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# COMBINING ABILITY ANALYSIS FOR YIELD AND RELATED TRAITS IN BASMATI RICE (*ORYZA SATIVA* L.)

**MUHAMMAD YUSSOUF SALEEM[1 *], JAVED IQBAL MIRZA[2] AND MUHAMMAD AHSANUL HAQ[1]**

*[1]Nuclear Institute for Agriculture and Biology (NIAB), P. O. Box 128, Faisalabad,*
*[2]Institute of Pure and Applied Biology, Bahauddin Zakariya University, Multan, Pakistan*

**Abstract**

Line × tester experiment was conducted to evaluate the performance of 27 $F_1$ hybrids along with 12 parents in Basmati rice. Analysis of variance revealed highly significant differences among treatments, parents, parents vs. crosses and crosses for number of tillers per plant, panicle length, number of grains per panicle, fertility percentage, 1000-grain weight and yield per plant. Lines were significant for number of tillers per plant, number of grains per panicle and 1000-grain weight while testers and lines × testers were significant for all the traits. The estimates of variance of specific combining ability effects, ratio of variance of general combining ability to specific combining ability and degree of dominance indicated preponderance of non-additive gene effects for each trait. On over all basis, role of testers in the expression of most of the yield components was more than lines and line × tester interaction. However, line × tester interaction contributed more than lines and testers for yield per plant. Three lines viz., Basmati 2000, Super Basmati and Kashmir Basmati and one tester Basmati-385 were identified as good general combiners based on their mean performance and GCA effects for yield and its various traits. Hybrids like Basmati Pak × Basmati-385, Super Basmati × Basmati-385, DM-107-4 × Basmati-385, Basmati 2000 × EL-30-2-1, Basmati 2000 × DM-25, DM-16-5-1 × Basmati-385 and Kashmir Basmati × DM-25 showed high mean performance, SCA effects and heterobeltiosis for grain yield and are proposed for heterosis breeding.

## Introduction

After cotton, rice (*Oryza sativa* L. 2n = 2x = 24) is second major export commodity of Pakistan. During 2007-2008, area, production and export figures indicated that rice (aromatic and non-aromatic) was grown on 2.51 million hectares with production of 5.56 million tonnes and average yield of 2212 kg per hectare. The contribution of Basmati rice in total production was 2.64 million tonnes from an area of 1.47 million hectares with average yield of 1801 kg per hectare. Pakistan earned 1346 million US$ by exporting 2.81 million tonnes of rice in which Basmati rice contributed 1.14 million tonnes worth of 784 million US $ (Anon., 2007-2008). The average yield of rice in Pakistan is low as compared to 4.11 tonnes per hectare of world rice yield (Nguyen, 2007). Attempts to improve yield of Basmati rice through hybridization in dwarf background has been partly successful. Basmati rice has narrow genetic base, scarcity of donor parents for grain quality and poor combining ability response. It is therefore necessary to concentrate breeding efforts on exploration of good combiners which can efficiently be hybridized to produce superior genotypes without loss of traditional Basmati quality. In this regard, pace of breeding efforts mainly depends on choice of parents, understanding of genetic phenomenon controlling the inheritance of yield and yield components and adaptation of suitable breeding methods.

*E-mail: mysaleem1966@gmail.com ; Fax: 92-41-2654213

Line × tester technique (Kempthorne, 1957) is useful in deciding the relative ability of female and male lines to produce desirable hybrid combinations. It also provides information on genetic components and enables the breeders to choose appropriate breeding methods for hybrid variety or cultivar development programmes. Lot of research work is available on combing ability analysis in rice; however there is need to analyze combining ability in relation to mean performance, heterosis and other genetic parameters in Basmati rice where the improvement has been slow over the world due to various genetic barriers. The present research work was therefore carried out with the objective to assess combining ability based on mean performance, genetic components and heterosis controlling some economic traits in Basmati rice. The information obtained thus will be used in selection of suitable parents and choice of appropriate breeding methods to develop high yielding Basmati rice cultivar(s) or hybrid variety(s).

## Materials and Methods

The study was conducted at the experimental field of Nuclear Institute for Agriculture and Biology (NIAB), Faisalabad, Pakistan.The experiment involved pure Basmati rice genotypes. Nine genotypes viz., Basmati-370, DM-2, DM-107-4, DM-16-5-1, Kashmir Basmati, Basmati-Pak, Basmati 2000, Super Basmati and Shaheen Basmati were used as females (lines) and 3 genotypes viz., Basamti-385, DM-25 and EL-30-2-1 as males (testers) were crossed according to lines × tester technique (Kempthorne, 1957) to generate 27 $F_1$ hybrids. Field evaluation of 39 genotypes (13 parents + 27 hybrids) was performed following randomized complete block design (RCBD) with three replications during 2005-06. The data were recorded on physiological, morphological and agronomic traits. Some preliminary results have been reported elsewhere (Saleem *et al*., 2008). In this paper the agronomic traits viz., number of tillers per plant, panicle length (cm), number of grains per panicle, fertility percentage, 1000-grain weight (g) and yield per plant (g) are discussed.

Genotype means were used for the analysis of variance (Singh & Chaudhary, 1985). Genotypes with significant and high mean performance than grand mean were adjudged as desirable ones. Combining ability analysis was also performed according to Singh & Chaudhary (1985). Significant and positive general combining ability (GCA) and specific combining ability (SCA) effects were considered as high (*h*), non-significant as average (*a*) and significant and negative as low (*l*). Heritability in broad sense $h^2_{(b.s)}$ was determined as outlined by Lush (1940). Standard error (S.E.) of broad sense heritability was calculated following Lothrop *et al*., (1985). Heterobeltiosis Ht (bel) was determined as outlined by Falconar & Mackey (1996).

## Results and Discussion

Analysis of variance, estimates of genetic components and contribution of lines, testers and line × tester interaction to the total variance have been shown in Table 1. Highly significant differences among treatments, parents, parents vs. crosses and crosses were observed in all traits. Lines were significant for number of tillers per plant, number of grains per panicle and 1000-grain weight while testers and line × tester were significant for all characters. Significant mean sum of square for parents vs. crosses indicated that crosses differed from the parents significantly therefore, it is inferred that variations were transmitted to progeny as indicated by high value of broad sense

**Table 1. Mean squares for analysis of variance, estimates of genetic components and contribution of lines, testers and line x tester to the total variance in rice genotypes.**

| Source | d.f | Number of tillers per plant | Panicle length (cm) | Number of grains per panicle | Fertility percentage | 1000-grain weight (g) | Yield per plant (g) |
|---|---|---|---|---|---|---|---|
| Replication | 2 | 0.16 | 1.35 | 9.04 | 20.76** | 0.18 | 1.18 |
| Treatments | 38 | 29.26** | 20.98** | 4334.54** | 98.92** | 17.79** | 164.85** |
| Parents | 11 | 8.44** | 14.93** | 3200.71** | 88.58** | 32.81** | 30.26** |
| Parents vs Crosses | 1 | 474.34** | 53.08** | 12706.56** | 29.51** | 2.26** | 3325.39** |
| Crosses | 26 | 20.96** | 22.30** | 4492.23** | 105.96** | 12.03** | 100.24** |
| Lines | 8 | 32.78** | 14.07 | 4218.91** | 48.10 | 5.98* | 96.83 |
| Testers | 2 | 82.39** | 148.49** | 35300.70** | 921.15** | 118.97** | 442.98** |
| Lines × Testers | 16 | 7.36** | 10.64** | 777.83** | 32.99** | 1.69** | 59.10** |
| Error | 76 | 0.26 | 0.53 | 8.53 | 3.90 | 0.11 | 3.43 |
| $\sigma^2_{GCA}$ | | 0.28 | 0.24 | 76.65 | 1.51 | 0.21 | 0.85 |
| $\sigma^2_{SCA}$ | | 2.37 | 3.37 | 256.43 | 9.70 | 0.53 | 18.56 |
| $\sigma^2_{GCA}/\sigma^2_{SCA}$ | | 0.12 | 0.07 | 0.30 | 0.16 | 0.41 | 0.05 |
| $\sigma^2_A$ | | 0.56 | 0.48 | 153.29 | 3.01 | 0.43 | 1.70 |
| $\sigma^2_D$ | | 2.37 | 3.37 | 256.43 | 9.70 | 0.53 | 18.56 |
| $(\sigma^2_D/\sigma^2_A)^{1/2}$ | | 2.05 | 2.65 | 1.29 | 1.79 | 1.11 | 3.31 |
| $\sigma^2 g$ | | 9.67 | 6.82 | 1442.00 | 31.67 | 5.89 | 53.81 |
| $\sigma^2 p$ | | 9.93 | 7.34 | 1450.53 | 35.57 | 6.00 | 57.24 |
| $\sigma^2 e$ | | 0.26 | 0.53 | 8.53 | 3.90 | 0.11 | 3.43 |
| $h^2_{(b.s)}$ ± S.E. | | 0.97±0.04 | 0.93±0.05 | 0.99±0.00 | 0.89±0.02 | 0.98±0.05 | 0.94±0.02 |
| Contribution (%) of Lines | | 48.13 | 19.42 | 28.90 | 13.97 | 15.29 | 29.72 |
| Testers | | 30.24 | 51.22 | 60.44 | 66.87 | 76.08 | 33.99 |
| Line × Tester | | 21.63 | 29.36 | 10.66 | 19.16 | 8.63 | 36.29 |

*, ** = Significant at 0.05 and 0.01 levels of probability, respectively.

heritability for each character. The value of variance of general combining ability ($\sigma^2_{GCA}$) was less than variance of specific combining ability ($\sigma^2_{SCA}$) for all traits showing the preponderance of non-additive gene action. It was further supported by ratio ($\sigma^2_{GCA}/\sigma^2_{SCA}$) being less than one and degree of dominance i.e. ratio of dominance variance ($\sigma^2_D$) to additive variance ($\sigma^2_A$) being greater than one. Several workers have reported preponderance of non-additive gene action for number of tillers per plant, total number of grains per panicle and fertility percentage (Vaithiyalingan & Nadarajan, 2005), panicle length and 1000-grain weight (Punitha *et al*., 2004) and yield per plant (Sharma, 2006). The relative share of lines, testers and line × tester interaction in the expression of various characters indicated dominant influence of paternal effects shown by testers for 1000-grain weight (76.08%), fertility percentage (66.87%), number of grains per panicle (60.44%) and panicle length (51.22%). Maternal effect shown by lines was important for number of tillers per plant (48.13%). The contribution of maternal × paternal effects in crosses was important for yield per plant (33.99%) only. Our results were similar for number of tillers per plant, 1000-grain weight and fertility percentage however, dissimilar for panicle length, total number of grains per panicle and yield per plant with Thirumeni *et al*., (2000) in rice.

**Identification of parents based on mean performance and GCA effects:** Mean performance of the parents and GCA effects have been given in Table 2. Significant and positive mean performance and GCA effects are preferable for all traits. It is evident that assessment of parents on the basis of mean performance and GCA effects separately, results in different sets of parents as better ones for 6 characters studied. However, mean performance of the parents with nature of combining ability provides the criteria to select the parents for hybridization as suggested by Harer & Bapat (1982). On this basis, those parents who perform better for both mean performance and GCA effects have been treated as good general combiners in present study.

Number of tillers per plant varied from 11.20 to 14.83 among lines and 14.07 to 15.97 among testers. Five parents had significantly high number of tillers per plant and five had significant and positive GCA effects. However, Super Basmati, Basmati-Pak among female and EL-30-2-1 among male parents were found good general combiners for number of tillers per plant. Akram *et al*., (2007) registered promising lines and testers with high GCA effects for number of tillers per plant in rice. Panicle length was variable from 28.20 to 35.35 cm among lines and 30.67 to 34.87 cm among testers. Four parents had significantly high panicle length and three had significant and positive GCA effects. Among all parents, Basmati-385 was the only desirable general combiner for panicle length. Current results are in agreement with those of Patil *et al*., (2003) wherein they identified number of general combiners based on high mean performance and GCA effects for panicle length in rice. Among lines, number of grains per panicle varied from 98.33 to 181.60 and among testers, it varied from 101.07 to 198.67. Six parents showed significant and high number of grains per panicle. Seven parents indicated high GCA effects but DM-16-5-1, Basmati-370, Shaheen Basmati and Basmati 2000 among females and Basmati-385 among males appeared as good general combiner for number of grains per panicle. Sharma (2006) identified desirable general combiners for this trait in rice.

Range of fertility % varied from 86.16 to 94.12% among lines and 73.81 to 92.91% among testers. Four parents showed significantly better mean performance for fertility percentage. Five parents expressed significant and positive GCA estimates. The attractive general combiners were Basmati 2000 among lines whereas DM-25 and Basmati-385

Table 2. Mean performance and general combining ability effects of parental rice genotypes.

| Parents | Number of tillers per plant | | Panicle length (cm) | | Number of grains per panicle | | Fertility percentage | | 1000-grain weight (g) | | Yield per plant (g) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | GCA | Mean | GCA | Mean | GCA | Mean | GCA | Mean | GCA | Mean | GCA |
| **Lines** | | | | | | | | | | | | |
| Basmati-370 | 11.77* | -0.57** | 30.17* | -1.24** | 173.50** | 4.81** | 88.91 | -3.76** | 19.55** | -0.07 | 20.03 | -4.65** |
| DM-2 | 11.20** | -1.22** | 30.65 | 0.48 | 146.10 | -19.19** | 93.20** | 0.11 | 19.78* | -0.75** | 19.22** | -4.65** |
| DM-107-4 | 12.27 | 0.78** | 29.48** | 1.45** | 114.03** | 13.78** | 86.85** | 0.95 | 18.73** | -0.72** | 19.90 | 1.58* |
| DM-16-5-1 | 13.27* | -1.47** | 32.62** | 0.30 | 181.60** | 11.58** | 92.27 | 2.16** | 19.05** | -1.27** | 20.90* | -2.36** |
| Kashmir Basmati | 11.63* | 1.40** | 30.35 | 1.39** | 144.70 | 7.55** | 89.75 | -0.61 | 20.15 | -0.03 | 20.87* | 2.85** |
| Basmati-Pak | 13.50** | 0.52** | 28.20** | -2.46** | 98.33** | -35.70** | 90.70 | -0.18 | 20.90** | 1.09** | 16.77** | 0.02 |
| Basmati 2000 | 11.50** | -1.54** | 35.35** | 0.20 | 165.50** | 30.18** | 94.12** | 2.68** | 21.51** | 0.95** | 22.48** | 4.89** |
| Super Basmati | 14.83** | 4.03** | 30.13* | -0.57* | 137.07** | -25.32** | 91.68 | 2.03** | 20.53* | 0.06 | 22.07** | 1.27* |
| Shaheen Basmati | 12.33 | -1.93** | 31.42 | 0.45 | 170.97** | 12.31** | 86.16** | -3.38** | 21.05** | 0.74** | 20.97* | 1.05 |
| G.M. | 12.48 | - | 30.93 | - | 147.98 | - | 90.40 | - | 20.14 | - | 20.36 | - |
| S.E. | 0.32 | - | 0.36 | - | 1.69 | - | 0.99 | - | 0.17 | - | 0.22 | - |
| C.D.(0.05) | 0.66 | - | 0.76 | - | 3.51 | - | 2.05 | - | 0.34 | - | 0.46 | - |
| C.D.(0.01) | 0.89 | - | 1.03 | - | 4.77 | - | 2.79 | - | 0.47 | - | 0.62 | - |
| S.E.(GCA for lines) | - | 0.17 | - | 0.24 | - | 0.97 | - | 0.66 | - | 0.11 | - | 0.62 |
| **Testers** | | | | | | | | | | | | |
| Basmati-385 | 15.80* | -0.58** | 33.95* | 2.66** | 198.67** | 37.67** | 88.06* | 4.15** | 19.26** | -1.37** | 29.38** | 4.67** |
| DM-25 | 14.07** | -1.38** | 30.67** | -0.90** | 173.90** | -3.23** | 92.91** | 2.53** | 18.91** | -1.04** | 21.80* | -2.57** |
| EL-30-2-1 | 15.97* | 1.96** | 34.87** | -1.76** | 101.07** | -34.44** | 73.81** | -6.68** | 30.97** | 2.41** | 17.33** | -2.10** |
| G.M. | 15.28 | - | 33.16 | - | 157.88 | - | 84.93 | - | 23.04 | - | 22.84 | - |
| S.E. | 0.16 | - | 0.27 | - | 0.77 | - | 0.71 | - | 0.10 | - | 0.37 | - |
| C.D.(0.05) | 0.44 | - | 0.74 | - | 2.14 | - | 1.96 | - | 0.27 | - | 1.02 | - |
| C.D.(0.01) | 0.73 | - | 1.22 | - | 3.55 | - | 3.25 | - | 0.44 | - | 1.69 | - |
| S.E.(GCA for testers) | - | 0.10 | - | 0.14 | - | 0.56 | - | 0.38 | - | 0.06 | - | 0.36 |

*, ** = Significant at 0.05 and 0.01 levels of probability, respectively, G.M. = Grand Mean; S.E. = Standard Error; C.D. = Critical Difference

among testers. Swamy *et al*., (2003) identified two good combiner lines for high fertility percentage in rice. Among lines, 1000-grain weight ranged from 18.73 to 21.51 g for lines and 18.91 to 30.97 g for testers. Five parents disclosed significantly high mean performance. Four parents revealed high GCA effects. Lines viz., Basmati 2000, Shaheen Basmati and Basmati-Pak and tester EL-30-2-1 were found potential general combiners for 1000-grain weight. Kumar *et al*., (2007) found number of parents having desirable GCA for 1000-grain weight. Yield being an ultimate product of all traits is very important. Mean yield varied from 16.77 to 22.48 g for lines and 17.33 to 29.38 g for testers. Six parents indicated significant and high yield performance. Five parents showed desirable GCA effects for this trait. However, Basmati-2000 followed by Super Basmati and Kashmir Basmati among females and Basmati-385 among males were found best general combiners for yield per plant. The results are in line with those of Petchiammal & Kumar (2007) who reported several good combiner rice lines on the basis of *per se* performance and GCA effects for yield per plant.

Desirable general combiners isolated in present studies for yield and its components are recommended to be used in multiple crossing programs to identify superior genotypes for development of high yielding cultivars. The GCA variance is primarily due to function of the additive genetic variance and represents a fixable portion of genetic variation. If epitasis is present, GCA also includes additive × additive type of non-allelic interaction (Singh & Narayanan, 2004). In perusal to Table 2, it was noted that high GCA effects were mostly dependant on the genetic make up of line or tester instead of its mean performance as reported earlier in tomato (Saleem *et al*., 2009a).

**Identification of hybrids based on mean performance, SCA effects and heterobeltiosis:** Marilia *et al*., (2001) stated that specific combining ability (SCA) effects of hybrids alone had limited value for parental choice in breeding programme, and must be used in combination with other parameters such as hybrid means and GCA of the respective parents. The hybrid combinations with high mean performance, desirable SCA estimates and involving at least one of the parents with high GCA would likely to enhance the concentration of favorable alleles (Kenga *et al*., 2004) and this is what a breeder desires to improve a trait. Similar views have been expressed by various researchers (Thirumeni *et al*., 2000; Manivannan & Ganesan, 2001; Gnanasekaran *et al*., 2006) in rice. The identification of good specific combiners (hybrids) has been adjudged on the basis of mean performance, SCA effects and heterosis estimates (Table 3) in present investigation.

Mean performance and heterobeltiosis for hybrids ranged from 13.47 to 23.30 and 10.13 to 45.93%, respectively for number of tillers per plant. Ten hybrids had significant high mean performance, 9 hybrids had high SCA effects and 19 hybrids had significant and positive heterobeltiosis. Five good specific combiners viz., Super Basmati × Basmati-385, Kashmir Basmati × EL-30-2-1, DM-2 × EL-30-2-1, DM-16-5-1 × EL-30-2-1 and Basmati-Pak × Basmati-385 were identified among all hybrids. Gnanasekaran *et al*., (2006) reported similar results for number of tillers per plant in rice. Panicle length ranged from 28.27 to 37.93 cm. High-parent heterosis was recorded from -16.87 to 11.73%. Nine hybrids possessed high panicle length, 9 hybrids had desirable SCA effects and 10 hybrids attained desirable significant heterobeltiosis. Four hybrids viz., DM-107-4 × Basmati-385, Basmati 2000 × Basmati-385, DM-16-5-1 × Basmati-385 and Super Basmati × Basmati-385 were found good specific combiners based on high mean performance, SCA effects and heterobeltiosis. Gnanasekaran *et al*., (2006) isolated best specific combiners in rice for

**Table 3. Mean performance, specific combining ability effects and heterobeltiosis of rice hybrids.**

| Hybrids | Number of tillers per plant | | | Panicle length (cm) | | | Number of grains per panicle | | |
|---|---|---|---|---|---|---|---|---|---|
| | Mean | SCA | Ht(bel) | Mean | SCA | Ht(bel) | Mean | SCA | Ht(bel) |
| Basmati-370 × Basmati-385 | 17.27 | 0.87** | 9.28** | 31.40** | -2.98** | -7.51** | 204.33** | -11.18** | 2.85* |
| Basmati-370 × DM-25 | 17.47 | 1.87** | 24.17** | 33.07 | 2.25** | 7.83** | 167.97** | -6.65** | -3.41* |
| Basmati-370 × EL-30-2-1 | 16.20** | -2.74** | 1.46 | 30.68** | 0.72 | -12.00** | 161.23** | 17.82** | -7.07** |
| DM-2 × Basmati-385 | 14.47** | -1.27** | -8.44** | 36.27** | 0.18 | 6.82** | 172.77 | -18.73** | -13.04** |
| DM-2 × DM-25 | 13.70** | -1.24** | -2.61 | 33.00 | 0.48 | 7.61** | 151.93** | 1.32 | -12.63** |
| DM-2 × EL-30-2-1 | 20.80** | 2.51** | 30.27** | 31.00** | -0.66 | -11.09** | 136.83** | 17.42** | -6.34** |
| DM-107-4 × Basmati-385 | 18.00 | 0.26 | 13.92** | 37.93** | 0.87* | 11.73** | 233.67** | 9.19** | 17.62** |
| DM-107-4 × DM-25 | 16.50** | -0.44 | 17.30** | 34.23** | 0.74 | 11.63** | 184.33** | 0.75 | 6.00** |
| DM-107-4 × EL-30-2-1 | 20.47** | 0.18 | 28.18** | 31.03** | -1.61** | -10.99** | 142.43** | -9.94** | 24.90** |
| DM-16-5-1 × Basmati-385 | 15.40** | -0.09 | -2.53 | 37.38** | 1.48** | 10.11** | 238.00** | 15.72** | 19.80** |
| DM-16-5-1 × DM-25 | 13.47** | -1.21** | -4.27 | 33.37 | 1.03* | 2.30 | 192.40** | 11.02** | 5.95** |
| DM-16-5-1 × EL-30-2-1 | 19.33** | 1.30** | 21.09** | 28.98** | -2.50** | -16.87** | 123.43** | -26.73** | -32.03** |
| Kashmir Basmati × Basmati-385 | 18.20* | -0.16 | 15.19** | 37.13** | 0.14 | 9.38** | 205.77** | -12.48** | 3.57** |
| Kashmir Basmati × DM-25 | 17.03 | -0.53 | 21.09** | 34.12** | 0.69 | 11.25** | 184.87** | 7.52** | 6.31** |
| Kashmir Basmati × EL-30-2-1 | 21.60** | 0.69* | 35.28** | 31.75** | -0.83 | -8.94** | 151.10** | 4.96** | 4.42** |
| Basmati-pak × Basmati-385 | 18.73** | 1.26** | 18.57** | 31.62** | -1.53** | -6.87** | 182.40** | 7.40** | -8.19** |
| Basmati-pak × DM-25 | 15.50** | -1.17** | 10.19** | 28.27** | -1.31** | -7.83** | 128.57** | -5.54** | -26.07** |
| Basmati-pak × EL-30-2-1 | 19.93** | -0.09 | 24.84** | 31.57** | 2.84** | -9.46** | 101.03** | -1.86 | -0.03 |
| Basmati-2000 × Basmati-385 | 14.20** | -1.22** | -10.13** | 37.50** | 1.69** | 6.08** | 233.80** | -7.08** | 17.68** |
| Basmati-2000 × DM-25 | 16.33** | 1.72** | 16.11** | 30.62** | -1.63** | -13.39** | 194.23** | -5.75** | 11.69** |
| Basmati-2000 × EL-30-2-1 | 17.47 | -0.50 | 9.39** | 31.33** | -0.06 | -11.36** | 181.60** | 12.82** | 9.73** |
| Super Basmati × Basmati-385 | 21.93** | 0.95** | 38.82** | 36.18** | 1.15** | 6.58** | 205.37** | 19.99** | 3.37** |
| Super Basmati × DM-25 | 19.47** | -0.72* | 31.24** | 29.27** | -2.20** | -4.57* | 126.07** | -18.41** | -27.51** |
| Super Basmati × EL-30-2-1 | 23.30** | -0.23 | 45.93** | 31.67** | 1.05* | -9.18** | 111.70** | -1.58 | -18.51** |
| Shaheen Basmati × Basmati-385 | 14.43** | -0.59* | -8.65** | 35.07** | -0.99* | 3.30 | 220.17** | -2.84 | 10.82** |
| Shaheen Basmati × DM-25 | 15.96** | 1.73** | 13.44** | 32.45 | -0.05 | 3.28 | 197.87** | 15.75** | 13.78** |
| Shaheen Basmati × EL-30-2-1 | 16.43** | -1.14** | 2.92 | 32.68 | 1.04* | -6.26** | 138.00** | -12.91** | -19.28** |
| G.M ± S.E. | 17.54 ± 0.26 | - | - | 32.95±0.41 | - | - | 173.03± 1.53 | - | - |
| C.D.(0.05) | 0.52 | - | - | 0.83 | - | - | 3.07 | - | - |
| C.D.(0.01) | 0.68 | - | - | 1.09 | - | - | 4.03 | - | - |
| S.E.(SCA for hybrids) | - | 0.29 | - | - | 0.42 | - | - | 1.69 | - |
| S.E.(heterobeltiosis) | - | - | 0.42 | - | - | 0.59 | - | - | 2.39 |

*, **Significant at 0.05 and 0.01 levels of probability, respectively, G.M. = Grand Mean, C.D. = Critical Difference, S.E. = Standard Error

**Table 3. (Cont'd.).**

| Hybrids | Fertility percentage | | | 1000-grain weight (g) | | | Yield per plant (g) | | |
|---|---|---|---|---|---|---|---|---|---|
| | Mean | SCA | Ht(bel) | Mean | SCA | Ht(bel) | Mean | SCA | Ht(bel) |
| Basmati-370 × Basmati-385 | 85.78* | -2.57* | -3.52 | 19.39** | -0.33 | -0.80 | 33.59 | 1.04 | 14.32** |
| Basmati-370 × DM-25 | 86.96 | 0.24 | -6.40** | 20.85 | 0.80** | 6.67** | 27.02** | 1.71 | 23.93** |
| Basmati-370 × EL-30-2-1 | 79.84** | 2.33* | -10.20** | 23.04** | -0.47* | -25.61** | 23.03** | -2.75* | 14.98 |
| DM-2 × Basmati-385 | 92.79** | 0.58 | -0.44 | 18.16** | -0.87** | -8.17** | 27.34** | -5.22** | -6.97 |
| DM-2 × DM-25 | 89.22 | -1.37 | -4.27* | 19.27** | -0.10 | -2.60 | 25.10** | -0.20 | 15.14* |
| DM-2 × EL-30-2-1 | 82.17** | 0.79 | -11.83** | 23.80** | 0.98** | -23.13** | 31.19 | 5.41** | 62.29** |
| DM-107-4 × Basmati-385 | 95.87** | 2.82* | 8.86** | 19.55** | 0.47* | 1.51 | 41.27** | 2.49* | 40.44** |
| DM-107-4 × DM-25 | 89.55 | -1.88 | -3.62* | 20.10** | 0.69** | 6.28** | 32.25 | 0.71 | 47.94** |
| DM-107-4 × EL-30-2-1 | 81.28** | -0.94 | -6.41** | 21.70** | -1.17** | -29.94** | 28.81** | -3.20** | 44.76** |
| DM-16-5-1 × Basmati-385 | 95.43** | 1.17 | 3.42 | 18.65** | 0.12 | -3.13* | 37.20** | 2.37* | 26.61** |
| DM-16-5-1 × DM-25 | 92.30** | -0.33 | -0.65 | 18.45** | -0.41* | -3.17* | 27.53** | -0.07 | 26.27** |
| DM-16-5-1 × EL-30-2-1 | 82.58** | -0.84 | -10.50** | 22.62** | 0.29 | -26.96** | 25.77** | -2.29* | 23.32** |
| Kashmir Basmati × Basmati-385 | 90.76** | -0.73 | 1.13 | 19.95** | 0.19 | -0.99 | 39.74** | -0.31 | 35.24** |
| Kashmir Basmati × DM-25 | 94.07** | 4.20** | 1.25 | 20.50** | 0.40* | 1.74 | 35.32* | 2.52* | 62.03** |
| Kashmir Basmati × EL-30-2-1 | 77.19** | -3.48** | -14.00** | 22.96** | -0.59** | -25.84** | 31.07 | -2.21* | 48.88** |
| Basmati-pak × Basmati-385 | 94.29** | 2.37* | 3.96* | 21.31 | 0.43* | 1.95 | 44.21** | 7.00** | 50.46** |
| Basmati-pak × DM-25 | 91.08** | 0.78 | -1.97 | 21.02 | -0.19 | 0.57 | 25.69** | -4.28** | 17.84* |
| Basmati-pak × EL-30-2-1 | 77.94** | -3.15** | -14.08** | 24.44** | -0.24 | -21.09** | 27.73** | -2.71* | 59.98** |
| Basmati-2000 × Basmati-385 | 94.43** | -0.34 | 0.33 | 19.81** | -0.93** | -7.92** | 35.96** | -6.14** | 22.38** |
| Basmati-2000 × DM-25 | 94.13** | 0.98 | 0.01 | 20.84 | -0.23 | -3.10* | 37.41** | 2.56* | 66.38** |
| Basmati-2000 × EL-30-2-1 | 83.30** | -0.64 | -11.50** | 25.68** | 1.16** | -17.06** | 38.89** | 3.57** | 72.96** |
| Super Basmati × Basmati-385 | 96.61** | 2.49* | 5.38** | 20.27** | 0.41* | -1.27 | 41.80** | 3.33** | 42.26** |
| Super Basmati × DM-25 | 91.39** | -1.11 | -1.64 | 19.70** | -0.49* | -4.03** | 25.80** | -5.44** | 16.92* |
| Super Basmati × EL-30-2-1 | 81.92** | -1.37 | -10.64** | 23.72** | 0.08 | -23.39** | 33.80 | 2.10 | 53.17** |
| Shaheen Basmati × Basmati-385 | 82.93** | -5.79** | -5.83** | 21.04 | 0.51** | -0.05 | 33.67 | -4.58** | 14.58** |
| Shaheen Basmati × DM-25 | 85.57* | -1.52 | -7.90** | 20.39** | -0.47* | -3.12* | 33.51 | 2.50* | 53.70** |
| Shaheen Basmati × EL-30-2-1 | 85.20** | 7.31** | -1.11 | 24.28** | -0.04 | -21.59** | 33.57 | 2.09 | 60.10** |
| G.M ± S.E. | 87.95±1.02 | - | - | 21.17±0.19 | - | - | 32.5 3±1.24 | - | - |
| C.D.(0.05) | 2.05 | - | - | 0.38 | - | - | 2.50 | - | - |
| C.D.(0.01) | 2.70 | - | - | 0.49 | - | - | 3.28 | - | - |
| S.E.(GCA for hybrids) | - | 1.14 | - | - | 0.19 | - | - | 1.07 | |
| S.E.(heterobeltiosis) | - | - | 1.61 | - | - | 0.27 | - | - | 1.51 |

*, **Significant at 0.05 and 0.01 levels of probability, G.M. = Grand Mean, C.D. = Critical Difference, S.E. = Standard Error

increased panicle length. Number of grains per panicle and their extent of high-parent heterosis were variable from 101.03 to 238 and -32.03 to 24.90%, respectively. Eleven hybrids showed favourable SCA effects however, 15 hybrids showed desirable heterobeltiosis. Seven desirable specific combiners viz., DM-16-5-1 × Basmati-385, DM-107-4-1 × Basmati-385, Super Basmati × Basmati-385, Shaheen Basmati × DM-25, DM-16-5-1 × DM-25, Kashmir Basmati × DM-25 and Basmati 2000 × EL-30-2-1 were identified for the improvement of number of grains per panicle. Vanaja & Babu, (2004); Gnanasekaran *et al*., (2006) reported several promising hybrids showing high per se performance, SCA effects and heterosis for number of grains per panicle in rice.

Considerable variations were observed in fertility among hybrids. It varied from 77.19 to 96.61%. Heterobeltiosis ranged from -11.50 to 8.86%. Twelve hybrids showed significant high mean performance, 6 hybrids showed high SCA effects and 3 hybrids indicated heterobeltiosis in desirable direction. Hybrids viz. Super Basmati × Basmati-385, DM-107-4 × Basmati-385 and Basmati-Pak × Basmati-385 were scored as promising specific combiners. These results are in line with Panwar (2005) who adjudged some best hybrids based on high SCA effects and mean performance for spikelet fertility from line × tester experiment in rice. Thousand grain weight was variable ranging from 18.16 to 25.68 for line × tester crosses. Heterobeltiosis varied from -29.94 to 6.67%. Nine hybrids indicated significant high mean performance, 9 hybrids showed desirable SCA effects whereas 2 hybrids had desirable heterobeltiosis. Hybrids viz. Basmati 2000 × EL-30-2-1 and DM-2 × EL-30-2-1 attained better mean performance and SCA effects but they had highly significant negative heterobeltiosis. The current result contradicted to that of Agrawal (2003) for 1000-grain weight wherein he reported significant positive heterobeltiosis for 1000-grain weight in rice. Among hybrids, grain yield ranged from 23.03 to 44.21 g and heterobeltiosis varied from -6.97 to 72.96%. Nine hybrids were significantly high yielder, 9 hybrids expressed high SCA effects while 25 hybrids showed significant and positive heterobeltiosis. Seven hybrids viz. Basmati-Pak × Basmati-385, Super Basmati × Basmati-385, DM-107-4 × Basmati-385, Basmati 2000 × EL-30-2-1, Basmati 2000 × DM-25, DM-16-5-1 × Basmati-385 and Kashmir Basmati × DM-25 were found best specific combiners. Several hybrids having high SCA effects for grain yield per plant in rice were reported by Petchiammal & Kumar (2007).

Specific combining ability refers chiefly to dominance variance and epistatic interaction (dominance × dominance, additive × dominance or additive × additive). It has relationship with heterosis therefore good specific combiners identified in present study for yield and its components are proposed for heterosis breeding.

Hybrids which had significant and positive SCA effects (presence of non-additive gene effects) and emerged from parents having significant and positive GCA effects can also be used for cultivar or valuable germplasm development provided that the selection of better genotypes should be postponed to later generations $F_6$ or $F_8$ to allow fixation of homozygosity for majority of the loci (Singh & Narayanan, 2004; Subbaraman & Rangaswamy, 1989; Saleem *et al*., 2009b). In this regard the potential hybrids are Kashmir Basmati × EL-30-2-1 for number of tillers per plant; DM-107-4 × Basmati-385 for panicle length; DM-16-5-1 × Basmati-385 and DM-107-4 × Basmati-385 for number of grains per panicle; Super Basmati × Basmati-385 for fertility and Super Basmati × Basmati-385 and DM-107-4 × Basmati-385 for grain yield. Hybrids which showed average SCA effects and emerged from parents having significant and positive GCA effects (presence of additive gene effects) can also be used for germplasm or cultivar development following pedigree method with early selection of better genotypes (Singh & Narayanan, 2004). In this regard the potential hybrids are DM-107-4 × EL-30-2-1, Basmati-Pak × EL-30-2-1 and Super Basmati × EL-30-2-1 for number of tillers per plant; Kashmir Basmati × Basmati-385 for panicle length, Shaheen Basmati × Basmati-385 for higher number of grains; DM-16-5-1 × Basmati-385, DM-16-5-1 × DM-25, Basmati 2000 × Basmati-385, Super Basmati × DM-25 and Basmati-2000 × DM-25 for higher fertility and Kashmir Basmati × Basmati-385 for high grain yield.

Analysis of SCA effects of hybrids in relation to GCA effects of their parents revealed that expression of SCA effects was independent of the GCA combinations (*h* × *h*, *h* × *l*, *h* × *a*, *l* × *h*, *l* × *l*, *l* × *a*, *a* × *h*, *a* × *l* and *a* × *a*) of the parents for the traits studied. All types of SCA effects (high, low or average) were observed from any kind of GCA combination of parents for various traits studied. Hybrids with high mean performance were not essentially those originating from parents possessing high mean performance. Similarly high heterotic hybrids were not necessarily those showing high mean performance.

The present study has identified four good general combiners ( Basmati 2000, Super Basmati, Kashmir Basmati and Basmati-385) and seven good specific combiners (Basmati Pak × Basmati -385, Super Basmati × Basmati -385, DM-107-4 × Basmati -385, Basmati-2000 × EL-30-2-1, Basmati-2000 × DM-25, DM-16-5-1 × Basmati-385 and Kashmir Basmati × DM-25) for the improvement of grain yield in rice. Further more, sets of different parents and hybrids have also been identified which can be used in hybridization programme to improve certain yield components with appropriate breeding methods. The role of non-additive gene effect has been prominent in controlling the inheritance of all traits studied.

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