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Exploration of Possibilities to Identify Heterotic Cross Combinations in Aromatic Rice (*Oryza sativa* L.) for Grain Yield and Quality Parameters

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Authors' contributions

This work was carried out in collaboration among all the authors. Authors MKS and Banshidhar designed, executed the experiment and performed the statistical analysis. Author SKS provided technical support in interpretation of results and prepared the original draft of the manuscript. Authors AT and AK proof read the manuscript and prepared the final draft. All authors read and approved the final draft of the manuscript.

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ABSTRACT

Twenty eight crosses generated using eight aromatic rice varieties crossed in half diallel fashion were evaluated and analyzed along with parents to investigate combining ability and gene action for grain yield and various grain quality traits. The general combining ability and specific combining ability variances were significant for all the traits that indicated the role of both additive and non-additive genetic components. Ratio of $\sigma^2_{gca}/\sigma^2_{sca}< 1$ indicated preponderance of non-additive gene action in the expression of these traits. Pusa Basmati-1 was the good general combiner showing significantly high GCA effect for a maximum of seven-grain quality traits *viz.*, milling recovery (0.81), kernel length (0.28), kernel breadth (-0.05), kernel length/breadth ratio (0.26), cooked kernel length (0.79), alkali digestion value (0.67) and amylose content (0.60) but not for yield. Cross PSD-15×Pant Basmati-1 (P_7×P_8) was the good specific combiner showing high SCA effects for a

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maximum of eight grain quality traits *viz.* hulling recovery (2.76), milling recovery (2.06), kernel length (0.89), kernel length/breadth ratio (0.69), cooked kernel length (3.06), kernel elongation ratio (0.12), alkali digestion value (1.11) and amylose content (1.01) but not yield. None of the top three crosses (Pusa Sugandh-6×PSD-15, Pusa Basmati-1×PSD-15 and Pusa Sugandh-4×Basmati-370) based on high SCA effect for grain yield plant^{-1}exhibited as high SCA effect to fall within top three crosses on that basis for any of the grain quality traits.

Keywords: Aromatic rice; combining ability; gene action; diallel; grain quality.

ABBREVIATIONS

† *A- average general combiner,* † † *G- good general combiner,* † † † *P- Poor general combiner*

1. INTRODUCTION

After attainment of self-sufficiency in rice production, Indian rice breeding programmes have shifted its gear towards rice grain quality improvement. The market value of milled rice largely depends upon kernel dimensions and its physical appearance. Cooking quality of rice is mainly determined by water uptake, volume expansion and kernel elongation. These traits are primarily influenced by the alkali digestion value and amylose content of the kernels [1]. Thus, rice grain qualities are governed by a combination of physicochemical properties of the kernel.

The nature and magnitude of gene action involved in expression of various rice grain quality traits are important for the successful development of varieties choosing an appropriate breeding strategy. Also, the correct choice of parents is of utmost importance for the development of hybrids that has high yield along with several quality traits in its kernels or for development of pure line varieties through recombination breeding. Combining ability analysis [2] provides such information so as to frame the effectively breeding strategies. This analysis helps in the identification of parents with high general combining abilities (GCA) and parental combinations with high specific combining abilities (SCA). The estimation of additive and non-additive gene action through this technique may be useful in determining the possibility of commercial exploitation of heterosis and isolation of pure line among the progenies of hybrids. Numerous reports like Saleem et al. [3], Shankar et al. [4] and Tiwari et al. [5] are available in rice for combining ability and gene action on various characters including yield and quality traits. But, still there is paucity of information and lack of unanimity among several findings that concern these aspects in aromatic rice. Hence, the present investigation was carried out to obtain information on combining abilities of parents and the crosses and the gene actions involved in the expression of various rice grain quality traits along with the grain yield.

2. MATERIALS AND METHODS

The experimental materials comprised of eight aromatic rice varieties and twenty eight crosses obtained by crossing them in a half diallel fashion during *kharif*, 2015. The eight parents that were used in generation of twenty eight crosses were namely, Pusa Basmati-1, Pusa Sugandh-4, Pusa Sugandh-6, Type-3, Basmati-370, Taraori Basmati-1, PSD-15 and Pant Basmati-1. Thirty six entries (8 parents and 28 crosses) were evaluated during *kharif*, 2016 in a Randomized Block Design (RBD) with three replications at Crop Research Centre, G. B. Pant University of Agriculture and Technology, Pantnagar, Uttarakhand, India. Each replication consisted of 36 plots with one row gap, while each plot had three rows of 1.5 meter length. The row to row and plant to plant distance was maintained at 20 cm and 15 cm, respectively. Trait mean values on quality traits *viz.,* hulling recovery (%), milling recovery (%), kernel length (mm), kernel breadth (mm), kernel length/breadth ratio, cooked kernel length (mm), kernel elongation ratio, alkali digestion value and amylose content (%) along with grain yield plant^{-1} (g.) were subjected to combining ability analysis using statistical package, Windostat 9.1. Combining ability analysis was carried out according to Method 2 of Model I of Griffing (1956 b) [6].

3. RESULTS AND DISCUSSION

The analysis of variance for combining abilities for various traits revealed that mean sum of squares due to GCA and that due SCA was significant (P<0.01) for all the traits (Table 1) that indicated the importance of both additive and non-additive genes in expression of these traits [7]. It was also evident that σ^2_{sca} was greater than σ^2_{gca} for all these traits indicating preponderance of non-additive gene action in expression of these traits [8]. This suggested greater importance of non-additive gene action in their expression and indicated a very good prospect for the exploitation of non- additive genetic variation for grain quality traits and grain yield through hybrid breeding.

A perusal of Table 2 and Table 3 reflects the GCA effects of parents and SCA effects of cross combinations, respectively, that are discussed trait-wise in the following paragraphs.

ParentsBasmati-370 and Pant Basmati-1 were found to be good general combiner for hulling recovery and the crosses $P_1 \times P_6$ ($A^{\dagger}$/A), $P_1 \times P_8$ (A/$G^{\dagger\dagger}$) and $P_2 \times P_6$ (A/A) were the top three among nine crosses showing significantly positive SCA effects for hulling recovery. Cross $P_1 \times P_8$ can be used to isolate promising transgressive segregants as this involves parents with average and good general combining abilities.

Parents Pusa Basmati-1 and Pant Basmati-1 showed significantly high GCA effect for milling recovery and crosses $P_1 \times P_6$ (G/A), $P_2 \times P_6$ (A/A) and $P_3 \times P_6$ (A/A) were the top three among six crosses showing significantly positive SCA effects for milling recovery. Cross $P_1 \times P_6$ can be used to isolate promising transgressive segregants as this involves parents with good and average general combining abilities.

Parents Pusa Basmati-1, Pusa Sugandh-4, Pusa Sugandh-6 and PSD-15 showed significantly high GCA effect for kernel length and crosses $P_4 \times P_8$ ($P^{\dagger\dagger\dagger}$/A), $P_7 \times P_8$ (G/A) and $P_3 \times P_6$ (G/A) were the top three among eleven crosses showing significantly positive SCA effects for kernel length. Crosses $P_7 \times P_8$ and $P_3 \times P_6$ can be used to isolate promising transgressive segregants as this involves parents with good and average general combining abilities.

Parents Pusa Basmati-1and PSD-15 showed significantly high GCA effect for kernel breadth and crosses $P_3 \times P_6$ (A/P), $P_1 \times P_6$ (G/P) and $P_4 \times P_8$ (A/A) were the top three among four crosses showing significantly positive SCA effects for kernel breadth. Cross $P_1 \times P_6$ can be used to isolate promising transgressive segregants as this involves parents with good and poor general combining abilities.

Parents Pusa Basmati-1, Pusa Sugandh-6 and PSD-15 showed significantly high GCA effect for L/B ratio and crosses $P_3 \times P_6$ (G/P), $P_4 \times P_8$ (P/A) and $P_7 \times P_8$ (G/A) were the top three among eight crosses showing significantly positive SCA effects for L/B ratio. Crosses $P_3 \times P_6$ and $P_7 \times P_8$ can be used to isolate promising transgressive segregants as these involves one parent as good and other as either poor or average general combiners.

Parents Pusa Basmati-1and Pusa Sugandh-4 showed significantly high GCA effect for cooked kernel length and crosses $P_4 \times P_8$ (P/A), $P_3 \times P_6$ (A/A) and $P_7 \times P_8$ (A/A) were the top three among eight crosses showing significantly positive SCA effects for cooked kernel length.

The only parent Pusa Sugandh-4 showed significantly high GCA effect for kernel elongation ratio and crosses $P_1 \times P_4$ (A/P), $P_2 \times P_6$ (G/A) and $P_5 \times P_6$ (A/A) were the top three among nine crosses showing significantly positive SCA effects for kernel elongation ratio. Cross $P_2 \times P_6$ can be used to isolate promising transgressive segregants as this involves parents with good and poor general combining abilities.

Parents Pusa Basmati-1, Pusa Sugandh-4,Pusa Sugandh-6, Taraori Basmati-1 and PSD-15 showed significantly high GCA effect for alkali digestion value and crosses $P_5 \times P_8$ (P/A), $P_3 \times P_8$ (G/A) and $P_7 \times P_8$ (G/A) were the top three among eleven crosses showing significantly positive SCA effects for alkali digestion value. Crosses $P_3 \times P_8$ and $P_7 \times P_8$ can be used to isolate promising transgressive segregants as these involves one parent as good and other as average general combiners.

Parents Pusa Basmati-1, Pusa Sugandh-6, Taraori Basmati-1 and Pant Basmati-1 showed significantly high GCA effect for amylose content and crosses $P_5 \times P_8$ (P/G), $P_4 \times P_6$ (P/G) and $P_6 \times P_7$ (G/P) were the top three among fourteen crosses showing significantly positive SCA effects for amylose content. Crosses $P_5 \times P_8$, $P_4 \times P_6$ and $P_6 \times P_7$ can be used to isolate promising transgressive segregants as these involves one parent as good and other as poor general combiners.

Table 1. ANOVA for general combining ability (GCA) and specific combining ability (SCA) for various traits

Source of variation	Degree of freedom	Mean sum of squares									
		HR ((%)	MR (%)	KL (mm)	KB (mm)	L/B ratio	CKL (mm)	KER	ADV	AC (%)	GY (g)
GCA	7.00	2.10**	4.01**	0.73**	0.01**	0.42**	5.49**	0.04**	3.79**	4.65**	130.94**
SCA	28.00	4.63**	4.15**	0.37**	0.01**	0.23**	2.80**	0.02**	0.92**	1.40**	89.08**
Error	70.00	0.08	0.37	0.00	0.00	0.01	0.06	0.00	0.01	0.02	1.14
σ^2_{gca}		0.20	0.36	0.07	0.00	0.04	0.54	0.00	0.38	0.46	12.98
σ^2_{sca}		4.55	3.78	0.36	0.01	0.22	2.73	0.02	0.92	1.38	87.94
$\sigma^2_{gca} / \sigma^2_{sca}$		0.04	0.10	0.20	0.19	0.18	0.20	0.19	0.41	0.34	0.15

**Significant @ 5% level of significance, ** Significant @ 1% level of significance*

HR- Hulling recovery, MR- Milling recovery, KL- Kernel length, KB- Kernel breadth, L/B- Kernel length/breadth, CKL- Cooked kernel length, KER- Kernel elongation ratio, ADV- Alkali digestion value, AC- Amylose content, GY- Grain yield/plant

Table 2. Estimates of general combining ability (GCA) effects of parents for various traits

Parents	HR (%)	MR (%)	KL (mm)	KB (mm)	L/B ratio	CKL (mm)	KER	ADV	AC (%)	GY (g)
Pusa Basmati-1 (P_1)	0.12	0.81**	0.28**	-0.05**	0.26**	0.79**	0.02	0.67**	0.60**	-0.87*
Pusa Sugandh-4 (P_2)	-0.12	0.00	0.12**	0.03*	0.02	1.10**	0.12**	0.57**	-0.57**	-1.60**
Pusa Sugandh-6 (P_3)	-0.24*	0.17	0.27**	-0.02	0.19**	0.05	-0.08**	0.27**	0.16**	5.19**
Type-3 (P_4)	-0.02	-0.80**	-0.32**	0.01	-0.22**	-0.99**	-0.04*	-0.97**	-0.27**	0.62
Basmati-370 (P_5)	0.26*	0.00	-0.47**	0.01	-0.31**	-1.00**	0.01	-0.88**	-0.21**	1.10**
Taraori Basmati-1 (P_6)	0.09	-0.01	-0.04	0.05**	-0.12**	-0.07	0.01	0.25**	0.91**	-4.90**
PSD-15 (P_7)	-0.86**	-0.94**	0.14**	-0.05**	0.18**	-0.05	-0.06**	0.15**	-1.15**	4.45**
Pant Basmati-1 (P_8)	0.76**	0.78**	0.00	0.01	-0.02	0.16	0.02	-0.05	0.52**	-3.99**
SE (g_i)	0.20	0.43	0.05	0.02	0.06	0.18	0.03	0.06	0.11	0.75
SE (g_i - g_j)	0.30	0.65	0.07	0.03	0.09	0.27	0.05	0.10	0.16	1.13

**Significant @ 5% level of significance, ** Significant @ 1% level of significance*

HR- Hulling recovery, MR- Milling recovery, KL-Kernel length, KB- Kernel breadth, L/B- Kernel length/breadth, CKL- Cooked kernel length, KER- Kernel elongation ratio, ADV- Alkali digestion value, AC- Amylose content, GY- Grain yield/plant

Table 3. Estimates of specific combining ability (SCA) effects of hybrids for various traits

Crosses	HR ((%)	MR (%)	KL (mm)	KB (mm)	L/B ratio	CKL (mm)	KER	ADV	AC (%)	GY (g)
$P_1×P_2$	-1.12**	-1.42	0.25**	0.02	0.08	0.48	-0.03	0.05	-0.13	-6.91**
$P_1×P_3$	-2.10**	-1.49	0.09	0.03	-0.03	0.11	-0.02	0.39**	0.36	3.34*
$P_1×P_4$	-0.15	-0.44	-0.31**	0.00	-0.19	0.98**	0.27**	0.13	0.13	1.17
$P_1×P_5$	-0.59	0.83	-0.19*	0.02	-0.15	0.46	0.15**	0.00	0.62**	10.06**
$P_1×P_6$	4.05**	3.40**	0.72**	-0.10*	0.64**	1.37**	-0.06	0.16	0.83**	-0.71
$P_1×P_7$	-1.81**	0.34	0.15	0.00	0.09	0.33	0.01	-0.09	-0.69**	16.07**
$P_1×P_8$	3.39**	2.60**	0.68**	-0.06	0.53**	1.35**	-0.05	-0.70**	1.23**	3.26*
$P_2×P_3$	0.67	0.66	-0.08	-0.04	0.02	0.28	0.05	0.38**	0.44*	1.33
$P_2×P_4$	-0.64	-0.10	-0.04	0.04	-0.12	-0.78*	-0.10	-0.19	-1.04**	4.97**
$P_2×P_5$	-0.73*	0.18	0.38**	0.08*	0.04	0.72*	-0.03	-0.71**	0.57**	11.73**
$P_2×P_6$	3.35**	3.16**	-1.27**	0.13**	-0.93**	-1.79**	0.24**	0.44**	0.48*	7.73**
$P_2×P_7$	0.57	0.37	0.27**	-0.07	0.34**	0.81*	0.02	-0.16	0.71**	-7.03**
$P_2×P_8$	2.07**	2.38**	-0.47**	0.05	-0.40**	-0.07	0.17**	0.60**	-1.36**	7.96**
$P_3×P_4$	0.93**	-1.51	0.17	-0.05	0.19	0.20	-0.02	0.00	0.15	6.21**
$P_3×P_5$	-0.92*	-0.63	0.08	0.08	-0.12	-0.37	-0.09	-0.44**	0.63**	7.63**
$P_3×P_6$	2.18**	2.78**	0.77**	-0.15**	0.79**	3.12**	0.16**	-2.82**	-0.96**	-1.16
$P_3×P_7$	0.97**	0.02	0.15	0.01	0.07	0.49	0.03	0.75**	0.10	19.22**
$P_3×P_8$	0.66	0.25	-1.30**	0.16**	-1.05**	-2.00**	0.18**	1.17**	1.15**	-2.04
$P_4×P_5$	-0.80*	-0.85	-0.32**	0.12	-0.39**	-1.10**	-0.05	-0.11	-0.64**	-8.85**
$P_4×P_6$	-2.51**	-1.62*	0.24**	0.02	0.07	-0.15	-0.11*	0.69**	1.93**	2.86*
$P_4×P_7$	-0.38	0.07	-0.13	0.01	-0.11	-0.22	0.02	-0.91**	0.36	1.74
$P_4×P_8$	2.73**	3.70**	0.98**	-0.10*	0.77**	3.48**	0.15**	0.15	-0.84**	1.67
$P_5×P_6$	0.33	0.49	0.54**	0.02	0.25*	2.95**	0.24**	0.37**	0.55**	0.93
$P_5×P_7$	0.59	0.50	-0.19*	0.02	-0.16	-0.15	0.05	-1.21**	-1.80**	3.55*
$P_5×P_8$	-0.83*	-1.34	0.33**	-0.09*	0.38**	-0.36	-0.17**	2.11**	2.13**	-0.20
$P_6×P_7$	0.00	-0.76	-0.01	0.09*	-0.22*	-1.21**	-0.18**	0.89**	1.82**	-3.29*
$P_6×P_8$	-1.33**	-1.13	-1.07**	0.08*	-0.77**	-2.15**	0.07	-0.64**	-0.08	7.17**
$P_7×P_8$	2.76**	2.06**	0.89**	-0.07	0.69**	3.06**	0.12*	1.11**	1.01**	-0.59
SE (S_{ii})	0.52	1.14	0.13	0.06	0.16	0.47	0.08	0.17	0.28	1.98
SE (S_{ij} - S_{ik})	0.77	1.68	0.19	0.08	0.23	0.69	0.12	0.25	0.42	2.94
SE (S_{ij} - S_{kl})	0.72	1.59	0.18	0.08	0.22	0.65	0.11	0.24	0.39	2.77

**Significant @ 5% level of significance, ** Significant @ 1% level of significance; HR- Hulling recovery, MR- Milling recovery, KL-Kernel length, KB- Kernel breadth, L/B- Kernel length/breadth, CKL- Cooked kernel length, KER- Kernel elongation ratio, ADV- Alkali digestion value, AC- Amylose content, GY- Grain yield/plant*

Parents Pusa Sugandh-6, Basmati-370 and PSD-15 showed significantly high GCA effect for grain yield/plant and crosses $P_3 \times P_7$ (G/G), $P_1 \times P_7$ (P/G) and $P_2 \times P_5$ (P/G) were the top three among fourteen crosses showing significantly positive SCA effects for grain yield/plant. Cross $P_3 \times P_7$ having both parents as good general combiner can be exploited through recombination breeding and crosses $P_1 \times P_7$ and $P_2 \times P_5$ can be used to isolate superior transgressive segregants [9].

Pusa Basmati-1 is the parent that has significantly high GCA effect for seven traits namely, milling recovery, kernel length, kernel breadth, kernel length/breadth ratio, cooked kernel length, alkali digestion value and amylose content followed by PSD-15 that has high GCA effect for five traits namely, kernel length, kernel breadth, kernel length/breadth ratio, alkali digestion value and grain yield plant^{-1}. Similarly, parent Pusa Sugandh-6 has high GCA effect for five traits namely, kernel length, kernel length/breadth ratio, alkali digestion value, amylose content and grain yield plant^{-1} [10]. But parents PSD-15 and Pusa Sugandh-6 should be given due consideration as best parent as these have high GCA for different combination of four rice grain quality traits as well as high GCA for grain yield which one would not wish to sacrifice. Cross PSD-15×Pant Basmati-1 ($P_7 \times P_8$) has significantly high SCA effects for eight traits followed by Pusa Basmati-1×Pant Basmati-1 ($P_1 \times P_8$) and Pusa Basmati-1×Tarori Basmati-1 ($P_1 \times P_6$) each having significantly high SCA effects for a different combination of seven traits (Table 3) but cross $P_1 \times P_8$ should be given preference as best specific combiner as this has high SCA effect for grain yield as well which is prime breeding objective for any breeding programmes [11].

4. CONCLUSION

It is clear from above discussion that the parents sowing good general combining ability for any trait may not always be reflected in cross combinations showing high SCA effects. In addition, crosses showing high SCA effects may not always show the high *per se* performance. Therefore, identification of heterotic crosses based solely on high SCA effects may not be sufficient that decides the economic feasibility of any hybrid variety. Economic feasibility of a hybrid is justified when *per se* performance of any hybrid is not ignored for the want of SCA effect. None of the top three hybrids that showed high SCA effect for grain yield plant^{-1} expressed high SCA falling within top three crosses for any of the quality parameters. Therefore, isolation of a cross that shows high SCA effects for both the grain yield and grain quality parameters is a chance event and a challenge to the breeders. Breeders have to make a compromise between rice grain yield and grain quality.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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