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Combining ability analysis for grain yield and quality characters in rice (*Oryza sativa*)

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ABSTRACT

Genetic variances were estimated for grain yield and quality characters in rice (*Oryza sativa* L.) by full-sib and half-sib analysis in 20 F_1 hybrids produced from crosses between five high yielding genotypes namely IR 50, IR 62, IET 5656, IET 8002 and IET 6441 as lines and four quality rice genotypes namely Basmati 385, Dudheswar, Kalonunia and Sambamahsuri as testers. The lines were significantly varying for the characters, whereas variances due to testers were significant for all the characters except panicle weight. Line × tester interaction was highly significant for all the characters. Combining ability analysis revealed predominance of non-additive gene action for days to flowering, total tillers/plant, productive tillers/plant, 1000 grain weight, grain yield/plant and kernel elongation ratio; additive gene action for plant height, panicle length, panicle weight, spikelet/panicle, filled grains/panicle, spikelet fertility, grain length, grain breadth, grain length/breadth ratio, grain weight/panicle, kernel length, kernel breadth and kernel length/breadth ratio and both additive and non-additive gene actions for cooked kernel breadth. Among the lines IET 5656 was found to be the best general combiner for grain yield as well as its components and quality characters, while IET 8002 and IET 6441 were superior general combiners for quality characters only. Among the testers Kalonunia was the best general combiner for yield and its components followed by Basmati 385, whereas, for the quality characters Dudheswar was the best general combiner, followed by Basmati 385. The three crosses namely IET 5656 × Kalonunia, IR 50 × Basmati 385 and IR 62 × Sambamahsuri were superior over their superior grain quality parents like Kalonunia, Dudheswar and Sambamahsuri for most of the yield and quality characters. When all the 23 yield and quality characters were considered together in an overall ranking on the basis of specific combining ability for grain yield per plant and kernel elongation ratio as the base characters and the actual field performance of their attributing characters, the cross IET 8002 × Dudheswar was the best performer, closely followed by IR 50 × Basmati 385 and IET 6441 × Dudheswar in this regard.

Key words: General and specific combining ability, Grain yield and quality, Line × tester analysis, *Oryza sativa*, Predictability ratio

Rice is the staple food of more than half of the world's population as it provides about two-third of the calorie intake for more than two billion people in Asia and one-third of the calorie intake of nearly one billion people in Africa and Latin America (Shastry *et al.* 2000). India now occupies second position in rice export, next only to Thailand, among the rice trading countries of the world (Mishra 2004). There has been no increase in the area planted with rice since 1980 and increasing urbanization and industrialization can be expected to reduce this area (FAO 1988). It follows that increase in production has to necessarily come from increased productivity under depleting and diminishing resources and has to meet the demands of sustainability and preservation of environmental quality. Rice production in world has trebled since the turn of the 21st century, which has enabled a stable decline in the world rice price (Mitchell 1987). In rice research, grain quality was initially overshadowed by the need for higher yield. Improvement in rice grain quality has become an important breeding objective as many countries have achieved rice self-sufficiency (Juliano and Duff 1991). Moreover, improvement in grain quality that do not lower yields will generally benefit all rice consumers by lowering the cost of better quality rice (Unnevehr *et al*. 1985). The rice grain quality preferences vary across countries and regions (IRRI and IDRC 1992). Although the preferences for rice grain characteristics vary with different consumer groups, long and slender rice is generally preferred by many

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consumers in China, USA and most of the Asian countries (Unnevehr *et al*. 1992, Juliano and Villareal 1993). Some varieties expand more in size than others upon cooking. Length-wise expansion without increase in girth is considered a highly desirable character in some quality rices (Khush *et al.* 1979). Thus grain size and shape are the principal criteria of rice quality that breeders consider in developing new varieties to be released for commercial production (Adair *et al.* 1966). Thus to formulate a sound breeding programme the present study on genetic analysis of rice grain yield and quality through line × tester analysis assumes significance.

MATERIALS AND METHODS

Five high-yielding rice genotypes namely IR 50, IR 62, IET 5656, IET 8002 and IET 6441 were crossed with four quality rice genotypes namely Basmati 385, Dudheswar, Kalonunia and Sambamahsuri in a line × tester design (Kempthorne 1957) during the *kharif* season 2004 at Regional Research Station, New Alluvial Zone, Bidhan Chandra Krishi Viswavidyalaya, Sub-Centre: Chakdah, Nadia, West Bengal. The 20 F_1 hybrids along with their nine parents (five lines and four testers) were planted in a randomized block design with three replications during the *aman* season of 2005. Twenty-eight days age old seedlings were transplanted at 1 seedling/hill at a spacing of 20 cm in either direction in five rows of 1.8 m length. During the course of investigation recommended agronomic practices were followed to obtain a good harvest. Observations were recorded on 16 yield related characters and seven grain quality characters. The yield related characters were days to flowering, plant height (cm), tiller number/plant, panicles/plant, panicle length (cm), panicle weight (g), spikelet/panicle, filled grains/panicle, spikelet fertility (%), grain length (mm), grain breadth (mm), grain length/breadth ratio, grain weight/panicle, 1 000 grain weight, grain yield/plant (g) and harvest index (%). The quality related characters were kernel length (mm), kernel breadth (mm), kernel length/breadth ratio, cooked kernel length (mm), cooked kernel breadth (mm), cooked kernel length/breadth ratio and kernel elongation ratio (KER). The days to flowering was recorded as days to 50% flowering against each entry separately. Observations for rest of the characters were recorded on five plants selected randomly from the middle of each row in each replication. The panicle characters were recorded from 10 randomly selected panicles and the grain and kernel characters were recorded from 10 randomly selected grains and kernels, respectively. Analysis of variance, general and specific combining ability (GCA and SCA) effects were estimated according to Kempthorne (1957).

RESULTS AND DISCUSSION

Combining ability analysis in self-pollinated crops is generally conducted to find out suitable parents and more appropriately a cross with greater potential to produce desirable recombinant lines. The combining ability analysis revealed that the mean squares among parents were highly significant for all the twenty-three yield and quality characters indicating presence of genetic variability among the parents (Table 1). The hybrids differed significantly for all the characters indicating genetic variability among the hybrids. The variance due to parent versus hybrids was significant for all the characters except cooked kernel length and breadth indicating the presence of substantial differences between the crosses (Singh *et al.* 2005). The lines showed significant differences for all the characters studied, whereas the testers were significant for all the characters except panicle weight. This indicated prevalence of additive variance for all the characters except panicle weight. The mean squares due to line × tester interaction component also emerged significant for all the characters indicating that combining ability contributed remarkably in the expression of these characters and it also provided a direct test indicating that dominance or non additive variance was important for the characters under study.

The magnitude of variances due to line × testers was higher than the magnitude of variances due to both lines and testers for grain yield/plant and cooked kernel length indicating the preponderance of non-additive variance controlling these characters. The significance of GCA variance (σ^2_{GCA}) and SCA variance (σ^2_{SCA}) obtained from line × tester design could not be tested, hence these statistics appeared to be of exploratory nature only. However, such estimates were used to determine the additive (σ^2_A) and non additive (σ^2_D) components of population variance and predictability ratio $\sigma^2_A/(\sigma^2_{A} + \sigma^2_D)$. The variance due to SCA was higher than GCA as indicated by the $\sigma^2_{GCA}/\sigma^2_{SCA}$ ratio being less than one for most of the characters, viz days to flowering, total tillers/plant, productive tillers/plant, spikelet fertility, grain breadth, grain weight per panicle, 1000-grain weight, grain yield/plant, harvest index, cooked kernel length, cooked kernel breadth, cooked kernel length/breadth ratio and kernel elongation ratio suggesting significant role of non additive gene actions like dominance, epistasis and other interaction effects in the expression of these characters. The variance due to GCA was higher than SCA as evidenced by the $\sigma^2_{GCA}/\sigma^2_{SCA}$ ratio being greater than one, for plant height, panicle length, panicle weight, spikelet/ panicle, filled grains/ panicle, grain length, grain length/breadth ratio and kernel length/ breadth ratio suggesting major role of additive gene action in the expression of these characters. This was in agreement with the findings of Mannuel and Palamisamy (1989) and Bobby and Nadarajan (1994). The characters kernel length and kernel breadth were equally controlled by additive and non additive genes as evidenced by $\sigma^2_{GCA}/\sigma^2_{SCA}$ ratio being equal to one.

Negative variance, though rare, was revealed for (σ^2_A) for grain yield/plant, cooked kernel length and cooked kernel length/breadth ratio as evidenced by the negative predictability

Table 1 Combining ability analysis and estimates of genetic variances for line × tester analysis for various yield and quality characters in rice

Parents	df	Plant height (cm)	Days to 50% flowering	Total tillers plant^{-1}	Productive tillers plant^{-1}	Panicle length (cm)	Panicle weight (g)	Spikelet/ panicle	Filled grains/ panicle	Spikelet fertility (%)	Grain length (mm)	Grain breadth (mm)	Grain length/ breadth ratio
Replications	2	7.28	0.62	6.99	22.11	0.47	0.23	199.78	91.32	5.50	0.01	0.00	0.00
Parents (P)	8	1363.97**	85.92**	20.56*	39.99**	11.09**	0.94**	2432**	1478**	188.08**	1.41**	0.16**	0.76**
Hybrids (H)	19	1417.60**	309.28**	301.91**	230.27**	27.70**	2.19**	3896**	5077**	648.53**	0.51**	0.08**	0.32**
P VS H	1	9504.80**	586.28**	2021.72**	1855.54**	213.63**	18.15**	24161**	24037**	517.38**	0.90**	0.40**	0.36**
Lines (L)	4	892.03**	534.04**	427.87**	268.95**	38.21**	8.12**	11951**	15452**	1135.09**	0.54**	0.22**	0.88**
Testers (T)	3	5945.70**	374.68**	475.85**	407.05**	97.64**	0.11	3583**	4947**	1355.57**	1.89**	0.06**	0.45**
L × T	12	460.76**	218.01**	216.45**	173.18**	6.71**	0.74**	1290*	1651**	309.58**	0.15**	0.03**	0.10**
Error	38	9.03	1.23	10.13	8.79	1.01	0.22	580.84	387.73	12.52	0.01	0.00	0.01
$\sigma^2_{GCA}/\sigma^2_{SCA}$		1.46	0.24	0.25	0.22	2.37	1.47	2.03	1.50	0.70	1.72	0.88	1.45
$\sigma^2_A/(\sigma^2_A+\sigma^2_D)$		0.74	0.33	0.34	0.31	0.83	0.75	0.80	0.75	0.58	0.76	0.67	0.73

*, ** Significant at 5% and 1% levels of probability, respectively

Table 1 *Continued*

Parents	df	Grain weight/ panicle (g)	1000 grain weight (g)	Grain yield/ plant (g)	Harvest index (%)	Kernel length (mm)	Kernel breadth (mm)	Kernel length/ breadth ratio	Cooked length kernel (mm)	Cooked kernel breadth (mm)	Cooked kernel length/ breadth ratio	Kernel elongation ratio (KER)
Replications	2	0.20	1.18	31.96	4.28	0.04	0.00	0.02	0.01	0.00	0.00	0.00
Parents (P)	8	0.71**	32.16**	104.41**	104.43**	0.79**	0.22**	0.44**	4.54**	0.17**	1.37**	0.04**
Hybrids (H)	19	3.79**	17.90**	1405.41**	209.25**	0.40**	0.06**	0.22**	16.11**	0.15**	1.64**	0.52**
P VS H	1	23.51**	260.45**	20551**	2007.72**	0.25**	0.10**	0.06**	0.48	0.00	0.26*	0.06**
Lines (L)	4	11.80**	27.87**	649.40**	177.64**	0.63**	0.15**	0.65**	10.47**	0.37**	0.22**	0.52**
Testers (T)	3	1.51**	18.83**	1431.15**	549.30**	0.99**	0.09**	0.26**	17.46**	0.10**	2.19**	0.71**
L × T	12	1.68**	14.34**	1650.97**	134.77**	0.17**	0.02**	0.06**	17.65**	0.09**	1.97**	0.47**
Error	38	0.18	1.76	21.08	3.06	0.03	0.00	0.01	0.17	0.02	0.04	0.01
$\sigma^2_{GCA}/\sigma^2_{SCA}$		0.73	0.16	-0.08	0.39	1.00	1.00	1.50	-0.05	0.50	-0.09	0.07
$\sigma^2_A/(\sigma^2_A+\sigma^2_D)$		0.60	0.24	-0.20	0.44	0.67	0.67	0.75	-0.10	0.50	-0.21	0.11

*, ** Significant at 5% and 1% levels of probability, respectively

ratio for the aforesaid characters. Variance by nature must not be negative as they are squared quantities. But they do occur some time, particularly when estimates of genetic variance are calculated from expectation of ANOVA as done for determination of σ^2_{GCA} from ANOVA for combining ability in the present analysis. The possible reasons that could be assigned for occurrence of negative estimates of variances are: (a) small sample size and presence of aberrant values, (b) presence of genotype × environment (G × E) interaction which might have inflated the error variance, and (c) lack of random mating while developing half sibs. However, occurrence of negative estimates should not be considered as invalid results and as such, they should be promptly reported. A repeated experimentation and then averaging will give the correct picture.

A predictability ratio greater than 0.5 indicates additive gene action, less than 0.5 indicates non-additive gene action and equal to 0.5 indicates predominance of both additive and non-additive gene action for a character. In the present study the predictability ratios were high and exceeded the value of 0.50 for plant height, panicle length, panicle weight, spikelet/panicle, filled grains/panicle, spikelet fertility, grain length, grain breadth, grain length/breadth ratio, grain weight/panicle, kernel length, kernel breadth and kernel length/breadth ratio indicating the predominance of additive gene action for these characters. Harvest index recorded moderate predictability ratio, whereas cooked kernel breadth recorded a predictability ratio of 0.50 indicating the importance of additive and non-additive gene action for this character. Days to flowering, total tillers/plant, productive tillers/plant, 1000-grain weight, grain yield/plant and KER recorded low predictability ratios indicating the predominance of non-additive gene action for these characters.

The GCA values revealed that among the five lines IET 5656 was the best combiner for grain yield/plant and the only one to exhibit significantly positive GCA value for grain yield/plant, while IR 62 exhibited significantly negative GCA value and IR 50, IET 8002 and IET 6441 showed non significant GCA values for the same (Table 2). This implied that favourable genes for grain yield/plant were present in IET 5656 and using this line as a parent may increase the grain yield/plant. On the other hand using IR 62 as a parent might reduce the grain yield/plant, harvest index and KER.

IR 50 showed significantly positive GCA values for other yield and quality characters like total tillers/plant, grain length, grain length/breadth ratio, kernel length and kernel length/breadth ratio. IET 5656 and IET 8002 showed significantly positive GCA values for panicle weight, filled grains/panicle, spikelet fertility, grain breadth, grain weight/panicle, harvest index, cooked kernel length and KER. IET 6441 exhibited significantly positive GCA values for panicle length, panicle weight, spikelet/panicle, filled grains/ panicle, spikelet fertility, grain breadth, grain weight/panicle, 1000-grain weight and KER. Negative GCA value is desirable in plant height, days to flowering, kernel breadth and cooked kernel breadth for bringing about dwarfness, earliness and grain fineness, respectively. Among the lines only IR 62 exhibited the desired significantly negative GCA values for plant height, days to flowering, kernel breadth and cooked kernel breadth. This indicated that favourable genes for dwarfness, earliness and grain quality characters were present in IR 62 but using it to improve the characters should be done with caution as using this line may ultimately reduce the yield drastically.

Among the testers Basmati 385 and Kalonunia exhibited significantly positive GCA values and Dudheswar and Sambamahsuri showed significantly negative GCA values for grain yield/plant. This implied that favourable genes for yield improvement were present in Basmati 385 and Kalonunia and they may be used as parents to improve the character, whereas using Dudheswar and Sambamahsuri might reduce the grain yield/plant. Basmati 385 showed significantly positive GCA values for other yield and quality characters like spikelet fertility, grain length, grain breadth, grain length/breadth ratio, 1000-grain weight, harvest index, kernel length, kernel breadth and kernel length/breadth ratio. Dudheswar on the other hand showed significantly positive GCA values for plant height, days to flowering, grain length, grain length/breadth ratio, harvest index, kernel length/breadth ratio, cooked kernel length, cooked kernel length/breadth ratio and KER. Kalonunia showed significantly positive GCA values for total tillers/plant, productive tillers/plant, panicle length and grain breadth. Sambamahsuri exhibited significantly positive GCA values for filled grains per panicle, spikelet fertility, grain weight/panicle and harvest index. This implied that among the testers, favourable genes for grain yield and linear elongation ratio were present in Basmati 385 and Kalonunia and they may be used as parents to improve yield and quality characters. The favourable genes for dwarfness were present in Basmati 385 and Sambamahsuri, whereas those for earliness were present in Basmati 385 and Kalonunia. The favourable genes for lower kernel breadth were present in Dudheswar and Sambamahsuri, whereas those for lower cooked kernel breadth were present in Basmati 385 only. This indicated that plant height might be reduced by using Basmati 385 and Sambamahsuri and earliness may be obtained by using Basmati 385 and Kalonunia as parents. Among the quality characters kernel breadth may be reduced by using Dudheswar and Sambamahsuri as parents, whereas cooked kernel breadth may be reduced by using Basmati 385 as a parent. However, caution should be taken while selecting Dudheswar and Sambamahsuri as the parents because they might cause reduction in ultimate grain yield/plant.

None of the lines or testers appeared to be good general combiners for most of the important yield and quality attributes however, IET 5656 among the lines can be selected as prospective parent for improving grain yield/plant, and

Table 2 Combining ability effects of parents (GCA) and crosses (SCA) for grain yield and quality characters in rice

Parents	Plant height (cm)	Days to 50% flowering	Total tillers/ plant	Productive tillers/ plant	Panicle length (cm)	Panicle weight (g)	Spikelets/ panicle	Filled grains/ panicle	Spikelet fertility (%)	Grain length (mm)	Grain breadth (mm)	Grain length/ breadth ratio
Lines (g_i)												
IR 50	4.71**	2.67**	7.86**	4.82**	0.53	–0.63**	–23.26**	–22.58**	–1.74	0.28**	–0.16**	0.35**
IR 62	–12.73**	–11.00**	3.40**	4.24**	–2.88**	–1.12**	–40.89**	–50.84**	–16.17**	0.11**	–0.13**	0.22**
IET 5656	–1.25	0.75	0.36	0.72	0.35	0.63**	31.33**	27.64**	4.09*	–0.29**	0.08**	–0.23**
IET 8002	–1.22	0.58	–6.71**	–5.13**	–0.02	0.41**	5.21	11.84*	6.02**	–0.06	0.08**	–0.14**
IET 6441	10.50**	7.00**	–4.91**	–4.65**	2.01**	0.70**	27.61**	33.94**	7.8**	–0.04	0.13**	–0.20**
SE (g_i)	0.76	0.40	0.79	0.77	0.29	0.12	6.29	5.00	1.54	0.03	0.02	0.03
Testers (g_j)												
Basmati 385	–13.12**	–3.77**	0.07	–0.32	–0.03	–0.06	–22.82**	–12.36**	4.43**	0.36**	0.04*	0.10**
Dudheswar	16.68**	2.17**	–3.80**	–2.14**	–0.72**	0.12	7.13	2.42	–3.84**	0.23**	–0.08**	0.19**
Kalonunia	17.36**	–4.43**	7.94**	7.30**	3.44**	–0.06	4.54	–14.80**	–11.17**	–0.19**	0.07**	–0.17**
Sambamahsuri	–20.92**	6.03**	–4.20**	–4.84**	–2.68**	0.00	11.15	24.74**	10.58**	–0.40**	–0.03	–0.12**
SE (g_j)	0.68	0.36	0.71	0.69	0.26	0.11	5.63	4.48	1.37	0.03	0.02	0.03
Crosses												
IR 50 × Basmati 385	–26.29**	–7.07**	15.23**	12.80**	–2.08**	–0.50*	–23.93	–22.74*	–5.65	0.38**	–0.05	0.26**
IR 50 × Dudheswar	12.21**	14.67**	–10.07**	–6.52**	2.07**	0.10	16.32	0.02	–5.47	–0.12	0.21**	–0.36**
IR 50 × Kalonunia	0.27	–12.73**	0.69	–3.29*	0.35	0.17	8.58	14.23	4.36	0.08	–0.03	0.06
IR 50 × Sambamahsuri	13.81**	5.13**	–5.84**	–2.99	–0.35	0.23	–0.97	8.50	6.76*	–0.34**	–0.13**	0.05
IR 62 × Basmati 385	18.34**	4.27**	–4.25**	–2.28	2.13**	0.81**	37.84**	35.06**	7.08*	0.04	0.02	–0.02
IR 62 × Dudheswar	–1.29	–1.33	5.75**	4.67**	–1.34*	–0.73**	–13.71	–32.52**	–19.37**	–0.14*	0.04	–0.08
IR 62 × Kalonunia	–5.77**	2.27**	–7.89**	–6.64**	–0.98	–0.29	–12.66	–1.84	0.81	0.16*	–0.04	0.11
IR 62 × Sambamahsuri	–11.29**	–5.20**	6.38**	4.26**	0.19	0.21	–11.47	–0.70	11.49**	–0.06	–0.02	–0.01
IET 5656 × Basmati 385	–1.39	4.85**	–6.23**	–7.90**	–1.87**	–0.11	–4.85	4.71	3.88	–0.30**	0.09*	–0.24**
IET 5656 × Dudheswar	–3.99*	–2.08*	1.59	–1.14	0.08	–0.40	–15.53	–15.13	–0.15	0.25**	–0.11**	0.27**
IET 5656 × Kalonunia	9.33**	3.52**	9.68**	12.94**	1.49*	0.34	21.19	9.41	–1.56	0.00	0.06	–0.06
IET 5656 × Sambamahsuri	–3.95*	–6.28**	–5.04**	–3.89*	0.31	0.17	–0.82	1.01	–2.18	0.05	–0.03	0.04
IET 8002 × Basmati 385	2.44	0.02	3.63*	2.89	0.71	0.15	6.54	8.57	2.33	–0.13	–0.01	–0.05
IET 8002 × Dudheswar	0.98	–1.92*	3.50*	3.82*	0.15	0.58*	19.32	33.20**	11.80**	0.04	–0.06	0.10
IET 8002 × Kalonunia	0.92	6.68**	–6.70**	–7.34**	0.04	–0.32	–15.22	–17.72	–4.28	–0.09	0.03	–0.07
IET 8002 × Sambamahsuri	–4.34**	–4.78**	–0.44	0.63	–0.90	–0.41	–10.64	–24.05*	–9.86**	0.19**	0.04	0.02
IET 6441 × Basmati 385	6.89**	–2.07*	–8.37**	–5.50**	1.11	–0.34	–15.60	–25.59*	–7.64*	0.01	–0.04	0.05
IET 6441 × Dudheswar	–7.91**	–9.33**	–0.78	–0.82	–0.96	0.45	–6.41	14.43	13.18**	–0.02	–0.07	0.08
IET 6441 × Kalonunia	–4.75**	0.27	4.22*	4.34**	–0.89	0.09	–1.89	–4.09	0.67	–0.16*	–0.02	–0.04
IET 6441 × Sambamahsuri	5.77**	11.13**	4.93**	1.98	0.75	–0.20	23.90	15.25	–6.21	0.17*	0.13**	–0.10
SE (±)	1.52	0.80	1.59	1.53	0.58	0.24	12.59	10.01	3.07	0.07	0.04	0.06

*, ** Significant at 5% and 1% levels of probability respectively

Table 2 Continued

Table 2 *Concluded*

Parent	Grain weight/ panicle (g)	1 000-grain/ weight (g)	Grain yield/ plant (g)	Harvest index (%)	Kernel length (mm)	Kernel breadth (mm)	Kernel length/ breadth ratio	Cooked kernel length (mm)	Cooked kernel breadth (mm)	Cooked kernel length/ breadth ratio	Kernel elongation ratio
Lines (g_i)											
IR 50	–0.77**	–0.68	–0.69	–3.30**	0.11*	–0.16**	0.25**	–0.15	0.01	–0.05	–0.07**
IR 62	–1.21**	–1.19**	–9.73**	–3.60**	0.35**	–0.08**	0.26**	–1.48**	–0.29**	–0.19**	–0.32**
IET 5656	0.44**	–1.07**	10.99**	1.40**	–0.19**	0.10**	–0.20**	0.94**	0.19**	0.08	0.22**
IET 8002	0.28*	0.47	–0.63	5.78**	–0.15**	0.05**	–0.14**	0.61**	0.02	0.17**	0.13**
IET 6441	1.26**	2.46**	0.05	–0.28	–0.12**	0.09**	–0.16**	0.08	0.06	–0.02	0.05*
SE (g_i)	0.11	0.34	1.14	0.48	0.04	0.01	0.02	0.13	0.03	0.06	0.02
Testers (g_j)											
Basmati 385	–0.16	1.29**	2.59*	3.89**	0.36**	0.02*	0.14**	–0.65**	–0.10**	–0.11	–0.22**
Dudheswar	–0.03	–0.45	–2.75*	1.05*	–0.03	–0.07**	0.07**	1.59**	–0.01	0.56**	0.29**
Kalonunia	–0.27**	0.46	11.74**	–8.85**	–0.09	0.10**	–0.16**	–0.69**	0.01	–0.27**	–0.09**
Sambamahsuri	0.45**	–1.30**	–11.58**	3.91**	–0.25**	–0.05**	–0.05*	–0.24*	0.10**	–0.19**	0.02
SE (g_j)	0.10	0.30	1.02	0.43	0.04	0.01	0.02	0.11	0.03	0.06	0.02
Crosses											
IR 50 × Basmati 385	–0.26	0.89	28.78**	7.02**	0.44**	–0.03	0.25**	3.39**	0.03	1.20**	0.44**
IR 50 × Dudheswar	0.25	2.20**	–15.36**	–5.1**	–0.07	0.07**	–0.12*	–0.43	0.14*	–0.33*	–0.06
IR 50 × Kalonunia	0.35	–1.58*	–8.39**	–1.28	–0.07	0.04	–0.10*	–1.09**	–0.10	–0.27*	–0.15**
IR 50 × Sambamahsuri	–0.34	–1.51*	–5.03*	–0.64	–0.30**	–0.08**	–0.03	–1.87**	–0.06	–0.60**	–0.23**
IR 62 × Basmati 385	0.86**	1.25	7.61**	1.31	0.08	–0.02	0.06	–0.30	0.08	–0.21	–0.02
IR 62 × Dudheswar	–0.64**	–0.25	–13.63**	–8.07**	0.08	0.03	0.02	–3.04**	–0.18*	–0.88**	–0.54**
IR 62 × Kalonunia	–0.08	–0.24	–20.31**	0.41	0.03	–0.02	0.03	0.32	–0.09	0.25*	0.03
IR 62 × Sambamahsuri	–0.14	–0.77	26.33**	6.35**	–0.19*	0.01	–0.10*	3.01**	0.19**	0.84**	0.53**
IET 5656 × Basmati 385	0.08	–0.77	–23.48**	–9.51**	–0.27**	0.11**	–0.25**	–1.83**	0.08	–0.70**	–0.23**
IET 5656 × Dudheswar	–0.26	0.20	2.29	5.07**	0.04	–0.05*	0.07	–0.36	0.09	–0.26*	–0.08
IET 5656 × Kalonunia	0.41	1.21	33.81**	–1.93	0.01	0.01	0.01	2.37**	0.17*	0.60**	0.41**
IET 5656 × Sambamahsuri	–0.23	–0.64	–12.62**	6.37**	0.22*	–0.07**	0.17**	–0.19	–0.35**	0.37**	–0.09
IET 8002 × Basmati 385	0.30	0.33	11.90**	2.2*	–0.31**	–0.01	–0.13*	–2.78**	–0.17*	–0.81**	–0.42**
IET 8002 × Dudheswar	0.72**	–0.43	22.49**	2.78**	0.15	0.01	0.05	1.42**	0.01	0.53**	0.20**
IET 8002 × Kalonunia	–0.19	2.16**	–22.40**	–3.11**	0.06	0.004	0.03	0.54*	0.07	0.13	0.09
IET 8002 × Sambamahsuri	–0.83**	–2.06**	–11.99**	–1.87	0.10	–0.004	0.05	0.81**	0.09	0.15	0.14**
IET 6441 × Basmati 385	–0.97**	–1.70*	–24.81**	–1.02	0.06	–0.05*	0.08	1.52**	–0.01	0.53**	0.24**
IET 6441 × Dudheswar	–0.08	–1.73*	4.20	5.32**	–0.20*	–0.06**	–0.02	2.40**	–0.07	0.94**	0.48**
IET 6441 × Kalonunia	–0.49*	–1.54*	17.29**	5.91**	–0.03	–0.03	0.03	–2.15**	–0.05	–0.71**	–0.37**
IET 6441 × Sambamahsuri	1.54**	4.97**	3.31	–10.2**	0.17*	0.15**	–0.09	–1.77**	0.13	–0.76**	–0.35**
SE (±)	0.22	0.68	2.27	0.97	0.08	0.02	0.05	0.25	0.07	0.12	0.05

*, ** Significant at 5% and 1% levels of probability, respectively

quality characters like cooked kernel length and KER and IR 50 for total tillers/plant, productive tillers/plant, grain length, grain length/breadth ratio, kernel length, kernel breadth and kernel length/breadth ratio and IET 8002 for panicle weight, filled grains/panicle, spikelet fertility, grain breadth, grain weight/panicle, harvest index, cooked kernel length, cooked kernel length/breadth ratio and KER. Among the testers Kalonunia can be judged as potential parent for earliness, total tillers/plant, productive tillers/plant, panicle length, grain breadth and grain yield/plant and Basmati 385 for dwarfness, earliness, spikelet fertility, grain length, grain breadth, grain length/breadth ratio, 1000-grain weight, grain yield/plant, harvest index, kernel length, kernel length/breadth ratio and cooked kernel breadth.

Out of 20 crosses only seven crosses, viz IR 50 × Basmati 385, IR 62 × Basmati 385, IR 62 × Sambamahsuri, IET 5656 × Kalonunia, IET 8002 × Basmati 385, IET 8002 × Dudheswar and IET 6441 × Kalonunia exhibited significantly positive SCA values for grain yield/plant (Table 2). On the other hand nine crosses, viz IR 50 × Dudheswar, IR 50 × Kalonunia, IR 50 × Sambamahsuri, IR 62 × Dudheswar, IR 62 × Kalonunia, IET 5656 × Basmati 385, IET 5656 × Sambamahsuri, IET 8002 × Kalonunia and IET 6441 × Basmati 385 exhibited significantly negative SCA values for grain yield/plant. Among the quality characters for KER significantly positive and negative SCA values were exhibited by seven crosses each, out of which IR 62 × Sambamahsuri, IET 5656 × Kalonunia, IET 8002 × Dudheswar, IET 8002 × Sambamahsuri, IET 6441 × Basmati 385 and IET 6441 × Dudheswar exhibited significantly positive SCA values and IR 50 × Kalonunia, IR 50 × Sambamahsuri, IR 62 × Dudheswar, IET 5656 × Basmati 385, IET 8002 × Basmati 385, IET 6441 × Kalonunia and IET 6441 × Sambamahsuri exhibited significantly negative SCA values. If grain yield/plant and kernel elongation ratio are assumed to be the most important yield and quality characters then IET 5656 × Kalonunia seemed to be promising for development of both high-yielding and superior grain quality genotype due to its high and significantly positive SCA values for grain yield/plant and KER. Moreover, IET 5656 × Kalonunia involved high × high type of general combiners for grain yield/plant and high × low type of general combiners for KER indicating that the cross may be subjected to heterosis breeding and also for improving grain yield/plant and KER in the advance generation.

Two best specific combiners with SCA values for different yield and quality characters are shown in Table 3. The parental GCA values were classified as high, medium and low, derived from the total range of the GCA value for any character which was divided into three parts where low (L) indicates the lower one third, medium (M) indicates the middle one third and high (H) indicates the upper one-third in the range. The desirable combinations involved high × high, high × medium, high low, medium × medium, medium × low and low × low type of general combiners. The desirable performance of combination like high × low may be ascribed to the interaction between dominant allele from good combiners and recessive alleles from poor combiners. Moreover, a high × low cross can result in strong transgressive segregants for the desired characters due to segregation of genes with strong potentials and their specific buffers (Langham 1961). Such combinations were observed in the hybrids IR 50 × Basmati 385 and IR 62 × Kalonunia for plant height; IR 50 × Kalonunia and IR 50 × Basmati 385 for days to flowering; IR 62 × Sambamahsuri and IR 62 × Dudheswar for total tillers/plant; IR 62 × Dudheswar, IET 6441 × Kalonunia and IR 62 × Sambamahsuri for productive tillers/plant; IET 6441 × Dudheswar, IET 8002 × Dudheswar, IR 62 × Sambamahsuri and IR 62 × Basmati 385 for spikelet fertility; IET 5656 × Dudheswar and IR 62 × Kalonunia for grain length; IET 5656 × Dudheswar for grain length/breadth ratio; IET 6441 × Sambamahsuri for 1000-grain weight; IR 50 × Basmati 385 and IR 62 × Sambamahsuri for harvest index; IET 5656 × Sambamahsuri, IET 6441 × Dudheswar and IET 5656 × Dudheswar for kernel breadth; IET 5656 × Kalonunia for cooked kernel length; IET 5656 × Kalonunia and IET 6441 × Basmati 385 for KER.

Involvement of both poor combiners also produced superior specific combining hybrids as evidenced from the combination of IR 62 × Basmati 385 for spikelet/panicle, IR 62 × Basmati 385 for filled grains/panicle, IR 50 × Dudheswar for grain breadth, IET 5656 × Sambamahsuri and IET 6441 × Sambamahsuri for kernel length, IET 5656 × Sambamahsuri for kernel length/breadth ratio, IR 62 × Sambamahsuri for cooked kernel length and IR 62 × Sambamahsuri for cooked kernel length/breadth ratio. Similar views were also expressed by Amirthadevarathinam (1983). Crosses involving good general combiners by and large had high SCA values in IR 62 × Sambamahsuri for plant height, IR 50 × Basmati 385 for grain length, IR 50 × Basmati 385 for grain length/breadth ratio, IET 6441 × Sambamahsuri for grain weight/panicle, IET 5656 × Sambamahsuri for harvest index, IET 5656 × Kalonunia for grain yield/plant, IR 50 × Basmati 385 for kernel length, IR 50 × Sambamahsuri for kernel breadth, IR 50 × Basmati 385 for kernel length/breadth ratio, IET 8002 × Dudheswar for cooked kernel length/breadth ratio and IET 6441 × Dudheswar and IET 8002 × Dudheswar for KER.

The SCA value is a useful index to determine the usefulness of a particular cross combination for exploitation of heterosis (Peng and Virmani 1990). Among the crosses which exhibited high SCA values and *per se* (actual field) performance for grain yield/plant were IR 50 × Basmati 385 and IR 62 × Sambamahsuri which also showed high SCA values for other yield-attributing characters like plant height, days to flowering, productive tillers/plant, total tillers/plant, spikelet fertility, grain length and harvest index thus indicating that high SCA values for grain yield exhibited by the crosses

Table 3 Superior F_1 hybrids based on the GCA estimate for grain yield and quality related characters in rice

Character	Superior F_1 hybrid	SCA value	*Per se* performance of crosses	GCA status of parent
Plant height (cm) (dwarfness)	IR 50 × Basmati 385	-26.29**	83.20	L × H
	IR 62 × Sambamahsuri	-11.29**	72.97	H × H
Days to flowering (earliness)	IR 50 × Kalonunia	-12.73**	91.67	L × H
	IET 6441 × Dudheswar	-9.33**	106.00	L × L
Total tillers/plant	IR 50 × Basmati 385	15.23**	50.83	H × M
	IET 5656 × Kalonunia	9.68**	45.67	M × H
Productive tillers/plant	IET 5656 × Kalonunia	12.94**	43.97	M × H
	IR 50 × Basmati 385	12.80**	40.30	H × M
Panicle length (cm)	IR 62 × Basmati 385	2.13**	24.43	L × M
	IR 50 × Dudheswar	2.07**	27.09	M × L
Panicle weight (g)	IR 62 × Basmati 385	0.81**	2.54	L × M
	IET 8002 × Dudheswar	0.58*	4.02	H × M
Spikelets/panicle	IR 62 × Basmati 385	37.84**	130.13	L × L
Filled grains/panicle	IR 62 × Basmati 385	35.06**	91.40	L × L
	IET 8002 × Dudheswar	33.20**	167.00	H × M
Spikelet fertility (%)	IET 6441 × Dudheswar	13.18**	92.16	H × L
	IET 8002 × Dudheswar	11.80**	89.00	H × L
Grain length (mm)	IR 50 × Basmati 385	0.38**	9.32	H × H
	IET 5656 × Dudheswar	0.25**	8.48	L × H
Grain breadth (mm)	IR 50 × Dudheswar	0.21**	2.40	L × L
	IET 6441 × Sambamahsuri	0.13**	2.67	H × M
Grain length/breadth ratio	IET 5656 × Dudheswar	0.27**	3.66	L × H
	IR 50 × Basmati 385	0.26**	4.14	H × H
Grain weight/panicle (g)	IET 6441 × Sambamahsuri	1.54**	5.91	H × H
	IR 62 × Basmati 385	0.86**	2.15	L ×M
1000-grain weight (g)	IET 6441 × Sambamahsuri	4.97**	28.30	H × L
	IR 50 × Dudheswar	2.20**	23.24	M × M
Harvest index (%)	IR 50 × Basmati 385	7.02**	49.25	L × H
	IET 5656 × Sambamahsuri	6.37**	53.31	H × H
Grain yield/plant (g)	IET 5656 × Kalonunia	33.81**	112.12	H × H
	IR 50 × Basmati 385	28.78**	86.25	M × H
Kernel length (mm)	IR 50 × Basmati 385	0.44**	6.90	H × H
	IET 5656 × Sambamahsuri	0.22*	5.78	L × L
Kernel breadth (mm)	IR 50 × Sambamahsuri	-0.08**	1.92	H × H
	IET 5656 × Sambamahsuri	-0.07**	2.19	L × H
Kernel length/breadth ratio	IR 50 × Basmati 385	0.25**	3.37	H × H
	IET 5656 × Sambamahsuri	0.17**	2.64	L × L
Cooked kernel length (mm)	IR 50 × Basmati 385	3.39**	12.85	M × L
	IR 62 × Sambamahsuri	3.01**	11.55	L × L
Cooked kernel breadth (mm)	IET 5656 × Sambamahsuri	-0.35**	2.76	L × L
(Thinness)	IR 62 × Dudheswar	-0.18*	2.33	H × M
Cooked kernel length/breadth ratio	IR 50 × Basmati 385	1.20**	4.69	M × M
	IET 6441 × Dudheswar	0.94**	5.14	M × H
Kernel elongation ratio (KER)	IR 62 × Sambamahsuri	0.53**	1.95	L × M
	IET 6441 × Dudheswar	0.48**	2.54	H × H

*, ** Significant at 5% and 1% levels of probability, respectively; *Per se,* Actual field; H, High GCA value, M, Medium GCA value and L, Low GCA value, derived from the total range of the parental GCA value for any character which was divided into three parts where L indicates the lower one third, M indicates the middle one third and H indicates the upper one-third in the range.

Table 4 Ranking of seven best hybrids on the basis of SCA and their parents on the basis of GCA for grain yield per plant and kernel elongation ratio (KER) and mean (*per se*) performance of other yield and quality characters in rice

Hybrid/parent	SCA (cross) and GCA (parent) values		Ranking according to *per se* performances for yield and quality characters																							Total rank	Mean rank
	Grain yield plant^{-1} (g)	KER	Y_1	Y_2	Y_3	Y_4	Y_5	Y_6	Y_7	Y_8	Y_9	Y_{10}	Y_{11}	Y_{12}	Y_{13}	Y_{14}	Y_{15}	Y_{16}	Q_1	Q_2	Q_3	Q_4	Q_5	Q_6	Q_7		
Hybrid																											
IET 5656 × Kalonunia	33.81**	0.41**	7	3	2	1	1	3	1	3	7	7	1	7	3	4	7	1	6	7	7	3	6	5	3	95	4.13
IR 50 × Basmati 385	28.78**	0.44**	2	2	1	2	6	7	7	7	6	1	7	1	7	2	2	2	1	1	1	4	1	3	5	78	3.39
IR 62 × Sambamahsuri	26.33**	0.53**	1	1	1	4	7	6	6	6	3	5	6	3	6	7	3	5	4	2	2	5	4	4	4	95	4.13
IET 8002 × Dudheswar	22.49**	0.20**	4	4	5	5	5	2	2	2	2	3	5	2	2	6	1	4	3	4	4	2	5	2	2	76	3.30
IET 6441 × Kalonunia	17.29**	–0.37**	6	6	3	3	2	4	3	4	5	6	2	6	4	3	6	3	5	6	6	7	5	6	7	108	4.70
IET 6441 × Basmati 385	–24.81**	0.24**	3	5	7	7	3	5	5	5	4	2	3	5	5	1	5	7	2	5	3	6	2	5	6	101	4.39
IET 6441 × Dudheswar	4.20	0.48**	5	3	6	6	4	1	4	1	1	4	4	4	1	5	4	6	7	3	5	1	3	1	1	80	3.48
Lines																											
IR 50	–0.69	–0.07**	3	1	2	3	4	4	4	4	1	1	5	1	4	2	1	5	1	1	1	1	5	2	1	57	2.48
IR 62	–9.73**	–0.32**	1	2	1	1	5	5	5	5	5	4	4	2	5	1	4	4	2	2	2	2	1	1	3	67	2.91
IET 5656	10.99**	0.22**	5	3	5	2	1	2	3	3	3	5	1	5	2	3	5	2	5	4	4	4	4	5	4	80	3.48
IET 8002	–0.63	0.13**	4	4	4	5	2	1	2	1	2	2	2	4	1	4	2	1	4	5	5	5	2	4	5	71	3.09
IET 6441	0.05	0.05*	2	5	3	4	3	3	1	2	4	3	3	3	3	5	3	3	3	3	3	3	3	3	2	70	3.04
Testers																											
Basmati 385	2.59*	–0.22**	3	2	4	3	2	4	4	4	4	1	2	1	4	1	3	3	1	3	1	1	1	1	1	54	2.35
Dudheswar	–2.75*	0.29**	4	3	3	4	3	1	1	1	2	2	4	2	1	2	1	4	2	2	2	2	2	2	3	53	2.30
Kalonunia	11.74**	–0.09**	2	1	1	1	1	2	3	3	1	3	1	4	2	3	4	1	4	4	4	3	3	3	2	56	2.43
Sambamahsuri	–11.58**	0.02	1	4	2	2	4	3	2	2	3	4	3	3	3	4	2	2	3	1	3	4	4	4	4	67	2.91

*, ** Significant at 5% and 1% levels of probability respectively; *Per se,* actual field; Y_1, plant height (cm); Y_2, days to flowering; Y_3, total tillers/plant; Y_4, productive tillers/plant; Y_5, panicle length (cm); Y_6, panicle weight (g); Y_7, spikelets/panicle; Y_8, filled grains/panicle; Y_9, spikelet fertility (%); Y_{10}, grain length (mm); Y_{11}, grain breadth (mm); Y_{12}, grain length/breadth ratio; Y_{13}, grain weight/panicle (g); Y_{14}, 1000 grain weight (g); Y_{15}, harvest index (%); Y_{16}, grain yield/plant (g); Q_1, kernel length (mm); Q_2, kernel breadth (mm); Q_3, kernel length/breadth ratio; Q_4, cooked kernel length (mm); Q_5, cooked kernel breadth (mm); Q_6, cooked kernel length/breadth ratio; Q_7, kernel elongation ratio (KER)

resulted from favourable interaction of moderate to high SCA values for different yield components. This seemed appropriate as yield is a complex character depending upon a number of component characters and any optimum manifestation of these characters in various crosses could produce desirable combination. Therefore, SCA for yield may ultimately be influenced by SCA for yield components. The crosses IR 50 × Basmati 385 and IR 62 × Sambamahsuri also performed well for quality characters like kernel length, kernel length/breadth ratio, cooked kernel length cooked kernel length/breadth ratio and KER. The cross IR 50 × Basmati 385 involved medium × high general combiners for grain yield/plant and also performed well for some quality characters and so may be used for obtaining superior recombinants in the advance generation. The cross IR 62 × Sambamahsuri involved low × low general combiner and therefore may be used for heterosis breeding for yield and as it has performed well for some qualitative characters, there is some probability of obtaining superior quality hybrids. Surprisingly the cross IET 5656 × Kalonunia, which exhibited the maximum positive SCA value and *per se* performance for grain yield/plant did not perform well in other yield attributing characters except productive tillers/plant and panicle length. The character productive tillers/plant compensated for all other yield-attributing characters in IET 5656 × Kalonunia, which also performed well in some quality characters like cooked kernel length, cooked kernel length/breadth ratio and KER.

The best hybrids and their parents were ranked amongst themselves on the basis of their yield and quality characters (Table 4), as suggested by Woolley and Evans (1979). Ranking of seven best hybrids and their parents was done on the basis of SCA for grain yield and KER as the base character and the *per se* performance of their attributing characters. When the ranking of seven best hybrids and their parents was done, IET 8002 × Dudheswar ranked the first (3.30), followed by IR 50 × Basmati 385 (3.39), IET 6441 × Dudheswar (3.48), IET 5656 × Kalonunia (4.13), IR 62 × Sambamahsuri (4.13), IET 6441 × Basmati 385 (4.39) and IET 6441 × Kalonunia (4.70) respectively.

It can be summarized considering all the variance estimates that plant height, panicle length, panicle weight, spikelet/panicle, filled grains/panicle, grain length, grain length/breadth ratio and kernel length/breadth ratio were controlled predominantly by additive gene action therefore, transgressive breeding may be useful for these characters whereas, days to flowering, total tillers/plant, productive tillers/plant, 1000-grain weight, grain yield/plant, harvest index, cooked kernel length, cooked kernel length/breadth ratio and KER were controlled predominantly by non additive gene action therefore, heterosis breeding is a better choice for these characters. The characters spikelet fertility, grain breadth, grain weight/panicle, kernel length, kernel breadth and cooked kernel breadth were controlled by both additive and non-additive gene action indicating that both transgressive breeding and heterosis breeding may be employed to improve these characters. Moreover, in case of characters controlled predominantly by non additive gene action breeding methodology such as biparental mating and diallel selective mating (Jensen, 1970, Frey 1975) may be resorted to, than conventional pedigree or backcross techniques which would leave the unfixable components of genetic variances unexploited for yield and its components. However, characters predominantly controlled by additive gene action would be amenable to conventional breeding methods.

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