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Heterosis for yield and quality traits in rice (*Oryza sativa* L.)

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Abstract: Twenty F_1 hybrids from three CMS lines and eight pollen parents were evaluated to study the heterosis for various yield and quality traits in rice (*Oryza sativa* L.). The findings suggested that the magnitude of heterosis differed from character to character and cross to cross. Majority of the hybrids recorded desirable heterosis for grain yield. Among the rice hybrids exhibiting high heterosis for grain yield, IR-68897A x Pusa Sugandh-3, IR-58025A x HUR-JM-59221 and IR-58025A x Pusa Sugandh-5 were top performers. The hybrid, IR-68897A x Pusa Sugandh-3 recorded highest yield per plant, and was among the best three performers for traits, days to 50% flowering, days to maturity and number of effective tillers per plant. Thus, IR-68897A x Pusa Sugandh-3 may be considered as the best heterotic combination for yield and yield traits. Among the three high yielding hybrids, IR-58025A x Pusa Sugandh-5 was found to be relatively better performing for majority of the quality traits. Thus, IR-58025A x Pusa Sugandh-5 may be considered as the best cross combination if both yield and quality traits are taken into consideration.

Keywords: Cross combination, Heterosis, Quality, Rice, Yield

INTRODUCTION

Rice (*Oryza sativa* L.) is a staple food for nearly half of the world's seven billion people. Global rice production for 2013-14 was estimated as 475.9 million tonnes (on milled basis), over an area of 160.9 million ha. However, more than 90% of rice is grown and consumed in Asia. Rice serves as staple food for nearly 65% of Indians. In India, during 2013-14, rice occupied an area of 43.5 million ha (about 22% of cropped area) with an annual production of 105.0 million tonnes (USDA Rice Outlook, 2014). There is an urgent need to increase rice production to meet the food requirements of ever growing population. Exploitation of heterosis in the form of hybrid rice technology has been contemplated as a potential strategy for yield enhancement in rice. Hybrid rice on average yields 20-25% over the best pure line varieties (Rather *et al.,* 2001). It has been anticipated that hybrid rice technology will play a key role in ensuring food security worldwide in the future decades.

Rice hybrids were first commercialized in the late 1970s in China. Since then many of the rice growing countries has adapted the strategic approach for commercial development of rice hybrids. In China, the area planted to hybrid rice is around 17.0 million hectares, which constitutes about 57% of the total rice area and has an average output capacity of 7.5 tonnes per hectare. India, a predominantly rice growing country has released as many as 65 hybrids for commercial cultivation. In 2013-14, the area of around 1.8 million hectares was planted under hybrid rice in India (USDA Post, 2014). It is expected that area under hybrid rice in India will increase substantially and contribute towards food security.

Significant heterosis in rice have been reported by various workers (Rashid *et al.,* 2007; Bagheri and Jelodar, 2010; Rahimi *et al.*, 2010; Latha *et al.*, 2013). Although, research on the commercial utilization of heterosis in rice has made tremendous gains during the last 20 years, it is still in its stage of infancy due to the lack of desirable quality of F_1 produce. Nowadays, quality considerations assume enhanced importance and most of the rice producing countries are pursuing to improve the quality of their produce, either for national consumption or as a revenue generating export. As living conditions are steadily improving, human demand for better quality rice is continuously on increase. This requires the incorporation of preferred grain quality features as the most important objective next to yield enhancement. Juliano and Duff (1991) surveyed 11 major rice growing countries and concluded that grain quality is second only to yield as the major breeding objective. In near future, grain quality will be even more important as once the very poor, many of whom depend on rice for their staple food become prosperous and begin to demand for higher quality rice (Welch and Graham, 2002). Thus, the most important challenge in hybrid rice breeding is to ensure that the heterotic rice hybrids possess grain quality that

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is at least comparable, if not superior, to that of popular inbred varieties grown by farmers. Thus, it is imperative that along with the yield and yield attributes, higher magnitude of heterosis for quality traits be taken into consideration during the commercial development of rice hybrids. In the present study, 20 rice hybrids obtained from three CMS lines and eight restorers were evaluated for their heterotic values with respect to both yield and quality traits.

MATERIALS AND METHODS

The present study was carried out during two seasons *viz.,* kharif-2012 and kharif-2013 at the Agricultural Research Farm, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi (UP). The site of study is situated at 25^0 18´ N latitude and 83^0 03´ E longitude, at an elevation of 80.71 m above mean sea level. The research material consists of three WA cytoplasmic male sterile (CMS) lines (IR-58025A, IR-68897A and Pusa 6A) and eight genotypes (Sanwal Basmati, Pusa Sugandh-2, Pusa Sugandh-3, Pusa Sugandh-5, Pusa 2517-2-51-1, HUR-JM-59221, Pusa-44 and Pusa Basmati-1121) identified as fertility restorers for the respective CMS lines. All the 11 genotypes were obtained from 'All India Coordinated Rice Improvement Project (AICRIP)' at the Department of Genetics and Plant Breeding, Institute of Agricultural Sciences, Banaras Hindu University.

During kharif-2012, all the genotypes were seeded in nursery at 3 dates, 10 days apart and transplanted in crossing blocks at 21 days after sowing. Six genotypes (Sanwal Basmati, Pusa Sugandh-2, Pusa Sugandh-3, Pusa Sugandh-5, Pusa 2517-2-51-1 and HUR-JM-59221) were crossed with all the three CMS lines. Moreover, Pusa-44 and Pusa Basmati-1121were crossed with IR-58025A and IR-68897A, respectively. Thus, the set of 20 rice hybrids were generated. In kharif-2013, the seed of F_1 hybrids generated during previous season along with the parental lines and check varieties were raised at a standard spacing of 20 x 15 cm in 5 m rows in randomized block design with three replications. The recommended package of practices was followed to raise a good crop.

Mean performance of hybrids along with their parental lines and checks were studied for both yield and quality traits. Heterosis was estimated for various yield and quality traits over respective better parent and over the standard varieties for all the 20 hybrids following the procedure out lined by Liang *et al.* (1972). For yield traits, the heterosis was estimated for days to 50 percent flowering, days to maturity, plant height, number of effective tillers per plant, 100 grain weight and grain yield per plant. In case of quality traits, heterosis was estimated for hulling recovery, milling recovery, head rice recovery, kernel length before cooking, kernel breadth before cooking, kernel length after cooking and kernel breadth after cooking. The significance of different types of heterosis was evaluated by the estimates of critical differences (C.D.) for various traits at 0.05 and 0.01 levels of significance. For the quality parameters *viz.,* kernel length/breadth ratio before cooking, kernel length/breadth ratio after cooking, kernel elongation ratio, elongation index, alkali spread value, amylose content and aroma, heterotic values were not estimated by usual calculations. For all such traits, the performance of F_1s was evaluated by simple comparison between their mean values and that of standard checks.

Kernel dimensional analysis was done with the help of electronic grain analyzer. Alkali digestion was estimated by the test devised by Little *et al.* (1958). The simplified calorimetric method described by Juliano (1971) was followed for the estimation of amylose content. Aroma was estimated on the scale from 1-4 (1= non aromatic; 2= slightly aromatic; 3= moderately aromatic and 4= strongly aromatic) following the method suggested by Sood and Siddiq (1978). Pusa Basmati-1 (yield check), Taraori Basmati (quality check) and Pusa RH-10 (hybrid check for both yield and quality) were used as standard varieties for comparison of yield and quality attributes of the F_1 hybrids. Due to the male sterile nature of the CMS or female lines, their corresponding maintainer lines were used for studying yield and quality traits.

RESULTS AND DISCUSSION

Twenty F_1 hybrids from three CMS lines and eight pollen parents were evaluated in the present investigation to study the heterosis for various yield and quality traits in rice. Analysis of variance for the treatments (parents and hybrids) revealed that all the genotypes expressed significant differences (at 0.001 level of significance) for both yield and quality traits (Table 1).

Estimation of heterosis for yield and yield traits: Heterosis for yield and yield traits in rice over the respective better parents and over the standard checks have been presented in Table 2. In case of yield traits, Pusa Basmati-1 and Pusa RH-10 were used for the estimation of standard heterosis over pureline check and hybrid check, respectively. For some of the traits, negative heterotic value is considered to be desirable, while in others positive heterotic estimates are usually preferable.

For days to 50 per cent flowering, negative value of heterosis is desirable as early flowering is usually associated with early maturity. It enhances the productivity per day per unit area. The heterobeltiosis and heterosis over Pusa RH-10 for days to 50 per cent flowering revealed both negative as well as positive values depending upon the cross combination. But, over Pusa Basamti-1, only early flowering hybrids were observed. As compared to respective better parents and Pusa RH-10, significantly earlier flowering was observed in three crosses. However, over Pusa Basmati-1, 19 hybrids displayed significant estimate of negative heterosis. Cross combination IR-68897A x Pusa Su-

Table 1. Analysis of variance for various yield and quality traits.

S. No.	Characters	Mean squares		
		Replication (d.f.= 2)	**Treatment (d.f.= 32)**	**Error (d.f.= 64)**
1	Days to 50 percent flowering	8.70707	151.31124***	3.43624
2	Days to maturity	3.03030	171.61364***	1.87405
3	Plant height	9.61026	269.08306***	4.77087
4	Number of effective tillers/plant	0.97485	10.89213***	1.30474
5	100 grain weight	0.00089	0.16543***	0.00140
6	Yield per plant	0.65925	103.10449***	2.03285
7	Hulling recovery	0.24395	14.19876***	1.08882
8	Milling recovery	1.42565	14.53662***	1.47804
9	Head rice recovery	3.61455	177.30576***	1.54682
10	Kernel length before cooking	0.00011	0.86328***	0.00203
11	Kernel breadth before cooking	0.00005	0.04711***	0.00046
12	Kernel length after cooking	0.00407	11.13118***	0.00243
13	Kernel breadth after cooking	0.00040	0.19223***	0.00061

*, **, *** = Significant at 0.05, 0.01 and 0.001 levels, respectively

gandh-5 recorded the highest negative value for all the three types of heterosis. A wide range of standard heterosis from negative to positive values have been reported by Leenakumari *et al.* (1998), Rahimi *et al.* (2010) and Latha *et al.* (2013) for the trait days to 50 per cent flowering in rice. Only negative values of standard heterosis for days to 50 per cent flowering in rice were reported by Young and Virmani (1990), Patil *et al.* (2003) and Tiwari *et al.* (2011). However, Lingaraju *et al.* (1999), and Sen and Singh (2011) reported positive heterotic values for days to 50 per cent flowering in their studies.

The negative value of heterosis for days to maturity is desirable because short duration varieties are generally preferable. The heterobeltiosis and heterosis over Pusa RH-10 for days to maturity evinced both negative as well as positive values depending upon the cross combination. With respect to Pusa Basamti-1, only early maturing hybrids were observed. Four crosses were observed to show significantly early flowering (at 0.01 level of significance) over the respective better parents, while all the 20 hybrids revealed significant negative heterosis (at 0.01 level of significance) over Pusa Basmati-1. However, only three hybrids exhibited significantly early flowering than Pusa RH-10. The hybrid, IR-68897A x Pusa Sugandh-5 recorded highest negative value for all the three types of heterosis studied. Significant desirable standard heterosis for earliness in rice has been reported by Bhandarkar *et al.* (2005), Gawas *et al.* (2007), Jayashudha and Sharma (2009) and Rahimi *et al.* (2010). However, Sen and Singh (2011), and Soni and Sharma (2011) reported significantly early maturity in only some of the crosses of rice.

Semi-dwarf plant height and hence negative value of heterosis is desirable for recording high yield in rice as vigour in plant height may lead to unfavourable grain/ straw ratio and below optimum yield due to lodging. Tall plants require more energy to translocate solutes to the sink (grain) and thereby lower grain weight (Sen and Singh, 2011). For plant height, all the F_1s were observed to be taller than their respective better parents. Although, heterotic response of F_1s over the standard checks varied in both positive and negative directions, most of the hybrids studied showed greater tendency towards tallness. It confirms the findings of Pandey *et al.* (1995) who reported that most of the hybrids studied manifested significant positive heterosis for tallness. Though, none of the hybrids exhibited significant negative value of heterobeltiosis, seven and five hybrids were observed to show the significantly dwarf plants than Pusa Basmati-1 and Pusa RH-10, respectively. Hybrid, IR-58025A x Pusa-44 recorded the highest desirable value for all the three types of heterosis. Sarawgi *et al.* (2000), Tiwari *et al.* (2011), and Sanghera and Hussain (2012) reported significant positive estimates of heterobeltiosis and standard heterosis (at 0.05 and 0.01 levels of significance) for tallness in rice as revealed in the present investigation. Negative heterotic values for plant height in rice were observed by Khoyumthem *et al.* (2005) and Gawas *et al.* (2007).

The positive value of heterosis for number of effective tillers per plant is desirable as more number of panicle bearing tillers is believed to be closely associated with higher grain yield. In the present study, both positive and negative heterotic values for number of effective tillers per plant were observed over respective better parents and over Pusa Basmati-1. Both positive and negative heterotic values for number of effective tillers per plant in different cross combinations of rice were also reported by Tiwari *et al.* (2011). However, all the hybrids in present study revealed higher number of tillers than Pusa RH-10. None of the cross combinations recorded significant positive value of heterobeltiosis. Nevertheless, two and 12 cross combinations

Table 2. Estimates of heterobeltiosis and standard heterosis for yield and yield attributes.

Cross combination	Days to 50% flowering			Days to maturity			Plant height			Effective tillers per plant			100 grain weight			Yield per plant		
	BP	SH1	SH2	BP	SH1	SH2	BP	SH1	SH2	BP	SH1	SH2	BP	SH1	SH2	BP	SH1	SH2
IR-58025A x Sanwal Basmati	12.11**	-10.31**	5.90**	7.56**	-12.11**	3.64**	38.21**	14.40**	16.22**	-12.97	-0.73	25.62*	-0.94	-1.10	-9.50**	20.68**	76.84**	6.45
IR-58025A x Pusa Sugandh-2	5.86**	-15.31**	0.00	4.94**	-14.25**	1.12	19.30**	-1.25	0.31	-14.30	-2.24	23.71*	-0.67	16.19**	6.33**	17.60**	72.33**	3.73
IR-58025A x Pusa Sugandh-3	7.42**	-14.06**	1.48	3.78**	-15.20**	0.00	18.52**	-1.90	-0.34	-27.30**	-17.07*	4.94	-12.26**	14.78**	5.04**	26.45**	85.30**	11.54*
IR-58025A x Pusa Sugandh-5	8.20**	-13.44**	2.21	4.65**	-14.49**	0.84	20.45**	-0.30	1.28	-22.37**	-11.44	12.06	-6.16**	14.94**	5.18**	31.21**	92.27**	15.74**
IR-58025A x Pusa 2517-2-51-1	6.25**	-15.00**	0.37	4.94**	-14.25**	1.12	24.71**	3.23	4.86**	-18.15*	-6.63	18.15	-4.44**	18.55**	8.49**	28.43**	88.20**	13.29**
IR-58025A x HUR-JM-59221	23.05**	-1.56	16.24**	16.86**	-4.51**	12.61**	20.84**	0.02	1.61	-25.79**	-15.35	7.12	-6.44**	9.59**	0.29	31.73**	93.03**	16.19**
IR-58025A x Pusa-44	12.89**	-9.69**	6.64**	9.59**	-10.45**	5.60**	5.81**	-12.42**	-11.03**	-17.19*	-5.54	19.53	-3.46*	-3.62*	-11.80**	20.86**	77.11**	6.61
IR-68897A x Sanwal Basmati	2.51	-10.63**	5.54**	1.36	-11.16**	4.76**	42.83**	11.82**	13.60**	-0.84	17.34*	48.49**	8.35**	8.18**	-1.01	31.35**	86.61**	12.33*
IR-68897A x Pusa Sugandh-2	-2.51	-15.00**	0.37	-3.52**	-15.44**	-0.28	12.29**	-12.08**	-10.69**	-2.74	15.10	45.65**	-4.44**	11.79**	2.30	5.08	49.28**	-10.14*
IR-68897A x Pusa Sugandh-3	-7.17**	-19.06**	-4.43*	-7.32**	-18.76**	-4.20**	17.76**	-7.80**	-6.34**	10.18	30.39**	64.99**	-12.86**	13.99**	4.32**	37.81**	95.77**	17.84**
IR-68897A x Pusa Sugandh-5	-8.60**	-20.31**	-5.90**	-8.40**	-19.71**	-5.32**	17.98**	-7.63**	-6.16**	-7.08	9.96	39.14**	-8.34**	12.26**	2.73*	8.94	54.77**	-6.84
IR-68897A x Pusa 2517-2-51-1	-8.24**	-20.00**	-5.54**	-8.13**	-19.48**	-5.04**	15.53**	-9.55**	-8.12**	-16.24*	-0.88	25.43*	-8.24**	13.84**	4.17**	6.31	51.03**	-9.09
IR-68897A x HUR-JM-59221	4.66**	-8.75**	7.75**	2.71**	-9.98**	6.16**	29.90**	1.70	3.31	-16.83*	-1.57	24.55*	0.00	17.14**	7.19**	33.26**	89.31**	13.95**
IR-68897A x Pusa Basmati-1121	6.81**	-6.88**	9.96**	3.79**	-9.03**	7.28**	22.51**	-4.08*	-2.56	-5.09	12.32	42.13**	-11.08**	12.26**	2.73*	19.39**	69.60**	2.09
Pusa 6A x Sanwal Basmati	9.73**	-11.88**	4.06*	7.58**	-12.35**	3.36**	44.10**	16.96**	18.82**	-25.49**	3.45	30.91**	-2.68	-2.83	-11.08**	24.33**	68.81**	1.61
Pusa 6A x Pusa Sugandh-2	5.45**	-15.31**	0.00	4.96**	-14.49**	0.84	20.51**	-2.18	-0.63	-35.03**	-9.81	14.13	-1.21	15.57**	5.76**	38.27**	87.74**	13.01**
Pusa 6A x Pusa Sugandh-3	2.72	-17.50**	-2.58	2.92**	-16.15**	-1.12	24.42**	0.98	2.58	-39.15**	-15.53	6.89	-7.93**	20.44**	10.22**	37.67**	86.92**	12.51**
Pusa 6A x Pusa Sugandh-5	7.39**	-13.75**	1.85	5.25**	-14.25**	1.12	18.90**	-3.49*	-1.96	-24.20**	5.24	33.17**	-7.57**	13.21**	3.60**	3.36	40.34**	-15.53**
Pusa 6A x Pusa 2517-2-51-1	6.23**	-14.69**	0.74	4.96**	-14.49**	0.84	22.04**	-0.95	0.62	-27.40**	0.79	27.54*	-1.14	22.64**	12.23**	40.32**	90.52**	14.69**
Pusa 6A x HUR-JM-59221	18.68**	-4.69**	12.55**	12.83**	-8.08**	8.40**	38.58**	12.48**	14.26**	-37.96**	-13.86	9.00	-4.43**	11.95**	2.45	14.28*	59.95**	-3.72
Overall mean	5.67	-12.89	2.86	3.56	-13.43	2.09	23.76	-0.10	1.48	-18.30	-0.30	26.16	-4.80	11.99	2.48	23.87	75.79	5.81
Range of heterosis	-8.60 -to 23.05	-20.31 to -1.56	-5.90 to 16.24	-8.40 to 16.86	-19.71 to -4.51	-5.32 to 12.61	5.81 to 44.10	-12.42 to 16.96	-11.03 to 18.82	-39.15 to 10.18	-17.07 to 30.39	4.94 to 64.99	-12.86 to 8.35	-3.62 to 22.64	-11.80 to 12.23	3.36 to 40.32	40.34 to 95.77	-15.53 to 17.84
Number of hybrids with significant positive heterosis	14	0	8	15	0	8	20	4	5	0	2	12	1	17	13	16	20	10
Number of hybrids with significant negative heterosis	3	19	3	4	20	3	0	7	5	13	1	0	13	1	3	0	0	2

Table 3. Estimates of heterobeltiosis and standard heterosis for quality traits.

Cross combination	Hulling recovery			Milling recovery			Head rice recovery		
	BP	SH1	SH2	BP	SH1	SH2	BP	SH1	SH2
IR-58025A x Sanwal Basmati	0.22	4.57**	1.98	2.79	1.65	1.95	0.69	25.53**	29.72**
IR-58025A x Pusa Sugandh-2	-0.16	3.35**	0.79	-0.97	-1.73	-1.44	-21.38**	-1.99	1.28
IR-58025A x Pusa Sugandh-3	1.43	5.23**	2.63*	-2.31	1.99	2.29	-12.02**	9.69**	13.35**
IR-58025A x Pusa Sugandh-5	0.18	6.22**	3.58**	0.10	1.44	1.74	-11.48**	13.40**	17.18**
IR-58025A x Pusa 2517-2-51-1	-1.33	2.13	-0.40	-0.29	-1.39	-1.10	-15.03**	5.93*	9.46**
IR-58025A x HUR-JM-59221	-3.53**	4.44**	1.85	-6.69**	0.99	1.28	-22.22**	18.75**	22.71**
IR-58025A x Pusa-44	0.56	5.91**	3.29**	-0.97	4.12**	4.43**	-21.27**	11.77**	15.49**
IR-68897A x Sanwal Basmati	2.85*	7.32**	4.66**	7.56**	2.11	2.41	24.07**	9.13**	12.77**
IR-68897A x Pusa Sugandh-2	5.67**	5.97**	3.34**	2.02	1.24	1.54	-15.34**	-3.59	-0.37
IR-68897A x Pusa Sugandh-3	-0.48	3.25**	0.70	-6.10**	-1.97	-1.68	-14.14**	-11.41**	-8.46**
IR-68897A x Pusa Sugandh-5	-2.31*	3.57**	1.00	-3.27*	-1.97	-1.68	-34.80**	-16.47**	-13.69**
IR-68897A x Pusa 2517-2-51-1	7.52**	6.22**	3.59**	8.78**	4.02**	4.32**	10.48**	27.05**	31.29**
IR-68897A x HUR-JM-59221	-2.18*	5.90**	3.28**	-6.56**	1.13	1.43	-27.02**	11.42**	15.13**
IR-68897A x Pusa Basmati-1121	6.17**	5.58**	2.96*	2.06	1.36	1.66	-22.59**	0.38	3.73
Pusa 6A x Sanwal Basmati	1.80	6.23**	3.60**	9.30**	3.77*	4.07**	22.23**	6.76**	10.32**
Pusa 6A x Pusa Sugandh-2	3.47**	5.69**	3.08**	3.41*	2.62	2.92	-4.71*	8.52**	12.14**
Pusa 6A x Pusa Sugandh-3	4.04**	7.95**	5.27**	-0.26	4.13**	4.44**	-9.61**	-6.74**	-3.63
Pusa 6A x Pusa Sugandh-5	4.08**	10.35**	7.61**	-0.05	1.29	1.59	-33.10**	-14.29**	-11.44**
Pusa 6A x Pusa 2517-2-51-1	3.08**	5.30**	2.69*	2.33	-2.15	-1.87	-26.74**	-15.76**	-12.95**
Pusa 6A x HUR-JM-59221	0.54	8.85**	6.16**	-9.20**	-1.73	-1.44	-42.94**	-12.89**	-9.99**
Overall mean	1.58	5.70	3.08	0.08	1.05	1.34	-13.85	3.26	6.70
Range of heterosis	-3.53 to 7.52	2.13 to 10.35	-0.40 to 7.61	-9.20 to 9.30	-2.15 to 4.13	-1.87 to 4.44	-42.94 to 24.07	-16.47 to 27.05	-13.69 to 31.29
Number of hybrids with significant positive heterosis	8	19	14	4	4	4	3	11	11
Number of hybrids with significant negative heterosis	3	0	0	5	0	0	16	6	5

Table 3 . Cont…

	Kernel length before cooking			Kernel breadth before cooking			Kernel length after cooking			Kernel breadth after cooking		
Cross combination	**BP**	**SH1**	**SH2**	**BP**	**SH1**	**SH2**	**BP**	**SH1**	**SH2**	**BP**	**SH1**	**SH2**
IR-58025A x Sanwal Basmati	0.28	-1.21*	-0.19	1.08	-7.13**	-6.94**	-9.03**	-15.49**	-19.75**	-10.36**	-1.82*	-10.59**
IR-58025A x Pusa Sugandh-2	0.00	6.65**	7.75**	13.36**	4.16**	4.37**	-11.53**	-15.72**	-19.97**	13.04**	14.15**	3.95**
IR-58025A x Pusa Sugandh-3	-7.54**	4.88**	5.97**	6.90**	-1.78	-1.59	-21.10**	-14.27**	-18.59**	-10.87**	-2.38**	-11.10**
IR-58025A x Pusa Sugandh-5	-5.39**	4.51**	5.59**	-2.37*	-10.30**	-10.12**	-20.76**	-15.82**	-20.06**	-23.37**	-22.41**	-29.34**
IR-58025A x Pusa 2517-2-51-1	2.54**	9.07**	10.20**	10.78**	1.78	1.98	-17.99**	-15.19**	-19.47**	9.93**	8.54**	-1.15
IR-58025A x HUR-JM-59221	-0.19	-2.28**	-1.27*	21.77**	11.88**	12.10**	-10.58**	-22.60**	-26.50**	-4.60**	4.48**	-4.85**
IR-58025A x Pusa-44	3.14**	-8.28**	-7.33**	10.99**	1.98	2.18*	4.47**	-20.98**	-24.96**	11.51**	22.13**	11.22**
IR-68897A x Sanwal Basmati	-5.85**	-7.26**	-6.30**	13.59**	10.89**	11.11**	-22.26**	-27.78**	-31.42**	-3.98**	11.62**	1.66*
IR-68897A x Pusa Sugandh-2	-3.14**	3.30**	4.37**	-6.38**	1.78	1.98	-19.60**	-23.40**	-27.26**	4.85**	5.88**	-3.57**
IR-68897A x Pusa Sugandh-3	-7.67**	4.74**	5.83**	-1.15	2.57*	2.78**	-29.72**	-23.63**	-27.48**	-12.93**	-3.78**	-12.37**
IR-68897A x Pusa Sugandh-5	-9.09**	0.42	1.46**	-3.02**	-4.75**	-4.56**	-21.42**	-16.52**	-20.73**	6.64**	7.98**	-1.66*
IR-68897A x Pusa 2517-2-51-1	-2.71**	3.49**	4.56**	2.24*	8.51**	8.73**	-23.29**	-20.68**	-24.67**	-3.55**	-4.76**	-13.27**
IR-68897A x HUR-JM-59221	-3.56**	-5.58**	-4.61**	5.42**	15.64**	15.87**	-4.48**	-17.32**	-21.49**	-4.62**	18.49**	7.91**
IR-68897A x Pusa Basmati-1121	-11.67**	1.40**	2.44**	5.71**	6.34**	6.55**	-43.04**	-19.75**	-23.79**	16.17**	9.66**	-0.13
Pusa 6A x Sanwal Basmati	-2.31**	-3.77**	-2.77**	14.19**	1.98	2.18*	-12.96**	-19.15**	-23.22**	7.65**	10.36**	0.51
Pusa 6A x Pusa Sugandh-2	0.65	7.35**	8.46**	11.53**	-0.40	-0.20	-15.53**	-19.52**	-23.58**	-3.33**	-2.38**	-11.10**
Pusa 6A x Pusa Sugandh-3	-8.28**	4.05**	5.12**	7.98**	-3.56**	-3.37**	-6.50**	1.60**	-3.52**	3.55**	6.16**	-3.32**
Pusa 6A x Pusa Sugandh-5	-5.85**	4.00**	5.08**	2.66*	-8.32**	-8.13**	-18.00**	-12.89**	-17.28**	0.97	2.24*	-6.89**
Pusa 6A x Pusa 2517-2-51-1	-0.44	5.91**	7.00**	13.53**	1.39	1.59	-20.62**	-17.92**	-22.06**	-0.14	-1.40	-10.20**
Pusa 6A x HUR-JM-59221	-3.56**	-5.58**	-4.61**	15.08**	2.77**	2.98**	-5.64**	-18.32**	-22.44**	6.83**	9.52**	-0.26
Overall mean	-3.53	1.29	2.34	7.19	1.77	1.97	-16.48	-17.77	-21.91	0.17	4.61	-4.73
Range of heterosis	-11.67 to 3.14	-8.28 to 9.07	-7.33 to 10.20	-6.38 to 21.77	-10.30 to 15.64	-10.12 to 15.87	-43.04 to 4.47	-27.78 to 1.60	-31.42 to -3.52	-23.37 to 16.17	-22.41 to 22.13	-29.34 to 11.22
Number of hybrids with significant positive heterosis	2	12	13	15	8	10	1	1	0	9	13	4
Number of hybrids with significant negative heterosis	13	7	6	3	5	5	19	19	20	9	6	12

Table 4. Mean performance of hybrids and the check varieties for kernel length/breadth ratio before, kernel length/breadth ratio after cooking, elongation ratio and elongation index.

Genotypes	Kernel length/ breadth ratio before cooking	Kernel length/breadth ratio after cooking	Elongation ratio	Elongation index
Cross combination				
IR-58025A x Sanwal Basmati	4.53	4.82	1.59	1.06
IR-58025A x Pusa Sugandh-2	4.36	4.13	1.47	0.95
IR-58025A x Pusa Sugandh-3	4.55	4.91	1.52	1.08
IR-58025A x Pusa Sugandh-5	4.96	6.07	1.50	1.22
IR-58025A x Pusa 2517-2-51-1	4.56	4.37	1.44	0.96
IR-58025A x HUR-JM-59221	3.72	4.15	1.47	1.11
IR-58025A x Pusa-44	3.83	3.62	1.60	0.95
IR-68897A x Sanwal Basmati	3.56	3.62	1.45	1.02
IR-68897A x Pusa Sugandh-2	4.32	4.05	1.38	0.94
IR-68897A x Pusa Sugandh-3	4.35	4.44	1.35	1.02
IR-68897A x Pusa Sugandh-5	4.49	4.33	1.54	0.96
IR-68897A x Pusa 2517-2-51-1	4.06	4.66	1.42	1.15
IR-68897A x HUR-JM-59221	3.48	3.90	1.63	1.12
IR-68897A x Pusa Basmati-1121	4.06	4.09	1.47	1.01
Pusa 6A x Sanwal Basmati	4.02	4.10	1.56	1.02
Pusa 6A x Pusa Sugandh-2	4.59	4.61	1.39	1.01
Pusa 6A x Pusa Sugandh-3	4.59	5.35	1.81	1.17
Pusa 6A x Pusa Sugandh-5	4.83	4.77	1.56	0.99
Pusa 6A x Pusa 2517-2-51-1	4.45	4.66	1.44	1.05
Pusa 6A x HUR-JM-59221	3.91	4.17	1.61	1.07
Check varieties				
Taraori Basmati	4.26	5.60	1.86	1.31
Pusa RH-10	4.22	5.37	1.98	1.27

Table 5. Mean performance of hybrids and the check varieties for alkali digestion, gelatinization temperature, amylose content and aroma.

Genotypes	Alkali spread value	Gelatinization Temperature (^{0}C)	Amylose content (%)	Aroma
Cross combinations				
IR-58025A x Sanwal Basmati	6.28 (High)	65-69(Low)	20.24 (Intermediate)	3(Moderate)
IR-58025A x Pusa Sugandh-2	5.84 (High)	65-69(Low)	21.42 (Intermediate)	3(Moderate)
IR-58025A x Pusa Sugandh-3	6.27 (High)	65-69(Low)	24.19 (Intermediate)	3(Moderate)
IR-58025A x Pusa Sugandh-5	6.22 (High)	65-69(Low)	23.43 (Intermediate)	3(Moderate)
IR-58025A x Pusa 2517-2-51-1	5.87 (High)	65-69(Low)	19.11(Low)	3(Moderate)
IR-58025A x HUR-JM-59221	6.71 (High)	65-69(Low)	22.31 (Intermediate)	1(Absent)
IR-58025A x Pusa-44	6.53 (High)	65-69(Low)	18.56 (Low)	1(Absent)
IR-68897A x Sanwal Basmati	3.64 (Intermediate)	70-74(Intermediate)	21.74 (Intermediate)	3(Moderate)
IR-68897A x Pusa Sugandh-2	6.39 (High)	65-69(Low)	23.19 (Intermediate)	3(Moderate)
IR-68897A x Pusa Sugandh-3	6.40 (High)	65-69(Low)	23.80 (Intermediate)	3(Moderate)
IR-68897A x Pusa Sugandh-5	6.37 (High)	65-69(Low)	23.21 (Intermediate)	2(Slight)
IR-68897A x Pusa 2517-2-51-1	6.15 (High)	65-69(Low)	21.78 (Intermediate)	3(Moderate)
IR-68897A x HUR-JM-59221	6.80 (High)	65-69(Low)	22.82 (Intermediate)	1(Absent)
IR-68897A x Pusa Basmati-1121	6.23 (High)	65-69(Low)	22.72 (Intermediate)	3(Moderate)
Pusa 6A x Sanwal Basmati	5.12 (Intermediate)	70-74(Intermediate)	20.85 (Intermediate)	3(Moderate)
Pusa 6A x Pusa Sugandh-2	6.12 (High)	65-69(Low)	22.57 (Intermediate)	3(Moderate)
Pusa 6A x Pusa Sugandh-3	4.57 (Intermediate)	70-74(Intermediate)	24.31 (Intermediate)	3(Moderate)
Pusa 6A x Pusa Sugandh-5	6.07 (High)	65-69(Low)	23.19 (Intermediate)	3(Moderate)
Pusa 6A x Pusa 2517-2-51-1	6.25 (High)	65-69(Low)	20.47 (Intermediate)	4(Strong)
Pusa 6A x HUR-JM-59221	5.73 (High)	65-69(Low)	22.23 (Intermediate)	3(Moderate)
Checks				
Taraori Basmati	5.08 (Intermediate)	70-74(Intermediate)	20.52 (Intermediate)	4(Strong)
Pusa RH-10	6.02 (High)	65-69(Low)	22.48 (Intermediate)	3(Moderate)

showed significant positive heterosis over Pusa Basmati-1 and Pusa RH-10, respectively. Cross combination, IR-68897A x Pusa Sugandh-3 registered the highest significant positive heterosis over both the standard checks. Significantly positive heterosis for number of effective tillers in rice has also been reported by Sarawgi *et al.* (2000), Vaithiyalingan and Nadarajan (2010), and Latha *et al.* (2013).

The positive estimate of heterosis for 100 grain weight is desirable as it is an important trait influencing yield. Both positive and negative heterotic values for 100 grain weight among different cross combinations were observed in the present study. Only one hybrid showed significant positive heterosis over its better parent. However, 17 and 13 hybrids recorded significantly higher 100 grain weight than Pusa Basmati-1 and Pusa RH-10, respectively. Highest positive value of heterobeltiosis was evinced by IR-68897A x Sanwal Basmati, while the highest desirable positive estimate of standard heterosis over both the checks was exhibited by Pusa 6A x Pusa 2517-2-51-1. Similar results for 100 grain weight in rice were also observed by Virmani *et al.* (1981), Rahimi *et al.* (2010), Tiwari *et al.* (2011), and Gokulakrishnan and Kumar (2013). However, Vaithiyalingan and Nadarajan (2010), and Latha *et al.* (2013) reported only negative heterotic values for test weight in rice.

Heterosis for grain yield in positive direction is desirable as higher grain yield is the main objective for almost all the breeding programmes. 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 varieties. In the present investigation, all the hybrids revealed higher heterotic values for grain yield per plant over their better parents and over Pusa Basmati-1. However, with respect to Pusa RH-10, both higher and lower grain yields were observed depending upon the cross combination. Sixteen hybrids exhibited significant positive heterosis over their better parents, whereas all the 20 hybrids revealed significantly higher yields (at 0.01 level of significance) than Pusa Basmati-1. Moreover, 10 cross combinations recorded significant positive heterosis over Pusa RH-10. Thus, most of the hybrids revealed higher grain yield than parental lines as well as check varieties. Cross combination, Pusa 6A x Pusa 2517-2-51-1 recorded the highest positive value of heterobeltiosis. However, highest value of standard heterosis over both the checks was recorded by IR-68897A x Pusa Sugandh-3. High magnitude of standard heterosis for grain yield in rice as observed in the present study, have also been reported by Kumar *et al.* (2010), Rahimi *et al.* (2010) and Reddy *et al.* (2012). However, a wide range of heterosis between negative and positive values for grain yield in rice have been reported by Lingaraju *et al.* (1999), Vaithiyalingan and Nadarajan (2010), Tiwari *et al.* (2011), Gokulakrishnan and Kumar (2013), and Latha *et al.* (2013).

Estimation of heterosis for quality traits: Heterosis for various quality traits over the respective better parents and over the standard checks have been presented in Table 3. For the quality traits where usual calculations of heterosis were not applied, the mean values of F_1s and that of standard checks have been given (Tables 4 and 5). In all the quality traits, Taraori Basmati and Pusa RH-10 were used for evaluating the performance of F_1 hybrids over pureline check and hybrid check, respectively. For some of the quality traits, negative heterotic value is considered to be desirable, while in others positive heterotic estimates are usually preferable.

Hulling recovery is an important factor deciding the amount of marketable produce. Its positive heterotic value is desirable. Heterobeltiosis and heterosis over Pusa RH-10 revealed both positive and negative values for hulling recovery depending upon the cross combination. However, all the hybrids show higher hulling recovery than Taraori Basmati. Eight hybrids displayed significant positive heterosis over the corresponding better parents, while 19 and 14 hybrids recorded the significant positive value of standard heterosis over Taraori Basmati and Pusa RH-10, respectively. The highest value of better parent heterosis was exhibited by IR-68897A x Pusa 2517-2-51-1, whereas the maximum estimate of standard heterosis over both the check varieties was recorded by Pusa 6A x Pusa Sugandh-5. Singh (2000) observed significant negative standard heterosis for hulling recovery in majority of the rice hybrids studied.

Milling recovery is also an important factor deciding the amount of marketable produce and its positive heterosis is desirable. For milling recovery, heterosis over respective better parents and over the standard checks varied both in positive and negative directions depending upon the cross combination. Heterobeltiosis as well as standard heterosis over both the checks were observed to show significant positive values for four different cross combinations. Highest positive value of better parent heterosis was revealed by Pusa 6A x Sanwal Basmati, whereas Pusa 6A x Pusa Sugandh-3 recorded the highest value of milling recovery over both the checks. The range of heterosis reported by Sarawgi *et al.* (2000) for milling recovery in rice is in accordance with the present findings.

Higher value of head rice recovery leads to substantial production of marketable produce and thus its positive heterotic value is considered to be desirable. For head rice recovery, heterosis over the better parents and over the standard checks varied in both desirable and undesirable directions depending upon the cross combination. Significant positive heterobeltiosis was observed for three hybrids, while 11 hybrids displayed significantly higher head rice recovery than Taraori Basmati and Pusa RH-10. Highest positive value of heterobeltiosis was revealed by IR-68897A x Sanwal

Basmati, while IR-68897A x Pusa 2517-2-51-1 recorded highest positive value of standard heterosis over both check varieties. Sarawgi *et al.* (2000) reported that the range of heterosis for head rice recovery varied in both positive and negative directions, which is quite similar to the results of present investigation.

Higher estimate of kernel length before cooking is one of the most important grain quality traits and hence its heterosis in positive direction is desirable. Kernel length before cooking for different cross combinations revealed both high and low values than respective better parents and standard checks. Only two hybrids recorded significant positive value of heterosis (at 0.01 level of significance) over their better parents, while 12 and 13 cross combinations revealed significantly higher kernel length (at 0.01 level of significance) than Taraori Basmati and Pusa RH-10, respectively. IR-58025A x Pusa-44 recorded the highest positive value of better parent heterosis, while IR-58025A x Pusa 2517-2-51-1 exhibited the highest positive value of heterosis over both the checks. Vivekanandan and Giridharan (1996) also reported negative as well as positive heterobeltiosis for kernel length in rice. However, Reddy *et al.* (2012) and Priyanka *et al.* (2014) reported positive estimates of standard heterosis for kernel length in the same crop. In contrast, Sarawgi *et al.* (2000) reported the estimates of standard heterosis in negative direction only.

Lower value of kernel breadth before cooking ensures grain fineness. Thus, negative value of heterosis for kernel breadth before cooking would be desirable. Heterobeltiosis and heterosis over the checks for kernel breadth revealed both positive and negative values depending upon the cross combination. Only three cross combinations recorded significant negative heterobeltiosis, whereas five hybrids revealed significant negative estimate of standard heterosis over both the checks. Thus, most of the cross combinations revealed higher value of kernel breadth than respective better parents and standard checks. Hybrid, IR-68897A x Pusa Sugandh-2 recorded highest negative value of heterobeltiosis, while the highest negative value of heterosis over both the check varieties was exhibited by IR-58025A x Pusa Sugandh-5. Both positive and negative heterotic values with most of the rice hybrids exhibiting significant positive heterosis for kernel breadth were also reported by Rahimi *et al.* (2010), and Sanghera and Hussain (2012).

Kernel length after cooking is one of the important grain quality parameters and its higher value is perceived to be desirable. Higher as well as lower values of kernel length after cooking over their better parents and standard checks for different cross combinations were observed in the present study. Significant positive value of heterosis (at 0.01 level of significance) over the better parent was exhibited by single cross combination. Over Taraori Basmati significant positive value of heterosis was also exhibited by single, but a different cross combination. None of the cross combinations revealed significant positive value of standard heterosis over Pusa RH-10. Cross combinations, IR-58025A x Pusa-44 and Pusa 6A x Pusa Sugandh-3 exhibited significant positive heterotic values over the better parent and over Taraori Basmati, respectively. A range of values from low to high for kernel length after cooking in rice has been observed by Srivastava and Jaiswal (2013).

Lower value of kernel breadth after cooking is preferable and thus its heterosis in negative direction is desirable. Both higher and lower estimates of kernel breadth after cooking than their better parents and standard checks were observed in different cross combinations. Nine cross combinations revealed significant negative value of heterobeltiosis, whereas six and 12 hybrids exhibited significant negative value of heterosis over Taraori Basmati and Pusa RH-10, respectively. IR-58025A x Pusa Sugandh-5 recorded the highest negative value of all the three types of heterosis. A range of values from low to high for kernel breadth after cooking has been observed by Srivastava and Jaiswal (2013).

The quality parameters *viz.*, kernel length/breadth ratio before cooking, kernel length/breadth ratio after cooking, kernel elongation ratio and elongation index are ratios of various traits, and thus their heterotic values were not estimated by usual calculations. Kernel length/breadth ratio before cooking is one of the important physical traits determining the quality of rice grain. A higher value of kernel length/breadth ratio before cooking is conceived to be desirable. Kernel length/breadth ratio in the present study revealed both higher and lower values than the standard checks depending upon the cross combination. Twelve cross combinations were found to reveal high value of kernel length/breadth ratio over both Taraori Basmati and Pusa RH-10. The highest value of kernel length/breadth ratio was recorded by IR-58025A x Pusa Sugandh-5. Both high and low value for kernel length/breadth ratio over the standard checks has been reported by Sanghera and Hussain (2012) in rice. However, studies of Vivekanandan and Giridharan (1996), Sarawgi *et al.* (2000), and Reddy *et al.* (2012) have evinced lower values for kernel length/breadth ratio than the check varieties in most of the cross combinations studied in this crop.

A higher value of kernel length/breadth ratio after cooking is desirable. Among all the 20 hybrids studied, only one cross combination (IR-58025A x Pusa Sugandh-5) exhibited higher value of kernel length/breadth ratio after cooking over the check varieties.

Kernel elongation ratio is an important cooking quality character of the rice grain. Length wise expansion of kernel (measured as elongation ratio) upon cooking without increase in girth is considered as desirable trait in Basmati rice, which elongate almost 100% (Khush *et al.,* 1979). During cooking, rice grains absorb water and increase in length, breadth and volume. This increase may be accompanied by length-wise or breadth-wise splitting of grains, which is a non-desirable character. All the hybrids in present study show lower value of kernel elongation ratio than the standard checks. Sarawgi *et al.* (2000) reported both higher and lower values for kernel elongation ratio than the standard checks.

Elongation index is an important measure of kernel expansion upon cooking that involves both length-wise and breadth-wise components. Kumar (1989) proposed that elongation index is a more reliable measure of kernel expansion. Higher value of elongation index is considered to be desirable. All the hybrids in the present study evinced lower value of elongation index than the standard checks.

As the value of alkali digestion is scored on scale of 1 to 7 and its intermediate value is preferable, the value of heterosis obtained by usual calculations is not suitable for selection of desirable cross combinations. The hybrids with intermediate alkali spread value are sorted through the mean value of observations. The alkali spread value is the basis for estimation of gelatinization temperature. Gelatinization temperature (GT) is the physical property of starch and refers to the range of temperature within which starch granules start swelling irreversibly in hot water. Thus, GT determines the time required for swelling of the starch granules at a particular temperature on cooking. The rice varieties with intermediate GT and alkali spread value (4-5) are preferred as they exhibit desirable volume expansion and linear kernel elongation under standard cooking procedures without being undercooked and/or overcooked. In the present study, alkali spread value varied from intermediate to high and gelatinization temperature from low to intermediate for hybrids as well as check varieties. Three hybrids (IR-68897A x Sanwal Basmati, Pusa 6A x Sanwal Basmati and Pusa 6A x Pusa Sugandh-3) and one check variety (Taraori Basmati) were observed to show the desirable (intermediate) value of alkali spread and gelatinization temperature. Thus, these three hybrids show superior performance for alkali spread and gelatinization temperature over the hybrid check Pusa RH-10, but were at par with pureline check Taraori Basmati. Tomar and Nanda (1985) observed that most of the rice hybrids recorded intermediate alkali digestion value and gelatinization temperature in their studies.

Amylose content is considered to be one of most important indices of rice cooking and processing behaviour, as it determines the hardness, gloss and rice to water ratio of cooked rice. Rice with low amylose content is waxy, sticky and remains firm after cooking. In contrast, non-waxy, non-sticky rice which cooks moist and tender, and does not become hard upon cooking is the consequence of intermediate amylose content (20-25%). The genotypes with intermediate amylose content are considered to be most desirable especially in the Indian context. Therefore, the value of heterosis for amylose content as obtained by usual calculations is not considered suitable for selection of desirable cross combinations. In the present study, estimates of amylose content varied from low to intermediate for various cross combinations. All the hybrids except IR-58025A x Pusa 2517-2-51-1 and IR-58025A x Pusa-44 as well as both the check varieties were observed to show an intermediate value of amylose content. Thus, most of the cross combinations revealed at par performance to both the check varieties. These findings are in close conformity with the findings of Kumar and Khush (1987) who reported intermediate amylose content in most of the rice hybrids studied.

The presence of aroma is one of the most desirable quality features of rice. The aroma was scored as 1 (Absent) to 4 (Strong) and therefore the usual calculations for estimation of heterosis cannot be applied for the selection of desirable cross combinations. In the present study, three cross combinations (IR-58025A x HUR-JM-59221, IR-58025A x Pusa-44 and IR-68897A x HUR-JM-59221) were non-aromatic, one cross (IR-68897A x Pusa Sugandh-5) revealed the presence of slight aroma and another cross (Pusa 6A x Pusa 2517-2-51-1) was found to be strongly scented. Rest 15 crosses recorded the presence of mild (moderate) aroma. Estimates of aroma for Taraori Basmati and Pusa RH-10 was observed to be strong and moderate, respectively. Thus 19 crosses revealed lower value and one cross (Pusa 6A x Pusa 2517-2-51-1) showed at par value of aroma with respect to Taraori Basmati. When compared to Pusa RH-10, four crosses (IR-58025A x HUR-JM-59221, IR-58025A x Pusa-44, IR-68897A x Pusa Sugandh-5 and IR-68897A x HUR-JM-59221) showed lower value, one cross (Pusa 6A x Pusa 2517-2-51-1) evinced higher value and rest 15 revealed at par value of aroma.

To summarise the present findings, desirable performance for all yield and quality traits was not expressed in a single hybrid combination. Relative magnitude of superiority differed from character to character and cross to cross. Latha *et al.* (2013) also reported that the magnitude of heterosis in rice varied from trait to trait and cross to cross and none of the cross combinations recorded significant hetero-sis for all the traits studied. Majority of the hybrids evaluated in present study recorded high heterosis for grain yield. High magnitude of standard heterosis for grain yield as observed in the present study has also been reported by Rahimi *et al.* (2010) and Reddy *et al.* (2012). Among the various hybrids exhibiting desirable value of heterosis for grain yield, IR-68897A x Pusa Sugandh-3, IR-58025A x HUR-JM-59221 and IR-58025A x Pusa Sugandh-5 were top performers. The hybrid, IR-68897A x Pusa Sugandh-3 recorded highest grain yield per plant (29 g), and was among the best three performers for traits, days to 50% flowering, days to maturity and number of effective tillers per plant. Thus, taking only yield traits in consideration, IR-68897A x Pusa Sugandh-3 may be considered as the best heterotic combination. For quality traits, the relative performance of different cross combinations with respect to standard checks was in both favourable and unfavourable directions. Similar trend has been reported in their studies on rice crop by Roy *et al.* (2009) and Tiwari *et al.* (2011). None of the three high yielding hybrids recorded desirable performance over standard checks for all the quality traits studied. Saravanan *et al*. (2008), Vaithiyalingan and Nadarajan (2010), and Adilakshmi and Reddy (2011) also reported that most of the high yielding hybrids exhibit lower values of desirable heterosis for quality characters. Among the three high yielding hybrids, cross combination IR-58025A x Pusa Sugandh-5 was found to perform relatively better for majority of the quality traits. Thus, IR-58025A x Pusa Sugandh-5 may be considered as the best heterotic combination, if both yield and quality traits are taken into consideration. This hybrid need to be further tested in observational/ multi-location trials before the commercial exploitation of its heterotic potential.

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