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Studies on combining ability for grain yield and its quality characteristics in rice (*Oryza sativa* L.)

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Abstract
An experiment was conducted on 10 ×10 half diallel analysis to study the combining ability effects and their variances in rice involving ten diverse parents and their forty-five hybrids made through diallel mating without reciprocals. Results revealed that SCA variances was found greater than GCA variances for most of the traits *viz*., days to 50% flowering, days to 75% maturity, panicle length, number of spikelets per panicle, 1000 grain weight, kernel length, kernel length-breadth ratio, kernel length after cooking, elongation ratio, hulling and milling per centage indicating the preponderance of non-additive gene action. The parents *viz*., P-1592, P-1121, P-2511, Surabhi and Mahi Sugandh were found best general combiner for quality traits, earliness and dwarfness based on *per se* performance and combining ability. Majority of cross combinations were involved with good × average, good × poor and poor × good type of gene interactions which substantiate the operation of non-additive gene action expression of these traits. Among the crosses *viz*., Pratap-1 × P-2511, P-1592 × P-2511, P-1121 × P-2511, P-1612 × P-2511, P-1592 × P-1612, P-1592 × P-1121, Pratap-1 × P-1612, P-1592 × Mahi Sugandha and P-1592 × Pratap-1 were found the most promising crosses for grain yield per plant and most of the grain quality traits.

Keywords: Combining ability analysis, half diallel, additive and non-additive gene action, grain yield and quantitative & Qualitative traits in rice

Introduction
Rice (*Oryza sativa* L.) is an important crop and stable food of almost half of the world. It is a self- pollinated crop belongs to the family Poaceae and genus Oryza. it is cultivated worldwide over an area of 163 million hectares with total production of 673 metric million tonnes and 4429 kg/ ha productivity. Rice is principally grown in China, India, Indonesia, and Bangladesh with smaller amount grown in Japan, Pakistan and various Southest Asian nation.

In Rajasthan, it is cultivated in an area of 2.19 lakh hectares with the production of 4.80 lakh tonnes and the productivity of 2180 kg/ha (Anonymous 2019-20) [2]. The rice growing terrain in Rajasthan can broadly be divided in four zones. The irrigated zone is humid south-eastern plain zone (Zone Vth) which covers Kota, Bundi, Baran and Jhalawar districts and severed by Chambal canal system. The agriculture university, Kota comes under Zone Vth (Humid South Eastern Plain Zone) of Rajasthan. In this Zone (Vth) it is cultivated in an area of 1.16 lakh hectares with the production of 3.03 lakh tonnes and the productivity of 2320 kg/ha (Anonymous 2019-20) [2]. Rice is mainly two types *i.e.* white and brown rice. Rice that is processed to remove only the husks, called brown rice which comes in a variety of shades, including reddish, purple or black and it contain 8% protein, small amount of fat, fibre, antioxidants, calcium, iron and vitamin like thiamine, riboflavin, niacin etc. it is better for diabetes patient because its lower glycaemic index and help in controlling blood sugar. Rice which is milled to remove the bran layer is called white rice that is diminished the nutritional value. White rice is refined and polished. This increased its cooking quality, shelf life and testiness. Combining ability analysis is one of the powerful tools available to estimate the combining ability effects and aids in selecting the desirable parents and crosses for the exploitation of heterosis. The diallel analysis provides information about general and specific combining ability effects of parents and crosses, respectively and is helpful in estimating various types of gene action.

Materials and Methods
The present experiment was undertaken at Agricultural Research Station, Ummedganj, Kota (Rajasthan), which is situated in south-eastern part of Rajasthan at latitude of 25º.13'N and

longitude of 75°54'E with an elevation of 257 m above mean sea level. The experimental material for present experiment consisted of 55 genotypes including 10 parents and their 45 crosses (F_1's). Forty-five hybrids were planted in randomized block design in three replications along with parents at a spacing of 20 cm × 10 cm during *Kharif*, 2020. Ten genotypes (parents) *viz*., P-1592, P-1121, Pratap-1, Surabhi, P-1612, Basmati-370, Pakistan Basmati, Mahi Sugandha, P-2511 and P-1509 were selected for study of combining ability and gene action with the following observation like; Days to 50% flowering, Days to 75% maturity, Plant height (cm), No. of effective tillers/ plant, No. of panicles/ plant, Panicle length (cm), No. of spikelets/ panicle, 1000-Grain weight (g), Grain yield/ plant (g), Hulling (%), Milling (%), HRR (%), Kernel length (mm), Kernel breadth (mm), L/B ratio, Kernel length after cooking (mm), Elongation ratio and Amylose (%). Crossing programme was carried out during *Kharif* 2019 under diallel mating design (without reciprocal) to generate hybrids. Observations on parents and hybrids were recorded on ten randomly selected competitive plants of each genotype in each replication for all traits except for days to 50% flowering and days to 75% maturity. These two observations were recorded on whole plot basis. The analysis of variances is estimate as per method suggested by Panse & Sukhatme (1967) [7] and estimates variances for combining ability and their effects computed as par Method 2 (Model-I) suggested by Griffing 1956 [5].

Results and Discussion

Analysis of variances

The analysis of variance (Table-1), showed highly significant difference among genotypes for all the traits which indicated the considerable amount of variability among the genotypes for most of the traits. The mean squares due to parents were significant for all the traits except days to 75% maturity and hulling per cent. it indicated that the parents selected were quite variable for all the traits under study. The mean squares due to crosses (F_1's) were found highly significant for all the traits. These results suggested that the considerable amount of variability existed among the crosses. The mean squares due to parent v/s crosse were found highly significant for all the traits except days to 50% flowering, plant height and number of spikelets per panicle indicating the presence of average heterosis. Similar results were reported by Singh *et al.* (2020) [9], Bano and Singh (2019) [3] in rice for grain yield and quality traits.

Table-2, showed significance GCA and SCA variances for all the traits and the ratio of σ^2gca/σ^2sca recorded less than unity which indicated that there is preponderance of non-additive type of gene effect for most of the traits under study like days to 50% flowering, days to 75% maturity, panicle length, number of spikelets per panicle, 1000-grain weight, kernel length, kernel length-breadth ratio, kernel length after cooking, elongation ratio, milling per cent and hulling per cent. This indicated that both additive and non-additive genetic components were involved in the inheritance of grain yield, its components and grain quality characters. Similar findings were also reported by Vadivel *et al.* (2018) [10], Senthil Kumar and Mudhalvan (2018) [8] in rice.

General combining ability effects

The estimates of GCA effects (Table 3) of parents, revealed that most of the parents showed significant GCA effects in the desired direction simultaneously for some of the traits studied. These results are in agreement with the findings of Singh *et al.* (2020) [9] and Ananda Lakshmi *et al.* (2020) [1]. Among the parents, P-1121, P-1612, P-1592 and P-2511 emerged out as good general combiner for number of effective tillers/ plant, number of panicles/ plant, panicle length (cm), number of spikelets/ panicle, 1000-grain weight (g), grain yield/ plant (g), kernel length (mm), kernel breadth (mm), L/B ratio, kernel length after cooking (mm), elongation ratio and amylose content. The parents P-1592, Surabhi and P-1509 were found to be good general combiner for days to 50% flowering, days to 75% maturity, plant height (cm). Pratap-1 emerged out as good general combiner for number of effective tillers/ plant, number of panicles/ plant, number of spikelets/ panicle, 1000-grain weight (g), grain yield/ plant (g) and amylose (%). Surabhi was found to be good general combiner for days to 50% flowering, days to 75% maturity, plant height (cm), number of spikelets/ panicle, elongation ratio, hulling (%), milling (%), HRR (%) and amylose (%). Whereas Basmati-370 traced out good general combiner for elongation ratio, milling (%) and HRR (%). Pakistan Basmati was found to be good general combiner for hulling (%) and HRR (%). Mahi Sugandha was found to be good general combiner for plant height (cm), kernel length after cooking, elongation ratio and HRR percent. Whereas P-1509 traced out good general combiner for days to 50% flowering, days to 75% maturity, plant height (cm), 1000-grain weight (g), kernel length (mm), kernel length after cooking (mm), elongation ratio and amylose (%). It is clear from above results that parent exhibited good general combining ability for grain yield per plant were always not good general combiner for all the component characters.

Specific Combining ability effects

Significant specific combining ability effect in favourable direction was observed in many hybrids, eleven for days to 50% flowering, thirteen for days to 75% maturity, eighteen for plant height (cm), five for number of effective tillers/ plant, seven for number of panicles/ plant, seven for panicle length (cm), ten for number of spikelets/ panicle, nine for 1000-grain weight (g), sixteen for grain yield/ plant (g), four for hulling (%), five for milling (%), nineteen for HRR (%), seventeen for kernel length (mm), six for kernel breadth (mm), fifteen for L/B ratio, eleven for kernel length after cooking (mm), four for elongation ratio, thirteen for amylose (%). The results are in agreement with findings of Ananda Lakshmi *et al.* (2020) [1], Mohana Sundaram *et al.* (2019) [6] and Bano (2019) [3]. On the basis of Table 4 (a & b) it can be concluded that the crosses having best specific combination for grain yield per plant would have been obtained either through good × good, good × poor, poor × good and poor × poor parental combinations. The top three crosses with regards to their SCA effects for different yield attributing and quality traits are described here.

The crosses Pakistan Basmati × P-2511, Pratap-1 × Pakistan Basmati and P-1592 × P-1612 were found to be the significantly superior than others with regards to SCA effects for days to 50% flowering. Similarly for days to 75% maturity, the crosses P-1121 × Surabhi, Pratap-1 × Pakistan Basmati and P-1592 × P-1612; for plant height, the crosses Pratap-1 × Pakistan Basmati, P-1121 × Surabhi and Pratap-1 × P-2511; for number of effective tillers per plant, the crosses P-1592 × Mahi Sugandha and Pratap-1 × Mahi Sugandha, Basmati-370 × P-1509 and P-1121 × P-1509; for number of panicles per plant, the crosses Surabhi × P-2511, P-1592 ×

Mahi Sugandha and Pratap-1 × Mahi Sugandha; for panicle length (cm), the crosses Pratap-1 × Surabhi, Pakistan Basmati × P-1509 and P-1121 × Surabhi; for number of spikelets per panicle, the crosses P-1612 × Pakistan Basmati, P-1121 × P-1509 and P-1121 × P-1612; for 1000-grain weight (g), the crosses P-1592 × P-1121, Surabhi × Basmati-370 and Surabhi × P-1612 and for grain yield per plant (g), the crosses P-1121 × P-1509, P-1612 × Pakistan Basmati and Pratap-1 × P-2511 showed highest significant SCA effects in desired direction.

The crosses P-1612 × Basmati-370, P-1121 × Surabhi and P-1121 × P-2511 showed the significant SCA effects in desirable direction for hulling per cent. Similarly, for milling per cent, the crosses Surabhi × P-1509, P-1121 × Surabhi and P-1121 × P-2511; for head rice recovery (%), the crosses P-1121 × Pratap-1, Surabhi × Mahi Sugandha and P-1612 × Mahi Sugandha; for kernel length (mm), the crosses Surabhi × Basmati-370, P-1612 × Basmati-370 and P-1592 × P-1509; kernel breadth (mm), the crosses P-1592 × P-2511 and P-1121 × P-1509, P-1121 × Basmati-370 and Surabhi × Mahi Sugandha; for kernel length-breadth ratio, the crosses P-1121 × Basmati-370, Surabhi × Basmati-370 and P-1612 × Basmati-370; for kernel length after cooking (mm), the crosses Surabhi × Basmati-370, P-1612 × Basmati-370 and Pakistan Basmati × P-1509; for elongation ratio, the crosses P-1592 × P-1121, Basmati-370 × P-2511 and P-1121 × P-2511 and for amylose content (%), the crosses P-1121 × Mahi Sugandha, Basmati-370 × Mahi Sugandha and P-1121 × Pratap-1 showed highest significant value of SCA effects in desired direction.

Majority of cross combinations of above traits were involved with good × average, good × poor and poor × good type of gene interactions which substantiate the operation of non-additive gene action expression of these traits. Mohana Sundaram *et al.* (2019) [6], Bano and Singh (2019) [3] and Bhatti *et al.* (2014) [4] also reported similar kind of results.

The present investigation infer that the non-additive gene action plays an important role in expression of various traits in the current study. The parents P-1121, P-1592, P-2511, P-1612 and Pratap-1 were identified as best combiners for grain yield per plant on the basis of *per se* performance and combining ability effects hence they could be used extensively in future breeding programme for improving grain yield traits in rice. Similarly, the crosses *viz.*, Pratap-1 × P-2511, P-1592 × P-2511, P-1121 × P-2511, P-1612 × P-2511, P-1592 × P-1612, P-1592 × P-1121, Pratap-1 × P-1612, P-1592 × Mahi Sugandha and P-1592 × Pratap-1 were found the most promising crosses for grain yield, its component traits.

For grain quality traits, earliness and dwarfness, the parents *viz.*, P-1592, P-1121, P-2511, Surabhi and Mahi Sugandh were found best general combiner based on *per se* performance and combining ability. Similarly, based on *per se* performance and specific combining ability effects, the hybrids *viz.,* P-1592 × P-1121, P-1121 × Surabhi, P-1121 × P-1612, P-1121 × Basmati-370, P-1121 × Pakistan Basmati, P-1121 × P-2511, P-1612 × Pakistan Basmati, Basmati-370 × P-2511 for quality parameters; the crosses *viz.*, P-1121 × Surabhi, Surabhi × P-1509, P-1592 × P-1509, P-1592 × Surabhi, P-1592 × Mahi Sugandha for short duration genotypes and the crosses *viz.*, P-1592 × Surabhi, P-1121 × Surabhi, P-1592 × Mahi Sugandha, P-1592 × P1509, Surabhi × P-1509 for short plant stature, were identified superior cross combination.

Table 1: Analysis of variance (mean sum of square) for quantitative and qualitative traits in rice

Source	D.F.	Days to 50% flowering	Days to 75% maturity	Plant height (cm)	No. of effective tillers/ plant	No. of panicles/ plant	Panicle length (cm)	No. of spikelets/ panicle	1000-Grain weight (g)	Grain yield/ plant (g)
Replication	2	19.24	8.37	59.24	0.04	0.56	0.43	215.22	0.08	1.16
Genotypes	54	102.98**	68.50**	415.09**	12.73**	11.84**	4.27**	1722.84**	3.61**	42.49**
Parents	9	211.20**	15.96	819.45**	25.26**	25.26**	4.93**	1773.19**	5.49**	50.25**
Hybrids	44	81.74**	78.60**	341.60**	9.87**	9.00**	3.99**	1750.93**	3.22**	40.68**
Parents vs. Hybrids	1	63.42	97.09**	9.75	25.80**	16.02**	10.73**	33.92	4.20**	52.28**
Error	108	25.85	11.42	27.97	1.03	0.77	1.08	123.59	0.30	3.12

Continue

Source	D.F.	Hulling (%)	Milling (%)	HRR (%)	Kernel length (mm)	Kernel breadth (mm)	L/B ratio	Kernel length after cooking (mm)	Elongation ratio	Amylose Content (%)
Replication	2	0.26	4.87	0.15	0.15	0.00	0.03	0.11	0.01	1.21**
Genotypes	54	6.48**	9.98**	12.47**	1.30**	0.04**	0.47**	11.00**	0.09**	3.17**
Parents	9	3.24	8.10*	4.64**	0.95**	0.01**	0.41**	15.10**	0.16**	2.88**
Hybrids	44	6.07**	6.73*	9.02**	0.93**	0.04**	0.46**	10.20**	0.07**	3.24**
Parents vs. Hybrids	1	53.28**	169.87**	234.99**	20.26**	0.21**	1.81**	9.41*	0.36**	2.80**
Error	108	2.53	3.94	1.28	0.09	0.00	0.03	1.97	0.02	0.21

*, ** Significant at 5% and 1% level of significance, respectively

Table 2: Analysis of variance of combining ability for quantitative and qualitative traits in rice

Source of variation	D.F.	Days to 50% flowering	Days to 75% maturity	Plant height (cm)	No. of effective tillers/plant	No. of panicles/ plant	Panicle length (cm)	No. of spikelets/ panicle	1000-Grain weight (g)	Grain yield/ plant (g)
GCA	9	60.24**	21.10**	605.22**	18.16**	16.92**	3.18**	2012.94**	4.21**	68.31**
SCA	45	29.14**	23.18**	45.00**	1.46**	1.35**	1.07**	286.55**	0.60**	3.33**
Error	108	8.62	3.81	9.32	0.34	0.26	0.36	41.20	0.10	1.04
Variance										

σ^2 gca	4.30	1.44	49.66	1.49	1.39	0.24	164.31	0.34	5.61
σ^2 sca	20.52	19.37	35.68	1.12	1.09	0.71	245.35	0.50	2.29
σ^2 gca/ σ^2 sca	0.21	0.07	1.39	1.33	1.27	0.34	0.67	0.68	2.45

Source of variation	D.F.	Hulling (%)	Milling (%)	HRR (%)	Kernel length (mm)	Kernel breadth (mm)	L/B ratio	Kernel length after cooking (mm)	Elongation ratio	Amylose content (%)
GCA	9	6.88**	8.02**	5.91**	0.84**	0.03**	0.45**	12.04**	0.10**	4.28**
SCA	45	1.21	2.39**	3.81**	0.35**	0.01**	0.10**	1.99**	0.02**	0.41**
Error	108	0.84	1.31	0.43	0.03	0.00	0.01	0.66	0.01	0.07
Variance										
σ^2 gca		0.50	0.56	0.46	0.07	0.003	0.04	0.95	0.008	0.35
σ^2 sca		0.37	1.08	3.38	0.32	0.0008	0.09	1.33	0.01	0.34
σ^2 gca/ σ^2 sca		1.35	0.52	0.14	0.22	3.75	0.44	0.71	0.08	1.03

*, ** Significant at 5% and 1% level of significance, respectively

Table 3: Estimation of general combining ability effects of parents for quantitative and qualitative traits in rice

Parents	Days to 50% flowering	Days to 75% maturity	Plant height (cm)	No. of effective tillers/ plant	No. of panicles/ plant	Panicle length (cm)	No. of spikelets/ panicle	1000-Grain weight (g)	Grain yield/ plant (g)
P 1592	-2.02*	1.58**	-10.51**	0.52**	0.43**	0.35*	6.26**	-0.38**	2.40**
P1121	1.03	-0.53	-2.35**	1.77**	1.65**	0.78**	11.26**	0.74**	2.21**
Pratap-1	1.76*	0.13	2.19*	0.33*	0.32*	-0.34*	4.12*	0.41**	0.57*
Surabhi	-2.97**	-1.64**	-6.49**	-1.03**	-0.93**	-0.11	5.62**	-1.12**	-1.91**
P 1612	1.28	0.47	-1.37	1.27**	1.23**	0.44**	18.17**	0.67**	2.20**
Basmati 370	1.98*	0.77	7.66**	-2.11**	-1.98**	-0.47**	-0.85	-0.53**	-2.53**
Pakistan Basmati	3.42**	2.19**	14.70**	-1.37**	-1.40**	-0.71**	-25.73**	-0.38**	-3.55**
Mahi Sugandha	-0.66	0.05	-3.15**	-0.28	-0.22	-0.44**	-15.20**	0.01	-0.93**
P 2511	-0.66	-1.20*	1.10	1.01**	1.13**	0.62**	3.88*	0.33**	3.09**
P 1509	-3.16**	-1.81**	-1.78*	-0.13	-0.22	-0.12	-7.53**	0.26**	-1.55**

Parents	Hulling (%)	Milling (%)	HRR (%)	Kernel length (mm)	Kernel breadth (mm)	L/B ratio	Kernel length after cooking (mm)	Elongation ratio	Amylose content (%)
P 1592	0.50*	0.13	-0.33	0.01	-0.03**	0.07*	-0.29	0.05*	-0.22**
P1121	-1.40**	-1.13**	-1.26**	0.40**	-0.10**	0.44**	1.64**	0.11**	-1.03**
Pratap-1	-0.25	-0.05	-1.04**	-0.11*	0.02*	-0.12**	-0.81**	-0.07**	0.87**
Surabhi	0.80**	1.17**	0.81**	-0.26**	-0.01	-0.13**	0.18	0.08**	0.57**
P 1612	0.28	0.53	0.42*	0.34**	0.03**	0.10**	1.29**	0.08**	0.20**
Basmati 370	0.41	0.68*	0.60**	-0.45**	0.01	-0.26**	-0.29	0.05*	-0.29**
Pakistan Basmati	0.67**	0.61	0.39*	-0.08	-0.01	-0.03	-1.46**	-0.16**	-0.72**
Mahi Sugandha	-0.31	-0.44	1.25**	-0.15**	-0.00	-0.07*	0.82**	0.06*	-0.05
P 2511	0.42*	-0.08	0.47**	0.15**	-0.01	0.11**	-0.37	-0.07**	0.25**
P 1509	-1.13**	-1.42**	0.19	0.15**	0.10**	-0.12**	0.94**	0.08**	0.62**

*, ** Significant at 5% and 1% level of significance, respectively

Table 4(a): Estimation of specific combining ability effects of hybrids for quantitative traits in rice

SN	Hybrids	Days to 50% flowering	Days to 75% maturity	Plant height (cm)	No. of effective tillers/plant	No. of panicles/ plant	Panicle length (cm)	No. of spikelets/ panicle	1000-Grain weight (g)	Grain yield/ plant (g)
1	P 1592 × P 1121	-7.54**	1.62	-6.02*	0.21	0.27	-0.34	9.98	2.33**	2.11*
2	P 1592 × Pratap 1	5.48*	3.28	1.87	-0.98	-0.72	0.30	11.41	-0.69*	2.26*
3	P 1592 × Surabhi	-0.46	-3.27	-5.73*	-1.59**	-1.66**	-0.42	4.80	-0.95**	1.36
4	P 1592 × P 1612	-7.96**	-7.95**	-6.07*	0.43	0.38	0.33	-18.93**	0.84**	2.18*
5	P 1592 × Basmati 370	-2.07	-4.69*	4.85	-0.64	-0.68	-1.05	8.52	0.19	-2.40*
6	P 1592 × Pakistan Basmati	9.15**	4.56*	3.47	1.04	0.99*	1.18*	21.77**	-0.49	-1.83
7	P 1592 × Mahi Sugandha	-5.10	-3.97*	-6.51*	1.83**	1.69**	-0.35	3.47	0.11	2.63**
8	P 1592 × P 2511	-5.77*	0.95	-7.69*	0.62	0.42	1.10*	-10.91	1.25**	2.80**
9	P 1592 × P 1509	-4.27	-3.44	-4.60	-2.51**	-2.28**	-0.50	-25.84**	0.39	2.26*
10	P 1121 × Pratap 1	-5.79*	-4.61*	-6.13*	-1.64**	-1.41**	-0.78	-17.63**	-0.17	-1.34
11	P 1121 × Surabhi	-6.52*	-13.16**	-11.25**	0.34	0.38	1.90**	-17.66**	-1.69**	-0.03
12	P 1121 × P 1612	-7.43**	-7.27**	2.17	-1.02	-0.71	0.71	27.93**	-0.73*	-0.55
13	P 1121 × Basmati 370	-6.01*	1.76	-10.25**	-1.66**	-1.28**	-0.15	17.25**	-0.22	2.15*
14	P 1121 × Pakistan Basmati	-0.57	3.01	-7.12*	-0.74	-1.95**	-0.03	-34.71**	-0.14	-2.65**
15	P 1121 × Mahi Sugandha	6.51*	6.48**	-0.03	0.36	0.24	-0.67	-18.57**	-0.28	-0.82
16	P 1121 × P 2511	2.85	7.73**	-2.95	0.69	0.91	1.00	14.36*	0.88**	2.64**

17	P 1121 × P 1509	3.35	-5.34**	-6.64*	1.63**	1.58**	-1.00	29.76**	-0.09	3.07**
18	Pratap 1 × Surabhi	2.10	1.51	2.35	-1.13*	-0.87	2.36**	12.35*	0.30	-1.69
19	Pratap 1 × P 1612	-5.82*	-2.94	-8.13**	-0.52	-0.66	1.37*	2.14	1.05**	2.40**
20	Pratap 1 × Basmati 370	-3.18	-1.24	-8.00**	0.71	0.42	-0.07	5.89	-0.50	1.26
21	Pratap 1 × Pakistan Basmati	-9.63**	-8.99**	-11.99**	0.09	0.66	1.16*	14.96*	0.16	-0.19
22	Pratap 1 × Mahi Sugandha	1.12	1.48	5.22	1.83**	1.60**	-1.30*	-16.55**	0.27	1.68
23	Pratap 1 × P 2511	-4.88	-3.61*	-11.11**	0.29	0.01	-0.91	-6.41	-0.57	2.67**
24	Pratap 1 × P 1509	8.96**	10.34**	7.44**	0.28	0.21	-0.19	-12.66*	0.47	-2.61**
25	Surabhi × P 1612	5.57*	5.51**	4.54	0.64	0.41	-0.25	-21.96**	1.10**	2.15*
26	Surabhi × Basmati 370	7.21**	6.53**	1.54	0.59	0.85	0.58	-0.28	1.89**	-0.49
27	Surabhi × Pakistan Basmati	0.43	-1.22	-4.98	0.79	0.80	-2.37**	9.60	0.10	-0.37
28	Surabhi × Mahi Sugandha	-0.82	-1.08	0.06	0.14	0.24	0.00	13.07*	-0.16	0.25
29	Surabhi × P 2511	4.51	0.17	6.37*	1.13*	1.70**	0.16	5.47	-0.13	1.68
30	Surabhi × P 1509	-0.99	-4.88**	4.65	-0.75	-0.92	-0.25	5.90	0.47	0.56
31	P 1612 × Basmati 370	-4.71	-5.24**	1.29	-0.85	-1.12*	-0.37	-24.28**	-0.25	-3.33**
32	P 1612 × Pakistan Basmati	-2.49	-1.33	-6.10*	-0.07	-0.18	0.12	30.05**	-0.44	2.76**
33	P 1612 × Mahi Sugandha	-1.74	-1.86	-4.73	-1.89**	-1.46**	-1.20*	4.08	-0.30	-1.48
34	P 1612 × P 2511	3.60	2.06	-2.68	-0.34	-0.02	0.93	10.41	0.61*	2.61**
35	P 1612 × P 1509	3.76	-1.66	-3.03	-0.20	-0.24	-0.03	2.25	-0.66*	2.17*
36	Basmati 370 × Pakistan Basmati	-4.18	0.37	-8.03**	1.01	1.47**	0.77	9.07	0.08	2.35*
37	Basmati 370 × Mahi Sugandha	5.57*	-0.16	2.19	-0.25	-0.04	0.90	1.10	0.18	-0.83
38	Basmati 370 × P 2511	2.57	1.42	-6.01*	-1.99**	-1.66**	0.11	-4.87	-0.49	1.49
39	Basmati 370 × P 1509	-3.93	-2.97	3.11	1.65**	1.44**	0.98	13.87*	-0.45	-1.06
40	Pakistan Basmati × Mahi Sugandha	-6.46*	3.09	-8.19*	-1.49**	-0.65	0.06	-8.02	-0.54	0.12
41	Pakistan Basmati × P 2511	-9.88**	-7.33**	10.32**	-0.25	-0.50	0.04	-23.13**	0.01	-0.30
42	Pakistan Basmati × P 1509	5.29	3.95*	7.86**	-0.23	-0.28	2.14**	-21.49**	0.59*	0.22
43	Mahi Sugandha × P 2511	1.87	0.81	14.81**	-2.04**	-2.39**	0.82	-27.55**	-0.19	-1.10
44	Mahi Sugandha × P 1509	-2.96	-3.24	1.18	-0.77	-0.91	-0.39	6.55	0.25	-1.42
45	P 2511 × P 1509	-1.63	-4.99**	4.22	-1.15*	-0.68	-0.98	5.81	-0.02	0.52

Table 4(b): Estimation of specific combining ability effects of hybrids for qualitative traits in rice

SN	Hybrids	Hulling (%)	Milling (%)	HRR	Kernel length (mm)	Kernel breadth (mm)	L/B ratio	Kernel length after cooking (mm)	Elongation ratio	Amylose (%)
1	P 1592 × P 1121	1.19	0.80	1.48*	-0.26	-0.01	-0.10	1.55*	1.11**	0.82**
2	P 1592 × Pratap 1	-2.08*	-1.66	2.17**	-0.22	0.01	-0.13	-1.59*	-0.16	-0.53*
3	P 1592 × Surabhi	1.56	-1.76	0.38	-0.31	-0.02	-0.12	-1.62*	-0.14	0.27
4	P 1592 × P 1612	-0.18	0.20	1.43*	0.68**	0.03	0.28**	0.61	-0.06	0.59*
5	P 1592 × Basmati 370	0.94	0.66	-0.39	-0.23	0.06*	-0.24*	-1.40	-0.11	-0.30
6	P 1592 × Pakistan Basmati	1.13	2.03	0.27	-0.02	0.01	-0.03	-0.49	-0.05	-0.24
7	P 1592 × Mahi Sugandha	-0.58	-0.00	-0.32	0.43**	-0.03	0.29**	-0.12	-0.10	0.01
8	P 1592 × P 2511	-0.46	0.52	1.03	0.10	-0.11**	0.32**	-0.52	-0.08	0.22
9	P 1592 × P 1509	0.47	1.08	0.42	0.93**	0.07*	0.29**	1.97**	0.03	0.29
10	P 1121 × Pratap 1	0.02	-0.09	2.81**	0.13	0.16**	-0.29**	-1.95**	-0.25**	0.90**
11	P 1121 × Surabhi	1.42*	1.66*	1.98*	0.16	0.01	0.07	-0.79	-0.13	-1.58**
12	P 1121 × P 1612	-1.38	-1.25	1.27*	0.21	-0.01	0.14	1.66*	-0.10	0.83**
13	P 1121 × Basmati 370	0.38	0.21	1.27*	0.67**	-0.10**	0.59**	1.97**	-0.01	-0.51*
14	P 1121 × Pakistan Basmati	1.22*	0.32	1.56*	0.15	-0.01	0.12	0.06	-0.01	-1.27**
15	P 1121 × Mahi Sugandha	-0.54	-0.72	-2.44**	-0.05	-0.06*	0.12	-1.16	-0.13	1.31**
16	P 1121 × P 2511	1.34*	1.21*	-1.31*	0.20	-0.02	0.16	0.95	0.67**	0.73**
17	P 1121 × P 1509	-1.18	-1.47	-2.00**	0.36*	-0.11**	0.41**	1.05	0.03	0.37
18	Pratap 1 × Surabhi	0.63	0.52	-0.67	-0.05	-0.02	0.02	-0.53	-0.06	0.30
19	Pratap 1 × P 1612	-0.14	0.01	-1.00	0.48**	0.01	0.22*	0.40	-0.05	-0.10
20	Pratap 1 × Basmati 370	0.59	0.60	-1.29*	0.75**	0.03	0.31**	1.57*	0.04	-0.13
21	Pratap 1 × Pakistan Basmati	0.68	0.59	-0.72	0.09	0.01	0.04	-0.80	-0.12	0.88**
22	Pratap 1 × Mahi Sugandha	0.76	1.21	-1.63**	0.49**	-0.00	0.26**	-0.15	-0.12	-1.08**
23	Pratap 1 × P 2511	0.41	1.17	-0.77	-0.03	0.04	-0.10	-0.48	-0.05	0.83**
24	Pratap 1 × P 1509	0.69	1.50	-0.47	0.47**	0.05	0.11	1.49*	0.07	0.65**
25	Surabhi × P 1612	0.09	0.52	-1.17	-0.33*	0.02	-0.20*	-0.67	-0.01	0.21
26	Surabhi × Basmati 370	1.22	0.96	0.50	1.19**	0.04	0.52**	3.09**	0.10	0.59*
27	Surabhi × Pakistan Basmati	0.80	0.95	-0.26	0.17	-0.04	0.17	0.42	0.02	0.86**
28	Surabhi × Mahi Sugandha	0.70	0.62	2.55**	0.33*	-0.08**	0.34**	0.41	-0.03	0.18
29	Surabhi × P 2511	-0.76	-0.11	1.11	0.06	0.02	-0.02	-0.34	-0.06	0.12
30	Surabhi × P 1509	0.36	2.17*	1.28*	0.26	0.14**	-0.16	1.01	0.06	-0.62*
31	P 1612 × Basmati 370	2.02*	1.60	1.62**	1.13**	0.04	0.46**	2.92**	0.09	-0.20
32	P 1612 × Pakistan Basmati	0.04	1.13*	1.29*	0.36*	0.02	0.15	0.77	0.52**	-0.03
33	P 1612 × Mahi Sugandha	1.10	1.64	2.50**	-0.16	0.01	-0.10	-0.97	-0.08	-0.01
34	P 1612 × P 2511	0.87	1.32	1.79**	0.27	0.05	-0.01	0.51	0.00	0.23
35	P 1612 × P 1509	0.53	2.06	1.76**	-0.84**	0.14**	-0.67**	-1.41	0.02	0.21

36	Basmati 370 × Pakistan Basmati	0.35	0.01	1.05	-0.53**	0.01	-0.29**	-0.53	0.05	0.45
37	Basmati 370 × Mahi Sugandha	0.36	1.18	1.99**	-0.29	0.01	-0.18	-0.63	-0.02	0.96**
38	Basmati 370 × P 2511	-0.01	1.13*	0.15	-0.37*	0.07*	-0.33**	1.05*	0.58**	-0.65**
39	Basmati 370 × P 1509	-0.81	0.12	2.23**	-0.57**	0.09**	-0.43**	-0.40	0.10	0.73**
40	Pakistan Basmati × Mahi Sugandha	-0.09	0.42	2.28**	0.46**	-0.07*	0.38**	0.90	0.02	-1.17**
41	Pakistan Basmati × P 2511	0.26	1.10	0.61	-0.00	0.03	-0.08	-0.81	-0.08	0.39
42	Pakistan Basmati × P 1509	0.27	1.31	0.95	0.72**	0.04	0.24*	2.26**	0.12	-0.22
43	Mahi Sugandha × P 2511	-0.41	0.66	0.80	0.37*	-0.01	0.19*	0.41	-0.02	-0.02
44	Mahi Sugandha × P 1509	-0.68	0.28	1.72**	-0.50**	0.08*	-0.39**	-1.39	-0.05	-0.10
45	P 2511 × P 1509	0.76	-0.86	0.50	0.57**	0.17**	-0.10	1.85*	0.10	-0.51*

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