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Research Article

Combining ability studies for yield and quality traits in aromatic genotypes of rice (*Oryza Sativa. L.*)

Dilruba A. Bano* **and S. P. Singh**
Department of Genetics and Plant Breeding, Institute of Agricultural Sciences, BHU, Varanasi-221005
***E-Mail**: dabgpb@gmail.com

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Abstract
The present investigation was aimed to study the general combining ability of eight aromatic genotypes of rice and specific combining ability of all possible crosses for grain yield and quality traits in 28 F1's obtained by 8x8 on way Diallel mating design. The estimates of SCA variance were revealed greater than GCA variance for all the characters except days to 50% flowering, days to maturity, plant height, effective tillers/plant and kernel length after cooking. It showed that both the additive as well as non-additive genetic variance exhibited importance for expression of the characters studied. The Parents, Pusa -2517-2-51-1and Pusa Sugandh-5 studied were identified as best general combiner for both yield and quality traits for most of the characters. Crosses, Pusa-2517-2-51-1×Type-3 showed non additive effects for yield traits only. However, the cross Ranbir Basmati x Pusa Basmati-1 showed non additive effects for quality traits. Cross combination *viz*., Pusa Sugandh-5 x Pusa Basmati-1, Ranbir Basmati x Kasturi Basmati, Kasturi Basmati × Pusa-2517-2-51-1 and Pusa Sugandh-3 x Type-3 showed non additive gene action for most of the yield as well as quality traits. For those traits which showed high performance were under the control of dominance and dominance × dominance gene effects, heterosis breeding would be most effective. Thus, present study aims to develop hybrids performing better for both yield as well as quality traits.

Keywords
Rice, Combining ability, Yield, Quality

Introduction

About half of the world's population and two third of Indians depend on rice for their survival. There is an urgent need to increase rice production to meet the requirements of ever growing population. In order to narrow the gap between production and demand, increase in productivity is the only option left. Exploitation of heterosis in the form of hybrid rice technology has been contemplated as a potential strategy for enhancing the productivity in rice. The average yield of hybrid rice is at least 15-20 percent more than that of rice variety used as parent and it has been anticipated that hybrid rice technology will play a key role in ensuring food security worldwide in the future decades (FAO, 2014).

Nowadays, the quality considerations assume enhanced importance, especially in the countries which are self-sufficient in their production. As per capita income increases the consumption preference of common man is shifting towards quality rice. Aromatic rices constitute a small but special group of rices which are considered best in quality (Among the quality rices, Basmati is the unique aromatic quality rice. It is a nature's gift to Indian sub-continent. As living standards are improving steadily, human demand for high quality rice is continuously on an increase. This entails in incorporation of preferred grain quality features as the most important objective next to yield enhancement. Based on the survey of 11 major rice growing countries, Juliano and Duff (1991) concluded that grain quality is second only to yield as the major breeding objective. In the future, improvement of grain quality traits will be even more enhanced as once the very poor, many of whom depend largely on rice for their staple food become better off and begin to demand higher quality rice (Welch and Graham, 2002).

The success of hybrid rice breeding depends on the appropriate selection of potential parental lines and subsequent superior crosses. Combining ability analysis is one of the important tools available in selecting the desirable parents and cross combinations for exploitation of heterosis (Sarkar *et al.,* 2002 and Rashid *et al.,* 2007). It provides information on the nature and magnitude of gene effects governing various traits. General combining ability (GCA) is attributed to additive gene effects and additive x additive epistasis, and is theoretically fixable. On the other hand, specific combining ability is attributable to non-additive gene action may be due to dominance or epistasis or both and is non-fixable. The presence of non-additive genetic variance is the primary justification for initiating the hybrid programme (Cockerham, 1961 and Pradhan *et al.,* 2006). Although, number of studies towards combining ability analysis has been carried out for yield and yield traits, but the studies involving both yield and quality traits are lacking, making this an important area of study. Grain quality is second only to yield as the most important breeding objective. In the future, grain quality will be even more important as the very poor portion of our population which depends on rice as the staple food may likely to become prosperous and begin to demand higher quality rice (Babu *et al*., 2013). Therefore, present investigation was undertaken to assess the combining ability for yield and quality traits in rice to identify the best heterotic combination for both the types of traits.

Materials and Methods

The present study was carried out during *Kharif*-2015 and 2016 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 longitudes, at an elevation of 80.71 m above mean sea level. The research material consisted of eight genotypes selected for crossing programme were namely Pusa Basmati-1, Pusa Sugandh-2, Pusa Sugandh- 3, Pusa Sugandh-5, Type 3, Kasturi Basmati, Ranbir Basmati and Pusa-2517-2-51-1. All the genotypes were obtained from the ‘All India Coordinated Rice Improvement Project’ (AICRIP) at the Department of Genetics and Plant Breeding, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi (U.P.).

During *Kharif* 2015, eight genotypes were selected on the basis of their quality and quantitative traits for making F_1 crosses and all the genotypes were seeded in nursery at 3 dates, 10 days apart and transplanted in crossing blocks at 21 days after sowing. Crosses are made in diallel fashion (excluding reciprocals) developing 28 F_1s, using model I and method II (Griffings, 1956). Thus, the set of 28 rice hybrids were generated. In kharif-2016, the seed of F_1 hybrids generated during previous season along with the parental lines was 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.

Observations were recorded from each replication for both yield and quality traits *viz.*, days to 50 per cent flowering, days to maturity, plant height at maturity, main panicle length, number of effective tillers per plant, filled spikelets per panicle, unfilled spikelets per panicle, 100 grain weight, grain yield per plant, kernel length before cooking, kernel breadth before cooking, kernel length after cooking , kernel breadth after cooking, elongation ratio, elongation index, alkali digestion value and amylose content. Kernel dimensional analysis was done with the help of electronic grain analyzer. The observations for various traits were recorded as per the standard evaluation system of IRRI (1988) The simplified calorimetric method described by Juliano (1971) was followed for the estimation of amylose content. Combining ability analysis for various yield and quality traits was accomplished by the method suggested by Kempthorne (1957) through Windostat Version 9.2 from Indostat Services, Hyderabad (India). Characters estimated in ratios were first converted to arc sine values before analysis. Character wise estimation of GCA effects of parental lines and SCA effects of cross combinations was carried out. The significance of General Combining Ability and Specific Combining Ability effects were evaluated by t-test

Results and Discussion

The present investigation was undertaken to assess the combining ability for yield and quality traits in order to identify appropriate genotypes as parents in the hybridization programmes. 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). Analysis of variance for combining ability revealed that the crosses varied significantly from each other indicating sufficient differences for all the traits. The magnitude of mean square due to GCA were greater than SCA for days to 50% flowering, days to maturity, plant height, main panicle length, effective tillers/ plant, filled spikelets per plant, 100 Grain weight, yield per plant, kernel length before cooking, kernel breadth before cooking, L/B ratio before cooking, kernel length after cooking, kernel breadth after cooking and L/B after cooking except unfilled spikelets per plant. The estimates of SCA variance (σ^2 SCA) were revealed greater than GCA variance (σ^2 GCA) for all the characters except days to 50% flowering, days to maturity, plant height, and kernel length after cooking indicated in Tables 2 and 3. For all the characters, the ratio of variance of GCA to SCA was lesser than unity except days to 50% flowering, days to maturity, plant height and kernel length after cooking. Therefore these characters exhibited additive variance, while all other characters exhibited non-additive variance. The existence of both additive and non additive type of gene action for various yield traits has also been reported by Kumar *et al.*(2007), Montazeri *et al.* (2014), Waza *et al*. (2015) and Priyanka *et al*. (2014). However, Saravanan *et al.* (2006), Kumar *et al.* (2004) and Thakare *et al.* (2013) reported lower value of σ^2A than σ^2D for all the characters studied indicating the predominance of non additive gene action. Predominance of non additive gene action for grain yield and its components has been reported by Satyanarayana *et al.* (2000), Rita and Motiramani (2005), Singh *et al.* (2005), Venkatesan *et al.* (2007), Dalvi and Patel (2009), Saidaiah *et al.* (2010), and Hasan *et al.* (2013).

Thus, in the present study, both general combining ability (GCA) and specific combining ability (SCA) effects were estimated for yield as well as quality traits. The estimates of combining ability effects aid in selecting desirable parents and crosses, as well as the suitable breeding procedures for further improvement of different traits (Sarkar *et al.*, 2002, Rashid *et al.*, 2007 and Waza *et al*., 2015. Therefore, to exploit maximum heterosis using one way 8 x 8 diallel mating design system in the hybrid breeding programmes, we must know the combining ability effects of eight genotypes for yield and quality traits. Both general and specific combining ability effects for yield and yield components are indicated in Tables 4 and 6. When the breeding programme is designed for earliness in days to 50 per cent flowering and days to maturity, the crosses with negative GCA and SCA would be considered desirable for further improvement. The result indicated significant negative GCA effect for Kasturi Basmati followed by Pusa-2517-2-51-1 and Ranbir Basmati .This indicated that these parents were good general combiner for earliness and significant positive GCA effect recorded for Type-3 and Pusa Basmati-1, indicated that these two parents were good general combiner for lateness.

Significant specific combining ability effect for days to 50 per cent flowering and maturity indicated that the best specific combiner for earliness recorded for the cross Pusa-2517-2-51-1×Type-3 and Kasturi Basmati × Pusa Sugandh-2 and for lateness significant positive estimates recorded for Ranbir Basmati × Pusa Sugandh-2. Significant negative GCA and SCA effects for days to 50 per cent flowering and maturity were also reported byTiwari *et al.* (2011), Latha *et al.* (2013) and Waza *et al.* (2015). For the trait plant height negative GCA and SCA effect were treated as desirable for further improvement. Highest and significant negative GCA effect recorded for Pusa Sugandh-2 followed by, Pusa-2517-2-51-1, Pusa Sugandh-5 and Pusa Basmati-1. Crosses Ranbir Basmati × Pusa Sugandh-5 and Pusa-2517-2-51-1 × Type-3 showed importance to SCA effect in desirable direction as shown in table 6. This indicates that these parents were good general combiners and crosses were excellent specific combiner for desirable short stature of plant. Similar findings were reported by Salgotra *et al.* (2009), Raju *et al.* (2014) and Waza *et al.* (2015) for GCA and SCA effect.

For main panicle length positive GCA and SCA effect were treated as desirable for breeder for further improvement. Out of eight parents, four parents showed desirable significant positive result for main panicle length. Out of 28 crosses, eleven crosses observed significant positive SCA effects (Table 6). Number of effective tillers is an important yield trait in rice. Highly significant GCA value recorded for three parents out of eight *i.e.* Ranbir Basmati followed by Pusa Basmati-1 and Type-3. Out of 28 hybrids, fifty per cent were recorded importance to SCA effect for this trait. Similar finding were reported by Raju *et al. (*2006), Hariprasanna *et al*. (2006), Salgotra *et al*. (2009), Raju *et al.* (2014) and Waza *et al.* (2015).
For the trait, filled spikelets per panicle positive and highest significant GCA effects were registered in parents viz., Type-3, Pusa-2517-2-51-1 and Pusa Sugandh-3. Out of 28 crosses, fourteen crosses showed importance to SCA effects. Highly significant estimates of SCA effect registered for crosses viz., Pusa Sugandh-3 × Pusa Sugandh-2, Pusa Sugandh-2 × Type-3 and Pusa-2517-2-51-1 × Pusa Basmati-1. Negative significant recorded for ten crosses (Table 5).These finding were in agreement with Salgotra *et al*. (2009), Raju *et al.* (2014) and Waza *et al.* (2015).

Similar to days to 50% flowering, days to maturity, plant height and kernel breadth, the crosses with negative GCA and SCA effects were treated as desirable for the number of unfilled spikelets per plant. Highly negative significant GCA effect recorded for crosses Type-3 and Kasturi Basmati. Significant estimates of SCA effect in desirable direction were recorded for the six crosses as shown in table.

Positive and highest significant GCA effects for 100 grain weight were registered in parents viz., Type-3, Pusa-2517-2-51-1 and Pusa Sugandh-3. Parents with lowest significant *gca* effects recorded few genotypes. Out of 28 crosses, fourteen crosses had significant positive estimates of SCA effects. Highly significant estimates of SCA effect registered for crosses viz., Pusa Sugandh-3 × Pusa Sugandh-2, Pusa Sugandh-2 × Type-3 and Pusa-2517-2-51-1 × Pusa Basmati-1. Negative significant recorded for ten crosses (Table 4.13).These finding were in agreement with Salgotra *et al*. (2009), Kumar *et al*. (2009), Raju *et al.* (2014) and Waza *et al.* (2015). Estimates of GCA effects for the seed yield per plant showed that the cultivar Pusa Basmati-1 Pusa Sugandh-2 and Pusa-2517-2-51-1 were best. Significant and highest positive *SCA* effects were recorded for ten crosses. The top three specific combiners for seed yield per plant were Kasturi Basmati × Pusa-2517-

2-51-1, Pusa Sugandh-5 × Type-3 and Pusa Sugandh-5 × Pusa Sugandh-2. These crosses were good specific combiners for grain yield per plant. Salgotra *et al.* (2009) reported that Pusa 2517-2-51-1 was the best general combiner. Similar findings as observed in the present study were also reported by, Hariprasanna *et al.* 2006, Dalvi and Patel, 2009 and Salgotra *et al.* 2009 and Waza *et al.* (2015).

Grain quality in rice is very difficult to define with precision as preferences for quality vary from region to region. The concept of quality varies according to the preparations for which grains are to be used. Although some of the quality characteristics desired by grower, miller and consumer may be the same, yet each may place different emphasis on various quality characteristics. The miller's basis of quality is dependent upon total recovery and the proportion of head and broken rice on milling. Consumers base their concept of quality on the grain appearance, size and shape of the grain, the behaviour upon cooking, the taste, tenderness and flavour of cooked rice. The quality in rice may, therefore, be considered from viewpoint of grain size, shape and appearance and cooking characteristics. Thus, for the quality traits, kernel length before cooking and kernel length after cooking, elongation ratio, elongation index, alkali digestion value and amylose content positive combining ability effects are generally considered to be desirable. However, for kernel breadth before and after cooking, negative estimates are usually preferable.

Critical perusal for the analysis of kernel length before cooking revealed that parent Viz., Pusa Sugandh-5, Pusa-2517-2-51-1 and Pusa Sugandh-3 exhibited highly significant positive GCA effect. Whereas, remaining five parents showed non-significant GCA effect for Kernel length before cooking. Ten crosses revealed more importance to SCA effect for kernel length . Top five specific combiners for Kernel length were Pusa Sugandh-5 × Type-3, Pusa Sugandh-5 × Pusa Basmati-1, Pusa Sugandh-5 × Pusa Sugandh-2, Ranbir Basmati × Kasturi Basmati and Pusa-2517-2-51-1 × Pusa Basmati-1. These crosses may be used as a best specific combiner for enhancing the kernel length. Priyanka *et al.* (2014) and Waza *et al.* (2015) reported similar results for these traits. For kernel breadth before cooking, analysis revealed that only two parent viz. Kasturi Basmati and Pusa Basmati-1 had the highly significant negative *GCA* effect. On the other hand, positive and highly significant *GCA* effect was observed in Pusa Sugandh-3 and Type-3. Out of 28 crosses five crosses showed importance desirable SCA effects and twenty three hybrids showed significant positive effects for kernel breadth before cooking. Waza *et al.* (2015) reported similar results for these traits.

Critical perusal of analysis revealed that parent viz., Pusa Sugandh-5 and Kasturi Basmati registered highly significant for kernel L/B ratio before cooking. Whereas two parent Pusa Sugandh-2 and type-3 showed negative significant gca effect. Out of 28 crosses only three crosses viz., Ranbir Basmati × Kasturi Basmati, Pusa Sugandh-5× Type-3 and Pusa Sugandh-5 × Pusa Basmati-1 exhibited significant positive SCA effect for kernel L/B ratio before cooking. Most of the crosses recorded negative value for kernel L/B ratio before cooking. These results are in conformity with the findings of earlier researchers, Sanjeev Kumar *et al.* (2007), Umadevi *et al.* (2010), Gonya nayak *et al.* (2011), Asfaliza *et al.* (2012), and Maleki *et al.* (2014).

Four parents revealed highly significant positive gca effect for kernel length after cooking were Pusa Basmati-1 Pusa Sugandh-3, Pusa Sugandh-5 and Pusa-2517-2-51-1. For kernel length after cooking ten crosses exhibited significant positive SCA effects and eleven crosses exhibited significant negative effects. In case of kernel breadth after cooking, observed data revealed to show significant negative GCA effect. Out of eight parents studied, only two parent Type-3 and Pusa Basmati-1 exhibited significant negative value for *GCA* effect. Whereas other parent posseses highly significant GCA value for this traits. Out of 28 crosses, three crosses revealed highly significant negative SCA effect for kernel breadth after cooking. Whereas, most of the crosses revealed positive value for this trait. This similar finding with additive and dominant effect were reported by Munhot *et al.* (2000) Pradhan and Singh (2008), Tyagi *et al.* (2010), Adilakshmi and Raghava reddy (2012) and Gonya nayak *et al.* (2011).

Critical persuals of analysis for elongation ratio revealed highly significant and positive *GCA* effect in parent Pusa Basmati-1, Pusa-2517-2-51-1 and Pusa Sugandh-3. Therefore, these parents may be used as outstanding general combiners for this trait. Whereas, three parents were poor general combiner for the elongation ratio. Eight crosses, viz. Ranbir Basmati × Pusa Basmati-1 , Pusa Sugandh-3 x Pusa Basmati-1 , Kasturi Basmati× Pusa Sugandh-2 , Pusa Sugandh-3 x Pusa Sugandh-5 , Kasturi Basmati × Pusa Basmati-1, Ranbir Basmati × Pusa-2517-2-51-1, Pusa-2517-2-51-1 × Pusa Sugandh-2 and Pusa-2517-2-51-1 × Type-3 showed significant SCA effect in positive direction. Therefore, these crosses may be used as a best specific combiner for enhancing the elongation ratio. These similar findings with good as well as poor general and specific combiner were reported by Adilakshmi and Upendra (2014) and Sahu *et al*. (2016).

Critical persuals for elongation index revealed positive and highly significant GCA effect for parent viz., Type-3, Pusa Basmati-1 and Pusa-2517-2-51-1. Therefore, these parents may be used as best general combiner for elongation index. Three superior crosses were Pusa Sugandh-3 × Pusa Sugandh-5, Ranbir Basmati × Pusa Basmati-1 and Type-3 × Pusa Basmati-1 posseses highly significant SCA effect. Parents used in this top three cross combination were good × good, good × poor and poor × poor general and specific combiner. Analysis of alkali digestion value revealed that four parent viz. Pusa Sugandh-5, Pusa Basmati-1, Pusa Sugandh-2 and Pusa-2517-2-51-1 registered the highly significant positive GCA effect. Top three crosses viz., Pusa Sugandh-3 × Type-3, Kasturi Basmati× Pusa-2517-2-51-1 and Ranbir Basmati × Kasturi Basmati studied highly positive SCA effect for alkali digestion value. Parents used in this top three cross combination were good × poor and poor × poor general and specific combiner. These findings were similar to Adilakshmi and Upendra (2014), Maleki *et al.* (2014) and Sahu *et al*. (2016).

Critical perusal for the analysis of amylose content revealed that all the parents exhibited significant estimate of *GCA* effects. Out of that four parents revealed positive and highly significant estimate of GCA effects, viz., PusaSugandh-5, Pusa Basmati-1, PusaSugandh-2 and Ranbir Basmati. These parents were best general combiner for GCA effect. Top three specific combiner for amylose content were viz., Ranbir Basmati × Kasturi Basmati, Pusa Sugandh-2 ×Type-3 and Kasturi Basmati× PusaSugandh-3. Parents used in this top three cross combination were good × good, good × poor and poor × poor general and specific combiner. These findings were similar to the findings of Maleki *et al.* (2014), Adilakshmi and Upendra (2014) and Sahu *et al*. (2016).

To summarise, none of the parents showed significant desirable GCA effects simultaneously in desired direction for all the traits studied. Similar results have been reported by Tiwari *et al.* (2011) and Latha *et al.* (2013). Moreover, none of the crosses exhibited significant and desirable SCA effects for all the characters, indicating that no specific combination was desirable for all traits. These results are in complete agreement with earlier findings of Tiwari *et al.* (2011), Ghara *et al.* (2012), and Sanghera and Hussain (2012). Among the parents, Ranbir Basmati revealed significant desirable value of GCA effect for most of the yield traits under study. However, Pusa Sugandh-5 revealed significant desirable value of GCA effect for most of the quality attributes in the study. Waza *et al*. (2016) reported that Pusa Sugandh -5 revealed best GCA value for most of the quality attributes . Among the parents, Pusa -2517-2-51-1(Days to 50 per cent flowering and early maturing, plant height, filled spikelets, 100 grain weight, seed yield per plants, KLBC, KLAC, ER, EI and ASV) and Pusa Sugandh-3(Days to 50 per cent flowering, Days to maturity, plant height, filled spikelets, 100 seed weight, KLBC, KLAC and ER) studied best general combiner for both yield as well as quality traits for most of the characters. However, Pusa Basmati-1 recorded superior general combiner for most of the traits for late maturing. Among the crosses evaluated, Pusa-2517-2-51-1×Type-3 (Days to 50% flowering, Days to maturity & plant height, main panicle length, yield per plant) observed superior specific combiner for yield traits only. However, Ranbir Basmati x Pusa Basmati-1 observed best specific crosses for quality traits respectively. Cross combination viz., Pusa Sugandh-5 x Pusa Basmati-1, Ranbir Basmati x Kasturi Basmati, Kasturi Basmati × Pusa-2517-2-51-1 and Pusa Sugandh-3 x Type-3 performed superior specific combiner for most of the yield as well as quality traits. It was observed that best cross combinations are not always found between high x high general combiners, but may also occur in other types of parental combinations. Waza *et al*. (2016) reported similar findings in their study. Chakraborty *et al*. (2009) and Tiwari *et al.* (2011) have reported that in order to obtain heterotic hybrids, it is better to select at least one parent possessing high GCA and other with low, average or high GCA. Hariprasanna *et al*. (2006) have reported that high x high GCA combination resulted in significant negative SCA for some traits in rice, which confirm the present findings.

The cross combination, Pusa-2517-2-51-1×Type-3 observed to be the superior specific combiner for yield traits only. However, Ranbir Basmati x Pusa Basmati-1 revealed significant desirable value of SCA effect for most of the quality traits. For both yield and quality traits, cross combination viz., Pusa Sugandh-5 x Pusa Basmati-1, Ranbir Basmati x Kasturi Basmati, Kasturi Basmati × Pusa-2517-2-51-1 and Pusa Sugandh-3 x Type-3 were found to be better performing.. These cross combinations were identified as the best specific crosses in view of their high *per se* performance, SCA effects and GCA of their respective parents. Among these, crosses recorded importance to SCA effect was revealed by Ranbir Basmati x Kasturi Basmati and Kasturi Basmati × Pusa-2517-2-51-1 for most of the yield as well as quality attributes. The hybrids recording positive and significant SCA effects in the present study need to be further tested in observational/multi-location trials to exploit their heterotic potential at commercial level. Moreover, the cross combinations which show least importance to SCA effects but originated from parental lines having high GCA effects can be used for recombination breeding with an easy selection of desirable segregants, particularly for developing better performing pure lines.

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Table 1. Analysis of variance for yield and quality characteristics

Sources of variation	Parents	Hybrids	Parent Vs Hybrids
DF(Degree of Freedom)	7.00	27.00	1.00
Days to 50% Flowering	300.95**	107.19**	5.98*
Days to Maturity	323.35**	104.02**	2.72
Plant Height (cm)	2185.16**	946.24**	0.45
Main Panicle Length (cm)	79.46**	39.07**	107.89**
Effective Tillers/ Plant	13.36**	6.79**	60.76**
Filled Spikelets	1039.51**	1784.79**	147.91**
Unfilled Spikelets	496.58**	419.87**	1967.32**
100 Grain Weight (g)	0.25**	0.10**	0.17**
Yield Per Plant (g)	158.55**	75.79**	442.22**
Kernel Length (mm)	0.58**	0.60**	1.01**
Kernel Breadth (mm)	0.04**	0.05**	0.08**
L/B Ratio Before Cooking	0.45**	0.51**	0.02
Kernel Length After Cooking(mm)	3.04**	1.60**	0.33**
Kernel Breadth After Cooking(mm)	0.03**	0.04**	0.01
L/B After Cooking	0.73**	0.32**	0.15**
Elongation Ratio (ER)	0.03**	0.04**	0.02**
Elongation Index (EI)	0.06**	0.04**	0.02
ASV/GT Value	9.07**	3.06**	0.00
Amylose Content	27.75**	19.12**	0.01

*Significant at 5 % level, ** Significant at 1 % level

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Table 2. Analysis of variance for combining ability for yield and yield traits in rice

Sources of variation	DF	DTF	DTM	PH (cm)	PL	ET/P	FS/P	US/P	100 SW	Y/P
GCA	7.00	183.33**	182.64**	1869.89**	52.66**	6.35**	1081.15**	135.33**	0.14**	94.44**
SCA	28.00	13.77**	14.75**	18.78**	7.30**	2.43**	391.78**	165.93**	0.02**	19.23**
Error	70.00	0.30	0.29	0.26	0.27	0.19	1.78	1.32	0.00	0.55
σ^2 gca		18.30	18.24	186.96	5.24	0.62	107.94	13.40	0.01	9.39
σ^2 sca		13.47	14.46	18.52	7.02	2.24	390.00	164.60	0.02	18.68
σ^2 gca/ σ^2 sca		1.36	1.26	10.10	0.75	0.27	0.28	0.08	0.79	0.50

*, ** = Significant at 0.05, and 0.01 levels, respectively. DTF-Days to 50% flowering; DTM-Days to Maturity; PH- Plant Height; PL-Main Panicle Length; ET/P- Effective Tillers/plant; FS/P-Filled Spikelet per panicle; UFS/P-Unfilled Spikelet per panicle; 100 SW-100Seed Weight and Y/P- Yield per plant;

Table 3. Analysis of variance for combining ability for quality traits in rice

Sources of variation	KLBC	KBBC	L/B BC	KLAC	KBAC	L/B AC	ER	EI	ASV/GT	AC
GCA	0.57**	0.04**	0.41**	2.37**	0.03**	0.46**	0.03**	0.04**	1.73**	10.29**
SCA	0.11**	0.01**	0.10**	0.18**	0.01**	0.05**	0.01**	0.01**	1.31**	5.88**
Error	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.01	0.02
σ^2 gca	0.06	0.00	0.04	0.24	0.00	0.05	0.00	0.00	0.17	1.03
σ^2 sca	0.11	0.01	0.06	0.17	0.01	0.05	0.01	0.01	1.30	5.86
σ^2 gca/ σ^2 sca	0.52	0.55	0.67	1.36	0.51	0.97	0.34	0.46	0.13	0.18

*, ** = Significant at 0.05, and 0.01 levels, respectively. KLBC-Kernel Length Before Cooking; KBBC-Kernel Breadth Before Cooking; L/B BC- Kernel length/breadth ratio before cooking; KLAC- Kernel Length After Cooking; KBAC-Kernel Breadth Before Cooking; L/B AC- Kernel length/breadth ratio after cooking; ER-Elongation Ratio; EI-Elongation Index; ASV-Alkali Spread Value; GT-Gelatinization Temperature; AC-Amylose Content. σ^2GCA= Variance due to GCA, σ^2SCA= Variance due to SCA

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Table 4. General combining ability (GCA) effects of parents for yield and yield components in rice

Parents	DTF	DTM	PH (cm)	PL	ET/P	FS/P	US/P	100 SW	Y/P
Ranbir Basmati	-2.11**	-2.09**	19.16**	0.94**	1.02**	3.41**	-0.12	-0.05**	-0.79**
Kasturi Basmati	-7.69**	-7.87**	2.40**	1.99**	-0.67**	-8.69**	-2.12**	-0.07**	-2.99**
Pusa Sugandh-3	-0.33*	-0.34*	-3.63*	-1.69**	-0.90**	4.40**	-0.36	0.13**	-0.32
Pusa Sugandh-5	3.96**	4.05**	-8.63**	-0.93**	-0.63**	-21.83**	5.74**	0.05**	-4.19**
Pusa-2517-2-51-1	-2.53**	-2.41**	-10.16**	-2.58**	0.07	7.33**	-1.32**	0.16**	1.01**
Pusa Sugandh-2	0.74**	0.99**	-14.93**	-2.53**	-0.56**	3.69**	1.80**	0.05**	2.95**
Type-3	6.23**	5.94**	21.99**	3.76**	0.70**	10.21**	-6.58**	-0.17**	-0.98**
Pusa Basmati-1	1.74**	1.73**	-6.19**	1.05**	0.97**	1.48**	2.97**	-0.12**	5.31**
SE (gi)±	0.38	0.37	0.36	0.37	0.31	0.93	0.80	0.03	0.52
SE (gi-gj) ±	0.58	0.57	0.54	0.56	0.47	1.41	1.22	0.04	0.78

*, ** = Significant at 0.05, and 0.01 levels, respectively. DTF-Days to 50% flowering; DTM-Days to Maturity; PH- Plant Height; PL-Main Panicle Length; ET/P- Effective Tillers/plant; FS/P-Filled Spikelet per panicle;UFS/P-Unfilled Spikelet per panicle; 100 SW-100Seed Weight and Y/P- Yield per plant

Table 5. General combining ability (GCA) effects of parents for quality traits in rice

Parents	KLBC	KBBC	L/B BC	KLAC	KBAC	L/B AC	ER	EI	ASV/GT	AC
Ranbir Basmati	-0.03*	-0.02	0.07	-0.32**	0.06**	-0.26**	-0.04**	-0.06**	-0.36**	0.45**
Kasturi Basmati	-0.23**	-0.10**	0.18**	-0.40**	0.01	-0.19**	0.00	-0.08**	-0.47**	-1.12**
Pusa Sugandh-3	0.26**	0.02	0.08	0.52**	0.08**	0.02	0.01*	-0.02	-0.04	-1.10**
Pusa Sugandh-5	0.43**	-0.01	0.25**	0.33**	-0.01	0.16**	-0.05**	-0.04**	0.60**	1.21**
Pusa-2517-2-51-1	0.21**	0.06**	-0.15*	0.08**	0.02*	0.02	0.01*	0.04**	0.10**	-0.26**
Pusa Sugandh-2	0.00	0.07**	-0.19**	-0.34**	-0.01	-0.10**	-0.04**	0.02	0.30**	0.87**
Type-3	-0.28**	0.07**	-0.34**	-0.61**	-0.09**	-0.06**	-0.01**	0.08**	-0.51**	-1.09**
Pusa Basmati-1	-0.13**	-0.07**	0.10	0.73**	-0.06**	0.42**	0.13**	0.06**	0.36**	1.03**
SE (gi)±	0.03	0.04	0.15	0.05	0.02	0.04	0.01	0.03	0.05	0.10
SE (gi-gj) ±	0.04	0.06	0.22	0.07	0.03	0.06	0.02	0.05	0.08	0.16

*, ** = Significant at 0.05, and 0.01 levels, respectively. KLBC-Kernel Length Before Cooking; KBBC-Kernel Breadth Before Cooking; L/B BC- Kernel length/breadth ratio before cooking; KLAC- Kernel Length After Cooking; KBAC-Kernel Breadth Before Cooking; L/B AC- Kernel length/breadth ratio after cooking; ER-Elongation Ratio; EI-Elongation Index; ASV-Alkali Spread Value; GT-Gelatinization Temperature; AC-Amylose Content. σ^2GCA= Variance due to GCA, σ^2SCA= Variance due to SCA

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Table 6. Specific combining ability (*SCA*) effects of crosses for grain yield and yield traits in rice

Crosses	DTF	DTM	PH (cm)	PL	ET/P	FS/P	US/P	100 SW	Y/P
Ranbir Basmati × Kasturi Basmati	-3.67**	-3.57**	8.77**	-1.05*	1.33**	11.80**	-9.13**	-0.04	1.38
Ranbir Basmati × Pusa Sugandh-3	-1.23*	-1.10*	-3.30**	-2.29**	-0.04	9.68**	12.02**	-0.04	4.71**
Ranbir Basmati × Pusa Sugandh-5	0.91	0.81	-6.13**	-0.79	0.85*	3.30**	-10.32**	0.04	-2.09**
Ranbir Basmati × Pusa-2517-2-51-1	-0.60	-0.57	5.04**	-3.04**	-1.81**	10.25**	5.08**	0.33**	0.71
Ranbir Basmati × Pusa Sugandh-2	7.70**	7.17**	-4.23**	4.44**	1.32**	3.31*	28.85**	0.20**	-0.89
Ranbir Basmati × Type-3	0.37	0.69	-1.72**	-2.08**	-0.34	-18.44**	-13.43**	0.02	0.03
Ranbir Basmati × Pusa Basmati-1	-1.00	-1.07*	3.27**	1.46**	0.89*	-15.94**	0.78	0.01	0.74
Kasturi Basmati × Pusa Sugandh-3	4.56**	4.88**	-1.67**	4.22**	0.75	-0.95	14.55**	0.04	0.57
Kasturi Basmati × Pusa Sugandh-5	5.26**	6.39**	-3.50**	-2.44**	1.00*	-19.73**	-6.45**	-0.08	-5.56**
Kasturi Basmati × Pusa-2517-2-51-1	2.12**	2.21**	3.93**	5.21**	3.67**	8.35**	-2.12	0.09*	8.58**
Kasturi Basmati × Pusa Sugandh-2	-6.18**	-5.29**	-3.23**	1.29*	-1.29**	-11.58**	17.62**	0.12**	3.64**
Kasturi Basmati × Type-3	3.75**	3.53**	5.21**	-1.80**	1.54**	6.13**	17.44**	-0.09*	2.57**
Kasturi Basmati × Pusa Basmati-1	0.58	0.57	-4.74**	2.04**	0.24	8.73**	-0.75	0.06	3.94**
Pusa Sugandh-3 × Pusa Sugandh-5	-2.80**	-2.87**	6.97**	0.48	-1.83**	-24.05**	5.36**	-0.15**	2.43**
Pusa Sugandh-3 × Pusa-2517-2-51-1	0.59	0.88	-4.67**	-2.54**	1.07*	-1.07	-10.58**	-0.08*	-1.76*
Pusa Sugandh-3 × Pusa Sugandh-2	0.79	0.59	-3.20**	-0.99*	0.51	39.23**	-11.24**	-0.05	5.30**
Pusa Sugandh-3 × Type-3	-4.04**	-4.56**	4.81**	1.69**	0.98*	-1.05	8.02**	0.24**	0.89
Pusa Sugandh-3 × Pusa Basmati-1	1.12*	0.75	-0.54	0.83	0.21	-20.22**	4.26**	0.02	-1.73*
Pusa Sugandh-5 × Pusa-2517-2-51-1	2.50**	2.26**	2.57**	1.80**	0.36	12.02**	1.32	-0.04	-3.89**
Pusa Sugandh-5 × Pusa Sugandh-2	-2.67**	-2.91**	1.10	2.31**	-0.47	-23.24**	-7.67**	-0.17**	6.50**
Pusa Sugandh-5 × Type-3	1.20*	1.35*	0.31	-0.21	1.77**	19.61**	4.12**	0.22**	6.76**
Pusa Sugandh-5 × Pusa Basmati-1	-0.54	-0.21**	-0.40	-0.10	1.20**	10.00**	4.89**	0.10*	4.13**
Pusa-2517-2-51-1 × Pusa Sugandh-2	-0.01	-0.05	1.63**	-1.30*	-0.30	-41.50**	13.16**	-0.07	-2.36**
Pusa-2517-2-51-1 × Type-3	-9.78**	-10.43**	-10.56**	3.45**	-0.06	-3.82**	-0.92	0.05	1.90**
Pusa-2517-2-51-1 × Pusa Basmati-1	0.25	0.94	2.33**	-0.15	-1.40**	27.11**	-16.25**	-0.13**	-1.39*
Pusa Sugandh-2 × Type-3	1.65**	1.97**	0.11	0.39	0.91*	35.18**	-10.25**	-0.01	-6.71**
Pusa Sugandh-2 × Pusa Basmati-1	-4.92**	-4.79**	1.40**	2.73**	1.64**	-31.45**	11.66**	0.10*	-0.67
Type-3 × Pusa Basmati-1	0.52	0.07	-0.56	1.41**	-1.46**	-9.14**	13.81**	-0.11**	2.59**
Sij	1.01	1.0	0.95	0.97	0.81	2.49	2.14	0.08	1.38
Sij-Sik	1.51	1.48	1.40	1.44	1.20	3.68	3.17	0.12	2.04
Sij-Skl	1.42	1.40	1.32	1.36	1.13	3.47	2.99	0.11	1.93

*, ** = Significant at 0.05, and 0.01 levels, respectively. DTF-Days to 50% flowering; DTM-Days to Maturity; PH- Plant Height; PL-Main Panicle Length; ET/P- Effective Tillers/plant; FS/P-Filled Spikelet per panicle; UFS/P-Unfilled Spikelet per panicle; 100 SW-100Seed Weight and Y/P- Yield per plant

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Table 7. Specific combining ability (SCA) effects of crosses for grain quality traits in rice

Crosses	KLBC	KBBC	L/B BC	KLAC	KBAC	L/B AC	ER	EI	ASV/GT	AC
Ranbir Basmati × Kasturi Basmati	0.43**	-0.14**	1.00**	-0.21**	0.01	-0.10	-0.12**	-0.18**	1.14**	4.30**
Ranbir Basmati × Pusa Sugandh-3	0.37**	0.14**	-0.13	0.90**	0.07*	0.23**	0.03*	0.10*	-1.12**	-3.69**
Ranbir Basmati × Pusa Sugandh-5	0.11*	0.07	-0.18	0.26**	0.09**	-0.08	0.00	0.02	0.23**	1.47**
Ranbir Basmati × Pusa-2517-2-51-1	-0.12**	0.10*	-0.37	0.44**	0.03	0.06	0.09**	0.10*	0.10	-2.39**
Ranbir Basmati × Pusa Sugandh-2	-0.03	0.03	-0.14	-0.24**	-0.03	-0.05	-0.03*	0.02	0.63**	1.18**
Ranbir Basmati × Type-3	-0.18**	-0.11*	0.12	-0.14*	-0.02	0.01	0.02	-0.04	0.57**	-0.02
Ranbir Basmati × Pusa Basmati-1	-0.24**	0.00	-0.19	0.50**	-0.19**	0.66**	0.13**	0.18**	1.00**	-0.11
Kasturi Basmati × Pusa Sugandh-3	0.14**	0.12*	-0.28	-0.06	0.02	0.00	-0.04**	0.05	1.13**	3.35**
Kasturi Basmati × Pusa Sugandh-5	-0.29**	-0.12*	0.11	-0.36**	0.01	-0.22**	0.01	-0.06	0.99**	2.08**
Kasturi Basmati × Pusa-2517-2-51-1	0.24**	0.18**	-0.32	-0.08	-0.11**	0.26**	-0.07**	0.12*	1.42**	3.02**
Kasturi Basmati × Pusa Sugandh-2	-0.33**	0.14*	-0.58**	0.23**	0.12**	-0.18**	0.10**	0.10*	-0.18**	-2.15**
Kasturi Basmati × Type-3	0.02	-0.03	-0.03	0.04	-0.13**	0.31**	-0.01	0.08	-1.07**	-3.35**
Kasturi Basmati × Pusa Basmati-1	0.00	-0.02	0.04	0.67**	0.03	0.19**	0.09**	0.03	0.06	-1.20**
Pusa Sugandh-3 × Pusa Sugandh-5	-0.31**	0.09	-0.38	0.15*	-0.06*	0.21**	0.09**	0.18**	-0.68**	-0.58**
Pusa Sugandh-3 × Pusa-2517-2-51-1	-0.04	-0.11*	0.25	-0.24**	0.01	-0.18**	-0.02	-0.11*	-2.92**	-2.01**
Pusa Sugandh-3 × Pusa Sugandh-2	0.18**	0.02	0.12	-0.15*	0.01	-0.09	-0.06**	-0.06	0.02	-0.54**
Pusa Sugandh-3 × Type-3	0.23**	0.08	-0.02	-1.02**	-0.18**	-0.03	-0.19**	-0.02	1.43**	2.89**
Pusa Sugandh-3 × Pusa Basmati-1	-0.49**	-0.14**	0.11	0.12	0.18**	-0.38**	0.13**	-0.10*	-0.58**	-0.76**
Pusa Sugandh-5 × Pusa-2517-2-51-1	-0.18**	0.09	-0.29	-0.34**	0.00	-0.19**	-0.01	0.05	0.07	-1.35**
Pusa Sugandh-5 × Pusa Sugandh-2	0.52**	0.08	0.08	-0.39**	-0.06*	0.00	-0.14**	-0.03	-1.83**	-4.65**
Pusa Sugandh-5 × Type-3	0.70**	-0.02	0.40*	0.08	0.05	-0.08	-0.13**	-0.13**	0.65**	0.39**
Pusa Sugandh-5 × Pusa Basmati-1	0.68**	-0.12**	0.43*	0.18**	0.04	-0.03	-0.13**	-0.14**	0.48**	2.93**
Pusa-2517-2-51-1 × Pusa Sugandh-2	-0.15**	-0.09	0.08	0.36**	0.01	0.11*	0.08**	0.01	0.20**	-1.01**
Pusa-2517-2-51-1 × Type-3	-0.07	-0.02	0.00	0.43**	0.09**	0.00	0.07**	0.02	-0.69**	-1.11**
Pusa-2517-2-51-1 × Pusa Basmati-1	0.38**	-0.01	0.20	-0.37**	-0.05	-0.05	-0.14**	-0.09*	-0.19**	0.60**
Pusa Sugandh-2 × Type-3	0.06	0.00	0.04	0.14*	0.02	0.02	0.00	-0.03	0.95**	3.69**
Pusa Sugandh-2 × Pusa Basmati-1	-0.16**	-0.06	0.07	-0.02	-0.02	0.07	0.02	-0.01	-0.99**	-0.36*
Type-3 × Pusa Basmati-1	-0.05	0.14**	-0.38	-0.02	-0.04	0.10	0.01	0.17**	-0.81**	-0.46**
Sij	0.09	0.10	0.39	0.12	0.06	0.11	0.02	0.09	0.13	0.28
Sij-Sik	0.13	0.15	0.58	0.18	0.08	0.16	0.04	0.13	0.20	0.41
Sij-Skl	0.12	0.14	0.55	0.17	0.08	0.15	0.03	0.12	0.19	0.38

*, ** = Significant at 0.05, and 0.01 levels, respectively. KLBC-Kernel Length Before Cooking; KBBC-Kernel Breadth Before Cooking; L/B BC- Kernel length/breadth ratio before cooking; KLAC- Kernel Length After Cooking; KBAC-Kernel Breadth Before Cooking; L/B AC- Kernel length/breadth ratio after cooking; ER-Elongation Ratio; EI-Elongation Index; ASV-Alkali Spread Value; GT-Gelatinization Temperature; AC-Amylose Content. σ^2GCA= Variance due to GCA, σ^2SCA= Variance due to SCA

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