **	12.26 **	-16.27 *	-25.03 **	-22.1 **	-3.27	-16.57 **	-17.83 **	-40.8 **	-24.60 **
Pusa6A/Sarjoo-52	12.66 **	4.99	8.48 **	-1.57	5.61	5.05	-5.15 **	-13.43 **	-42.86 **	-45.55 **	-45.3 **	-32.21 **	-16.85 **	-22.98 **	-26.5 **	-6.75 **
Pusa6A/Jaya	-10.75 **	-16.38 **	-14.8 **	-22.50 **	16.39 **	12.00 **	11.03 **	-1.24	-16.50 **	-17.17 *	-16.8	3.11	-5.41 **	-14.42 **	-14 **	9.13 **
Pusa6A/Sasyashree	14.33 **	4.72	12.24 **	1.96	41.22 **	37.87 **	27.21 **	12.41 **	-20.71 **	-27.14 **	-26 **	-9.3	-12.78 **	-20.43 **	-21.5 **	-0.4
Pusa6A/Swetha	7.89 *	1.72	5.48 **	-6.98 *	70.33 **	58.56 **	88.97 **	50.00 **	0.38	-9.21	-9.09	13.03	-22.81 **	-25.18 **	-34.6 **	-17.72 **
Pusa6A/HUR 5-2	2.31	-1.88	-2.78 **	-13.44 **	19.35 **	11.71 **	18.38 **	4.45	-30.99 **	-37.12 **	-37.2 **	-21.72 *	-26.36 **	-35.80 **	-48 **	-33.73 **
Pusa6A/PR-106	16.58 **	6.07	15.82 **	4.81	25.00 **	23.79 **	15.44 **	2.92	-17.89 **	-21.23 **	-20.8 **	-1.93	-14.33 **	-18.61 **	-26.8 **	-6.66 **
Pusa6A/BPT 5204	-12.55 **	-17.23 **	-25.1 **	-32.97 **	12.77 **	5.63	8.088 **	-1.39	-9.44	-17.60 **	-17.2 **	2.58	12.37 **	4.61 **	-15 **	7.98 **
IR68897A/Sarjoo-52	-12.30 **	-15.55 **	-4.94 **	-14.50 **	85.83 **	76.43 **	80.88 **	61.75 **	-29.01 **	-35.70 **	-30.3 **	-10.64	-34.70 **	-39.69 **	-42.7 **	-26.98 **
IR68897A/Jaya	1.07	-3.19	10.46 **	-2	42.78 **	40.05 **	45.59 **	28.39 **	30.32 **	22.59 **	37.6 **	70.37 **	-10.66 **	-19.40 **	-19 **	2.78 **
IR68897A/Sasyashree	-17.16 **	-18.74 **	-10.8 **	-17.74 **	26.21 **	16.56 **	19.85 **	6.86	-32.22 **	-40.68 **	-33.1 **	-17.56 *	-16.28 **	-23.85 **	-24.9 **	-4.67 **
IR68897A/Swetha	4.5	-0.55	12.57 **	0.68	54.23 **	51.85 **	61.03 **	43.65 **	-1.84	-15.36 *	-5.19	17.63 *	-20.04 **	-22.73 **	-33.3 **	-15.04 **
IR68897A/HUR 5-2	-32.42 **	-36.76 **	-28.8 **	-35.98 **	-11.63 **	-12.49 **	-20.6 **	-18.18 **	-21.11 **	-31.49 **	-23.2 **	-4.79	-20.78 **	-30.74 **	-44.2 **	-28.97 **
IR68897A/PR-106	-12.69 **	-13.74 **	-1.9	-12.68 **	-7.31	-11.62 **	-18.4 **	-18.98 **	-39.22 **	-44.60 **	-37.9 **	-23.01 **	-20.88 **	-25.07 **	-32.4 **	-14.06 **
IR68897A/BPT 5204	5.24	-9.79 **	0.422	-8.68 **	22.76 **	21.66 **	32.35 **	13.58 **	17.03 **	1.48	13.9 **	41.03 **	-22.74 **	-27.86 **	-41.7 **	-26.01 **

Contd……….

Hybrids	Grain length				Grain width				Brown rice length				Brown rice width			
	MH	BH	SH1	SH2	MH	BH	SH1	SH2	MH	BH	SH1	SH2	MH	BH	SH1	SH2
IR58025A/Sarjoo- 52	-2.70 **	-3.71 **	-3.26 **	-9.31 **	21.30 **	3.76	-5.56 **	44.93 **	11.40 **	5.20 **	-21.3 **	0.4	-10.78 **	-23.14 **	9.66 **	3.66
IR58025A/Jaya	-9.26 **	-9.48 **	-8.7 **	-14.34 **	32.28 **	9.29 **	4.167 **	66.30 **	3.52 *	0.42	-14.2 **	-4.16 **	34.74 **	14.52 **	4.66 **	59.54 **
IR58025A/Sasyashree	-5.47 **	-5.49 **	-5.65 **	-10.99 **	45.68 **	28.67 **	5.208 **	66.67 **	5.05 **	4.88 **	-27.9 **	0.1	-10.11 **	-22.14 **	6.66 **	3.66
IR58025A/Swetha	2.66 **	-1.85	-1.74	-7.56 **	19.00 **	-3.82	1.389	54.89 **	20.76 **	11.60 **	-16.7**	6.51 **	5.25	-10.08 **	20.17 **	23.70 **
IR58025A/HUR 5-2	13.14 **	6.72 **	6.739 **	0.51	6.15	-1.41	-27.1 **	14.13 **	9.03 **	-1.15	-36.7**	-5.66 **	6.33	2.96	2.83 **	0.39
IR58025A/PR-106	-4.65 **	-9.71 **	0.87	-4.86 **	47.33 **	37.44 **	0	57.61 **	1.77	1.21	-12.9 **	-3.41 *	24.28 **	20.37 **	4 **	25.24 **
IR58025A/BPT 5204	0.57	-4.54 **	-4.35 **	-10.10 **	-2.59	-14.48 **	-29.2 **	12.32 **	0.31	-1.57	-25.4 **	-2.4	24.28 **	20.37 **	4.33 **	25.24 **
Pusa6A/Sarjoo-52	9.56 **	6.96 **	8.37 **	3.56 **	20.17 **	11.28 **	0.694	55.43 **	9.59 **	-0.39	-19.6 **	3.31 *	-10.59 **	-21.00 **	14.17 **	6.55
Pusa6A/Jaya	3.54 **	2.37 *	5.435 **	-0.89	25.58 **	11.90 **	9.375 **	70.29 **	8.57 **	1.26	-8.75 **	5.01 **	5.08	-8.44 *	16.83 **	27.55 **
Pusa6A/Sasyashree	9.14 **	7.64 **	10.87 **	4.21 **	24.93 **	19.86 **	-0.35	55.25 **	-0.43	-4.54 **	-10.8 **	-1	5.54	-6.22	9.16 **	24.86 **
Pusa6A/Swetha	-7.10 **	-12.34 **	-9.89 **	-15.13 **	14.10 **	-0.79	4.167* *	59.78 **	1.57	-9.57 **	-15 **	-6.21 **	-1.36	-13.59 **	4.33 **	18.88 **
Pusa6A/HUR 5-2	0.85	-6.08 **	-4.02 **	-9.07 **	23.30 **	21.61 **	-6.6**	44.75 **	1.02	-11.69 **	-27.5 **	-8.42 **	4.65	-1.49	-1.5	1.93
Pusa6A/PR-106	19.77 **	14.91 **	29.35 **	21.08 **	35.35 **	32.88 **	0.694	58.15 **	11.23 **	6.23 **	-27.1 **	10.17 **	-4.18	-4.44	22.33 **	-0.58
Pusa6A/BPT 5204	-4.58 **	-10.60 **	-9.78 **	-13.45 **	3.76	-1.1	-16.7 **	29.89 **	-3.58 **	-5.70 **	-3.33 **	-2.2	8.40 *	-1.23	8.66 **	24.28 **
IR68897A/Sarjoo-52	-4.96 **	-8.24 **	-10.9 **	-15.37 **	10.49 **	7.26 *	-0.35	49.82 **	4.65 **	-0.43	-26.3 **	-6.46 **	-25.08 **	-28.71 **	1	-3.85
IR68897A/Jaya	5.31 **	0.43	-0.43	-4.96 **	9.20 **	1.79	1.736	54.89 **	11.89 **	9.39 **	-10 **	2.76	-3.76	-9.82 **	14.33 **	25.63 **
IR68897A/Sasyashree	4.18 **	-0.4	-1.09	-6.23 **	27.27 **	26.31 **	7.639 **	66.12 **	7.21 **	6.53 **	-14.6 **	1.35	7.63 *	3.04	13.33 **	37.19 **
IR68897A/Swetha	17.39 **	17.37 **	7.5**	0.82	-14.18 **	-22.05 **	-17.4 **	25.54 **	24.32 **	15.73 **	-33.3 **	8.72 **	-25.41 **	-29.69 **	21.67 **	-3.28
IR68897A/HUR 5-2	-10.73 **	-11.96 **	-20.1 **	-24.40 **	12.23 **	5.51	-10.1 **	38.77 **	0.53	-8.21 **	-19.2 **	-13.78 **	0.18	-12.34 **	-3	6.74
IR68897A/PR-106	9.20 **	-0.91	9.457 **	4.41 **	23.91 **	15.98 **	-0.35	52.54 **	9.76 **	9.50 **	-24.6 **	3.36 *	-8.70 *	-15.35 **	15.17 **	3.08
IR68897A/BPT 5204	0.5	-0.24	-10.7 **	-14.34 **	-4.89	-4.96	-22.6 **	25.00 **	-2.91 *	-5.46 **	-20.4 **	-6.26 **	-10.35 **	-11.79 **	1.167	10.98 *

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Hybrids	Brown rice length/width ratio				Kernel length				Kernel width				Kernel length/width ratio			
	MH	BH	SH1	SH2	MH	BH	SH1	SH2	MH	BH	SH1	SH2	MH	BH	SH1	SH2
IR58025A/Sarjoo- 52	20.34**	-1.14	40.32**	-3.21	11.33	4.38	9.96**	0.26	-9.11*	-21.56**	-18.8**	8.71	18.06	-3.49	38.88**	-7.77
IR58025A/Jaya	-26.02**	-38.64**	22.58**	-39.92**	4.06	0.48	5.23**	-3.49	33.61**	13.16**	-11.8**	64.11**	-25.20*	-38.44**	22.22**	-41.17**
IR58025A/Sasyashree	14.21**	-1.22	48.79**	-3.29	5.06	4.16	4.56**	0.05	-9.53**	-20.38**	-25.8**	5.39	14.31	-0.18	44.44**	-4.61
IR58025A/Swetha	9.81*	-12.09**	45.16**	-13.93**	21.82**	12.17	12.67**	7.74	-4.85	-18.99**	-17.5**	15.98**	22.22*	-2.77	40.07**	-7.09
IR58025A/HUR 5-2	2.64	-4	63.30**	-6.01	8.71	-1.76	1.85**	-5.64	5.56	1.86	-35.4**	2.49	3.08	-3.61	61.50**	-7.89
IR58025A/PR-106	-18.14**	-21.10**	20.16**	-22.75**	1.4	0.64	0.67	-3.33	21.12**	17.70**	-10.5**	25.52**	-16.13	-19.06*	15.07**	22.65*
IR58025A/BPT 5204	20.56**	8.77*	41.12**	6.5	-1.41	-3.48	4.73**	-3.23	-19.29**	-28.82**	-25.3**	-6.22	20.67*	8.38	43.65**	3.57
Pusa6A/Sarjoo-52	19.07**	-3.08	42.74**	-2.82	9.2	-1.57	13.18**	3.08	-13.01**	-22.90**	-16.6**	6.85	22.04*	-1.18	39.28**	-3.21
Pusa6A/Jaya	-0.07	-17.90**	29.03**	-17.67**	8.39	0.49	10.64**	5.23	5.02	-8.73**	-6.55**	32.37**	-0.43	-18.83*	21.42**	-20.50*
Pusa6A/Sasyashree	-7.23	-20.57**	23.38**	-20.35**	-0.95	-5.82	8.61**	-1.38	6.93*	-3.29	-19.2**	28.01**	-8.28	-20.74*	37.69**	-22.37*
Pusa6A/Swetha	-0.83	-21.31**	23.38**	-21.09**	1.66	-9.94	4.22**	-5.69	-6.80*	-18.55**	-14**	16.60**	4.9	-17.25	24.20**	-18.95*
Pusa6A/HUR 5-2	-2.82	-10.11*	37.09**	-9.86*	-2.31	-14.98*	-1.69	-10.97	1.34	-5.04	-26.2**	1.66	-2.72	-10.06	36.50**	-11.91
Pusa6A/PR-106	15.92**	10.46**	68.95**	10.76**	1.88	-3.03	14.02**	1.54	-6.8	-6.98	-27.9**	-0.41	9.22	4.18	62.30**	2.04
Pusa6A/BPT 5204	-11.86**	-21.32**	13.30**	-21.10**	-3.58	-5.63	8.61**	-1.18	4.26	-5.51	-3.93**	24.48**	-8.33	-18.56*	15.87**	-20.23*
IR68897A/Sarjoo-52	39.12**	26.26**	37.90**	-2.47	4.79	-0.55	-0.34	-6.92	-25.47**	-28.59**	-25.3**	-1.04	40.44**	27.94*	36.90**	-5.55
IR68897A/Jaya	15.47**	5.95	27.82**	-18.16**	8.54	6.13	8.27**	-0.67	-19.91**	-24.89**	-19.7**	8.92	34.75**	23.73*	38.09**	-8.66
IR68897A/Sasyashree	0.41	-3.36	33.46**	-25.35**	6.65	6.19	12.84* *	0.26	-10.56**	-12.38**	-13.5**	15.98**	19.26	17.25	33.73**	-13.45
IR68897A/Swetha	65.30**	45.62**	83.87**	12.48**	-8.14	-14.4	19.93**	-19.89*	-28.57**	-32.61**	-34.1**	-3.53	27.54*	12.56	86.50**	-16.9
IR68897A/HUR 5-2	-0.5	-5.17	20.96**	-19.17**	1.53	-7.17	-2.36	-13.12	-1.98	-14.87**	-21.8**	8.09	2.43	-3.31	27.77**	-19.60*
IR68897A/PR-106	19.27**	10.35*	53.62**	0.23	8.39	7.8	10.47**	2	-12.43**	-19.44**	-24.5**	2.28	22.78*	12.37	50**	-0.11
IR68897A/BPT 5204	8.25	7.21	27.82**	-15.56**	-4.97	-8.13	-1.69	-7.89	-12.11**	-13.70**	-18.3**	13.69**	8.15	6.54	23.41**	-18.93*

***Significant at 5% level, **Significant at 1% level, ***Significant at 0.1% level component traits were often related to late maturity with tallness, indicating that the cultivars did not transmit both these characters simultaneously in desirable directions (Tiwari *et al.* 2011). Similarly, Ghara *et al.* (2012) found that negative GCA and SCA effects are beneficial in case of earliness while studying general and specific combining ability on 50 F_1 hybrids in rice (5 cytoplasmic male sterile lines and 10 restorer varieties).

Among female parents, the significant negative GCA effect was shown by IR58025A (-2.19) and IR68897A (-2.45) for plant height. Among male parents, five showed significant negative GCA effect for plant height. Reduction in plant height is a desirable trait as it avoids lodging problem. Among twenty one crosses, nine showed significant negative SCA effect for plant height.

Among testers, IR68897A showed highest significant positive GCA effect (1.49) and among lines, HUR 5-2 recorded highest significant positive GCA effect (2.53) for panicles per plant. Among crosses, IR58025A/ Sasyashree showed highest significant positive SCA effect (2.49) for the trait. Seven hybrids manifested significant positive SCA effects among twenty one.

IR58025A showed highest positive GCA effect (1.01) for panicle length among the testers. Among the lines, Swetha recorded highest significant positive GCA effect (1.81). Among twenty one crosses, eight recorded significant positive SCA effect for panicle length. Panicle length directly contributes to yield.

Six crosses exhibited significantly positive SCA effect for seeds per panicle. More number of seeds per panicle is desirable for high yield and significant positive SCA shows existence of non-additive gene action. Sen and Singh (2011) reported that high SCA is desirable for seeds per panicle in rice as it directly contributes towards the yield. Among female parents, IR68897A recorded highest significant positive GCA effect (2.33) for the trait, yield per plant. Among pollen parents, Jaya (5.80) recorded highest GCA effect. The cross IR68897A/Jaya showed highest positive SCA effect (9.11) for yield per plant suggesting good x good GCA interaction between parents for yield. Cross combinations IR68897A/Jaya and IR68897A/BPT 5204 showed good x good parental GCA effects suggesting that there is an additive x additive type of gene action. Hariprasanna *et al.* (2006) reported that high x high GCA combination resulted in significant negative SCA for filled grains and productive tillers per plant in rice. The crosses that had significant positive SCA for grain yield were obtained from average x average GCA combinations; while average x average and average x low combinations also resulted in hybrids with significant negative SCA which is not in agreement with the present study. This may be due to the difference in the material under study. While working on rice, Chakraborty *et al.* (2009) reported that the superior specific cross combinations for high grain yield per hill were originated from 'high x low GCA' combination followed by 'low x high GCA', 'low x high GCA', 'low x low GCA', 'high x low GCA', 'low x high GCA' and 'high x high GCA'. Further, these crosses exhibited high SCA effects for some other characters as well, which is in support of the present finding. The hybrid combinations, which show non-significant SCA effects (average effects) but originated from parents having high GCA effects (additive gene effects), can be used for recombination breeding with an easy selection of desirable segregates, particularly for developing high yielding pure lines due to presence of additive gene action (Saleem *et al.,* 2010 and Tiwari *et al.,* 2011). Out of 21 crosses only 10% crosses showed significant and desirable SCA for grain yield. Tiwari *et al.* (2011) has reported 30% significant and desirable SCA among 60 crosses in rice.

Among female parents Pusa6A recorded highest positive significant GCA effect (0.15) for 100 seed weight. Among pollen parents, Sasyashree (0.11) recorded highest significant positive GCA effect. Out of twenty one, ten crosses showed significant positive SCA effect for 100 seed weight. High SCA is desirable for 100 seed weight. The best cross combinations are not always found between high x high general combiner. It may also occur in other types of parental combinations in rice as reported by Chakraborty *et al.* (2009) and Tiwari *et al.* (2011). This is in accordance to the present finding.

Among female parents, Pusa6A recorded highest positive significant GCA effect (0.45) for grain length. High GCA for grain length is a desirable trait, showing the additive gene action. Among pollen parents, PR-106 (1.26) followed by Sasyashree (0.16) recorded highest positive significant GCA effect for the trait. Out of 21 hybrids, eight showed significant positive SCA for the trait. Among 21 crosses, four crosses showed significant negative SCA effect for grain width. Seven crosses showed significant positive SCA effect for brown rice length whereas six crosses showed significant negative SCA effect for brown rice width. Six crosses showed significant positive SCA effect for brown rice length/width ratio. Cross IR58025A/Swetha manifested significant positive SCA effect for kernel length and five crosses showed significant negative SCA effect for kernel width. IR58025A/BPT 5204(0.62) and IR68897A/Jaya (0.57) showed significant SCA effect for kernel length/width ratio. Higher SCA for kernel length and Kernel length/ width ratio is a desirable trait. The desirability for kernel length is dictated by the miller and consumer. It is decided by milling %, head rice recovery and characteristics of the cooked rice in case of overall acceptability of the hybrids.

Based on the estimates of SCA effects none of the cross combinations exhibited significant and desirable

SCA effect for all the parameters simultaneously indicating that no specific combination was desirable for all traits. These results are in complete agreement with ear-lier findings (Sanghera and Hussain, 2012; Tiwari *et al.*, 2011). They also found that none of the crosses exhibited high specific combining ability for all the characters in rice.

The general combining ability (GCA) and specific combining ability (SCA) effects are significant for most of the characters indicating the importance of both additive and non-additive gene effects in their inheritance (Sanghera and Hussain, 2012). Similar result in rice has been reported by Chakraborty *et al*. (2009). Tiwari *et al* (2011) reported that it is better to select at least one parent possessing high GCA and the other a low, average or high GCA to get heterotic hybrids in rice. Exploitation of heterosis to develop superior rice hybrids using some of the local parents with proven GCA and SCA effects has been demonstrated as a potentially better method for grain yield enhancement in rice (Verma and Srivastava, 2004).

Heterosis: In the present investigation, heterosis over mid parent (MH), better parent (BH), Standard inbred check (SH1) and Standard hybrid check (SH2) were estimated for sixteen characters in all the 21 hybrids (Table 4). The findings suggested that the magnitude of heterosis differed from character to character depending on hybrid combination. Latha *et al.* (2013) also reported in rice that the magnitude of heterosis varied from trait to trait and cross to cross and none of the cross combinations recorded significant heterosis for all the traits studied.

Negative heterosis is desirable for days to 50% flowering as it makes the hybrid to mature earlier compared to their parents. Among the 21 hybrids, fourteen showed significant negative heterosis over mid parent value, twenty showed significant negative heterosis over better parent value, six crosses exhibited significant negative heterosis over inbred check and one cross manifested significant negative heterosis over hybrid check for days to 50% flowering. None of the hybrids showed positive heterobeltiosis for the trait. The heterobeltiosis ranged from -25.22% (IR58025A/BPT 5204) to 0 (IR68897A/Sasyashree). The standard heterosis ranged from -12.9% (IR58025A/HUR 5-2) to 13.98% (IR68897A/BPT 5204). Similarly Tiwari *et al.* (2011) reported heter-obeltiosis in rice ranged from -16.57% to 7.27% and standard heterosis ranged from -4.22% to -16.57%. However, Sen and Singh (2011) has reported positive heterobeltiosis (8.21) for days to 50% flowering in the same crop.

Out of 21, fifteen hybrids recorded significant negative heterosis over mid parent for days to maturity, nineteen hybrids manifested significant negative heteo-sis over better parent, six crosses showed significant standard heterosis over inbred check and two crosses showed significant negative heterosis over hybrid check. Similar result has been reported in rice by Tang *et al.* (2002), Bhandarkar *et al.* (2005) and Gawas *et al.* (2007). Sen and Singh (2011) reported significant negative heterosis in some of the crosses in their study. Soni and Sharma (2011) reported that seven rice hybrids recorded negative heterosis for earliness out of twenty seven hybrids evaluated.

Dwarf and semi dwarf plant height is a desirable character in rice. Positive heterosis may lead to less yield due to unfavorable grain/straw ratio. Dwarfness also avoids lodging. Tall plants require more energy to translocate solutes to the grain and have lower grain weight (Sen and Singh, 2011). Among twenty one hybrids, seven hybrids recorded significant negative heterosis over mid parent, thirteen recorded significant negative heterosis over better parent, seventeen crosses over inbred check and fourteen crosses over hybrid check. Negative heterosis for plant height was also observed by Ghosh (2002), Tang *et al.* (2002), Khoyumthem *et al.* (2005) and Gawas *et al.* (2007). Similar results were observed by Sen and Singh (2011) while studying the heterosis in boro x high yielding varieties of rice.

Out of twenty one, only two crosses (IR68897A/PR-106 and IR68897A/BPT 5204) recorded significant positive heterosis over mid parent for panicles per plant. Eleven crosses observed significant positive heterosis over inbred check and eight crosses showed significant positive hybrid check heterosis. The heter-obeltiosis ranged from -42.75% (IR68897A/Jaya) to 10.14% (IR68897A/HUR 5-2). The standard heterosis ranged from -11.1% (IR58025A/Sarjoo-52) to 55.56% (IR68897A/BPT 5204). Similarly, Tiwari *et al.* (2011) reported heterobeltiosis ranged from -20.66% to 46.61% and standard heterosis ranged from -19.62% to 0.18% in rice hybrids.

Panicle length is an important trait which directly con-tributes to yield. Among 21 hybrids, five recorded sig-nificant positive heterosis over mid parent and ten over standard inbred check for the trait. The standard het-erosis ranged from -28.8% (IR68897A HUR 5-2) to 16.03% (IR58025A/BPT 5204). Similar results has been reported by Sen and Singh (2011) and Tiwari *et al* (2011) which is in accordance to the findings of the present study. However, Gokulakrishnan and Kumar (2013) reported the standard heterosis range of -21.94% to -0.89% for panicle length in rice.

Fifteen hybrids recorded significant positive heterosis over mid parent, thirteen over better parent, sixteen over standard inbred check and ten over standard hy-brid check for the trait, seeds per panicle. More than 50% of the hybrids showed significant positive mid parent, better parent, standard (inbred and hybrid) heterosis for the trait seeds per panicle, which is desirable. Sen and Singh (2011) have reported that significant positive heterosis for number of grains per panicle directly contributes to grain yield in rice.

For yield per plant, out of twenty one, only two hybrids showed significant positive heterosis over mid parent, one over better parent, two over standard inbred check and four over standard hybrid check. In present study, IR68897A/Jaya recorded 37.6% heterosis over standard inbred check (Jaya) and 70.37% heterosis over standard hybrid check (PRH-10). The cross, IR68897A/BPT 5204 recorded 13.9% heterosis over standard inbred check and 41.3% heterosis over standard hybrid check. Virmani *et al.* (1981) suggested that the yield advantage of 20% to 30% over best available standard variety should be sufficient to encourage farmers for adapting the hybrid rice cultivation. The range of standard heterosis was found to be -45.3% (Pusa6A/Sarjoo-52) to 37.6% (IR68897A/Jaya). Kumar *et al.* (2010) reported the standard heterosis ranging from 14.12% to 65.32% and Gokulakrishnan and Kumar (2013) reported the relative heterosis ranging from -29.32% to 65.73% while working on rice crop.

Among the 21, only one hybrid observed significant positive heterosis over better parent and three over standard hybrid check for the trait 100 seed weight. Rest other hybrids showed negative heterosis for the trait. Increase in grains per panicle, panicles per plant and 100 grain weight has positive effects towards higher grain yield. The per se performance of rice hybrids were in general related to the heterotic response for majority of characters (Patil *et al.*, 2012).

For grain length, ten crosses showed significant positive heterosis over mid parent, six over better parent, seven over standard inbred check and four over standard hybrid check. Long grains are more in demand than the shorter ones. Significant positive heterosis is desirable for the trait grain length.

Among twenty one, thirteen hybrids showed significant standard heterosis over mid parent, eight over better parent and six over standard hybrid check for brown rice length. For brown rice width, eight hybrids recorded negative heterosis over mid parent and thirteen over better parent. For brown rice length/width ratio, ten hybrids showed significant positive heterosis over mid parent, five over better parent and two over standard hybrid check. The width of kernel should be less and the high kernel length/width ratio is preferable.

Only one hybrid exhibited significant positive heterosis over mid parent and sixteen showed heterosis over standard inbred check for kernel length. Eleven crosses recorded significant negative heterosis over mid parent and fourteen over better parent for kernel width. All the hybrids showed significant negative standard inbred heterosis for kernel width. It means that all hybrids possess lesser kernel width than inbred check and are therefore better than Jaya with respect to the trait grain width. For kernel length/width ratio, among 21 crosses, seven showed significant positive heterosis over mid parent, two over better parent and one over standard hybrid check. All hybrids showed significant positive heterosis over standard inbred check. It means that all the hybrids in the present study have better Kernel length/width ratio than the inbred check Jaya. Reddy *et al*. (2012) reported that the quantum of superiority expressed by cross combinations in rice over better parent for kernel length and kernel length / breadth ratio, by and large, was very low and for kernel breadth it was low or significant on undesirable side.

There exists the considerable heterosis in both the direction for traits, grain length, grain width, brown rice length, brown rice width, brown rice length/width ratio, kernel length, kernel width, and kernel length/width ratio. Similar trend has been reported for most of the traits in rice by Roy *et al.* (2009), Sen and Singh (2011), Tiwari *et al.* (2011) and Gokulakrishnan and Kumar (2013).

Conclusion

Out of twenty one rice hybrids studied, cross IR68897A/Jaya showed highest positive SCA effect for yield traits. Among the testers, CMS line IR68897A was found to be good general combiner, whereas among the pollen parents, Jaya followed by Swetha and BPT 5204 exhibited good general combining ability. The two best heterotic crosses IR68897A/Jaya and IR68897A/BPT5204 for yield per plant were also found to be heterotic for two or more component traits. The higher magnitude of heterosis for all yield and quality traits were not expressed in any single hybrid combination. Overall, IR68897A/Jaya and IR68897A/BPT 5204 were found outstanding among all crosses for mid parent heterosis, better parent heterosis, standard heterosis, hybrid check heterosis, GCA and SCA effects for yield and some quality traits. It varied from cross to cross due to diverse genetic background of their parents. The rice hybrids recording positive and significant SCA effects and high values of relative heterosis, heterobeltiosis and standard heterosis need to be further tested in multi-location trials to exploit their heterotic potential.

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