Combining ability studies for grain and nutritional quality in some rice crosses

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ABSTRACT

In the present investigation four with high yielding capacity and seven lines with good quality features were considered for hybridization programme using Line × Tester mating design to study the combining ability for grain and nutritional quality during 2011, 2012 and 2013 following Randomized Block Design with three replications. Desirable significant sca effect were found in Taraori Basmati × Satabdi for kernel length, kernel length: breadth ratio, kernel length after cooking, Zn content, Jayasilet × Swarna-Sub 1 for kernel breadth, Seetabhog × IR 64 for amylose content, Zn content, Taraori Basmati × IR 64 for gel consistency, hulling percentage, Fe content and yield plant^{-1}, Taraori Basmati × Pankaj for milling percentage, head rice recovery and yield plant-1. The reflection of sca effect in superior specific combinations towards desirable direction for different yield and quality characters highlighted that these superior crosses involved all the possible combination between parents like (high × high), (high × average), (high × low), (average × average), (average × low) and (low × low) gca effect.

Key words: *Rice, quality,combining ability, gca, sca*

Rice (*Oryza sativa* L.) is the most important staple food for a large part of the world's human population and in India rice plays a pivotal role in the food and livelihood security system providing about 75 percent of calories and 55 percent of the protein in average daily diet of the Indians. Global demand for rice is projected to grow at least equal to population growth, thus requiring 70 percent increase in supply by the year 2025 i.e. 765 million tonnes of rice (IRRI, 1993). The current world population of 6.1 billion is expected to reach 8.0 billion by 2030 and rice production must increase by 50 percent in order to meet the growing demand. With the enhanced income levels and changing food habits, breeding rice varieties with preferred grain quality features has become the second most important objective after yield (Juliano and Villareal 1993). Rice consumer mainly poor people of developing countries are dependent on the crop as a source of dietary energy, protein and minerals. The rice grain, however, is low in protein quantity and deficit in micronutrients required for human growth. The milling and polishing of rice grains further depletes the nutrients from outer layer of endosperm. Millions of rice eaters who cannot afford to diversify their diet for more balanced nutrition are affected by 'hidden hunger' due to micronutrient deficiency induced malnutrition. Eastern India, especially West Bengal, is a rich source of small and medium grain indigenous aromatic germplasm with excellent grain quality parameters including aroma. But most of these traditional aromatic genotypes are low yielding, photoperiod sensitive, lodging type with tall and weak culm and less responsive to fertilizer. Therefore, there is enough scope to increase these small and medium grain scented germplasm by bringing them in breeding programme with the varieties having desirable traits for the development of high yielding good quality scented rice varieties. With this background, the present investigation has been envisaged to bring improvement in grain quality as well as biofortification with respect to iron and zinc.

MATERIALS AND METHODS

The laboratory experiments were carried out in the Department of Plant Breeding, Bidhan Chandra Krishi Viswavidyalaya, Mohanpur, Nadia, and West Bengal during the year 2011, 2012 and 2013. Field studies in kharif season of 2011, 2012 and 2013 were carried out in Agricultural Instructional Farm, Bidhan Chandra Krishi Viswavidyalaya, Jaguli located at Gangetic new alluvial zone of West Bengal at south of Tropic of Cancer within 22.87^{0}N latitude, 88.59^{0}E longitudes and above 9.75 m altitude from mean sea level. The laboratory experiments were carried out in the Department of Genetics and Plant Breeding, Department of Agricultural Chemistry and Soil Science and Quality laboratory of Rice Research Station, Chinsurah. The high yielding and genotypes with good quality parameters identified based on evaluation through field and laboratory experiments were subjected to line × tester mating design (Kempthorne 1957). Seven lines with good quality features which included Patnai-23, Jayasilet, Seetabhog, Taraori Basmati, CN 1794-2, Badshahbhog and Kataribhog and four testers with high yield which included Satabdi, IR 64, Pankaj and Swarna-Sub1were considered for the hybridization programme . All the parents were sown in the field in eleven different dates to effect nicking among them. Clipping method was followed for emasculation. For F_1 generation trial twenty eight hybrids along with eleven parents were sown on 5th June 2013. The experiment was laid out in Randomized Block Design following three replications. Twenty one days old seedlings were transplanted @ 1 plant per hill at a spacing of 15 cm in either direction. The usual recommended doses of N, P and K fertilizers were applied @ 60:40:40 kg per ha. Intercultural operations and crop protection measures were taken as and when necessary. Observations were recorded on 1) Milling quality which included hulling percentage, milling percentage and head rice recovery. Hulling is the process of dehusking paddy. For small sample dehusking in the laboratory, specialized hulling machine (Satake, Japan, Model-THU35 B) was used. Hulling percentage was calculated as the ratio of weight of dehusked grain after hulling to weight of rough rice sample before hulling expressed in percentage. Milling was done in the same way by special type of Miller (Satake, Japan, Model- TMO 5C &TM-05) designed for small samples. After dehusking, milling was done to remove the bran layer and to polish the kernels for further tests. Milling percentage was calculated as the ratio of weight of milled kernel to weight of rough rice sample before hulling expressed in percentage. Head rice recovery is the percentage of the full length intact kernels after milling. Some kernels are broken during milling process. The broken kernels were separated manually as well as with the help of Test Rice Grader (Satake, Japan, Model-TRG 05B) and both the unbroken and broken kernels were weighed separately. Head rice recovery was calculated as the ratio of weight of intact whole kernel to total weight of rough rice expressed in percentage. 2) Grain morphology: Grain length (mm), grain breadth (mm), grain l:b ratio, kernel length (mm), kernel breadth, kernel l:b ratio, were measured as the average length of ten unbroken milled rice measured in mm in Annadarpan, a machine vision system for rice quality analysis developed by C-DAC, Kolkata and RRS, Govt. of West Bengal. Grain size and shape were classified on the basis of average length of kernels following IRRI, SES, 1996. 3) Cooking and eating quality: Kernel length after cooking (KLAC) (mm) was recorded as the average of the length of ten cooked kernels measured in mm. Kernel elongation ratio (KER), was measured by dividing the length of cooked rice by the length of original (uncooked) kernel Hussain *et al.* (1987). Amylose content (AC) was measured following Sadasivam and Manickam (2008), gelatinization temperature (GT) by Little *et al.* (1958), gel consistency by Cagampang *et al.* (1973), presence and concentration of aroma following Organoleptic panel test, IRRI (1971). Nutritional quality: Iron and zinc content was estimated following DTPA extractable, Lindsay and Norvell (1978). Statistical analysis was carried out using sample mean values. All the analysis was processed in computer using Windostat Version 9.1 from Hyderabad licensed to Plant Breeding Division Sugarcane Breeding Institute, Coimbatore. Line × tester method of Kempthorne (1957) was followed for analysis of variance.

RESULTS AND DISCUSSIONS

Analysis of variance (Table 1) exhibited significant

Table 1. Analysis of variance of quality traits for parents and hybrids

Sources of variation	d.f	KL (mm)	KB (mm)	Kernel L:b ratio	KLAC (mm)	K ER	AC (%)	GT	GC	Hulling percentage	Milling percentage	HRR (%)	Fe content (mg kg^{-1})	Zn content (mg kg^{-1})
Replication	2	0.16	0.01	0.013	0.09	0.09	0.46	0.03	1.085	4.292	7.911	0.913	6.183	2.16
Genotypes	38	2.72	0.36	1.95	4.03	0.03	4.69	1.75	634.32	182.288	181.742	111.982	68.59	29.63
Parents (P)	10	4.70	0.51	3.26	10.06	0.09	4.52	3.34	550.96	87.039	79.831	76.138	85.30	34.67
Lines (L)	6	5.96	0.17	1.52	14.31	0.1	3.36	4.84	681.65	98.079	98.508	93.170	71.30	26.99
Tester (T)	3	3.71	1.01	7.57	2.52	0.05	7.79	0.78	140.08	87.175	53.278	62.040	124.29	41.97
Parents- (L vs T)	1	0.12	0.99	0.80	7.21	0.21	1.68	2.02	999.48	20.389	47.427	16.235	52.31	58.8
P vs H	1	0.10	5.58	22.12	1.20	0.01	7.14	7.49	4314.46	609.11	1001.09	1030.18	16.47	8.84
Hybrids(H)	27	2.08***	0.11***	0.708***	1.91***	0.01**	4.6***	0.96-1***	528.8***	201.7-5***	189.1-4***	91.25***	64.33***	28.54***
Line effect	6	7.14	0.24***	1.82***	6.11***	0.041*	8.16	1.2	1120.16**	316.47	264.94	74.47	64.73	18.80
Tester effect	3	1.49	0.27***	1.43**	1.63	0.01	4.37	0.495	874.7*	411.66*	439.24*	223.41	16.74	54.51
Line Tester effect	18	0.50***	0.04***	0.22***	0.50	0.01	3.55***	0..95***	274.16***	128.53***	122.18***	74.81***	72.12***	27.46***
Error	76	0.11	0.01	0.071	0.31	0.01	0.84	0.106	16.471	6.62	7.76	10.22	1.704	1.09

*Significantat at 5% level ** Significant at 1% level *** Significant at 0.1% level

KL:Kernel length KB: Kernel breadth KLAC: Kernel length after cooking KER: Kernel elongation ratio AC: Amylose content GT: Gelatinization temperature GC: Gel consistency HRR: Head rice recovery

differences for almost all the quality traits among all the entries, parents, hybrid and parent vs hybrid except for parent vs hybrid where kernel length, KLAC and KER were found to be non significant. Lines and testers exhibited significant variation for all the quality traits indicating the predominance of additive gene action. The influence of additive gene action on kernel length, kernel breadth and kernel l:b ratio was also reported by Nayak *et al.* (2011). Significant line × tester interaction for quality traits was also reported by Srivastava *et al.* (2012). Parents and hybrids exhibited significant variance for all the characters which indicated the existence of wider genetic differences among parents which resulted in divergent hybrids. Lower magnitude of interaction component of lines and testers for almost all the characters except kernel breadth, hulling percentage, milling percentage, head rice recovery and Zn content indicated the preponderance of additive gene

Table 2. Estimates of genetic variance for quality traits in rice

Sources of variation	KL (mm)	KB (mm)	Kernel L:b	KLAC (mm) ratio	KER	AC (%)	GT	GC	Hulling percentage	Milling Percentage	HRR (%)	Fe content ($mgkg^{-1}$)	Zn content ($mgkg^{-1}$)
σ^2 gca	0.255***	0.015***	0.094***	0.215**	0.001	0.328*	0.045	59.453***	21.663**	20.868**	8.407*	2.366	2.155
σ^2 sca	0.130***	0.011***	0.048***	0.081	0.000	0.902***	0.281***	85.898***	40.636***	38.140***	21.529***	23.475***	8.788***
σ^2 A	0.510	0.030	0.188	0.430	0.002	0.656	0.091	118.906	43.326	41.736	16.814	4.732	4.311
σ^2 D	0.130	0.011	0.048	0.081	0.000	0.902	0.281	85.898	40.636	38.140	21.529	23.475	8.788
h^2 % (N.S.)	75.314	67.751	72.108	69.760	36.065	35.657	22.322	56.542	50.279	50.610	40.27	16.444	32.016
σ^2_A/σ^2_D	3.925	2.731	3.853	5.257	10.05	0.728	0.323	1.384	1.066	1.094	0.781	0.201	0.490
$\frac{\sigma^2_A}{\sigma^2_A+\sigma^2_D}$	0.662	0.731	0.796	0.841	1.893	0.421	2.377	0.580	0.051	0.522	0.438	0.167	0.329

Table 3. Proportional contribution of lines, testers and their interactions to the total variance for different quality traits in Rice

Sources	KL (mm)	KB (mm)	Kernel L:b ratio	KLAC (mm)	KER	AC (%)	GT	GC	Hulling perce-ntage	Milling perce-ntage	HRR (%)	Fe con-tent (mg kg^{-1})	Zn con -tent(mg kg^{-1})
Lines	76.004	47.832	57.071	70.993	48.986	38.843	28.257	47.064	34.857	31.128	18.136	22.362	14.640
Testers	7.979	26.829	22.390	9.4706	9.792	10.404	5.728	18.376	22.671	25.803	27.204	2.892	21.221
Line × Tester	16.016	25.337	20.538	19.536	41.221	50.752	66.013	34.558	42.471	43.068	54.659	74.745	64.138

action in the expression of these characters. Contribution of females were high for kernel length, kernel breadth, kernel l: b ratio, kernel length after cooking, kernel elongation ratio and gel consistency (Table 3) while contribution of line × tester was high for amylose content, GT, hulling percentage, milling percentage, hulling percentage, Fe content and Zn content.

The analysis of variance for combining ability (Table 2) revealed the variance due to general and specific combining ability to be significant for almost all the characters considered in the present investigation suggesting the importance of both additive and non additive components of gene action. The magnitude of sca variance was larger, in general, for most of the characters except for kernel length, kernel breadth, kernel l:b ratio, KLAC and KER where gca variance was comparatively higher and it may be concluded that all these characters are predominantly controlled by non-additive gene action. Shivani *et al.* (2009)and Mirarab *et al.* (2011) also revealed the predominance of non additive variance for most of the quality traits from their investigation. However, Nayak et al. (2011) found kernel length, kernel breadth and kernel l: b ratio as influenced by additive gene action which was also in confirmation with the findings of the investigation. Gnanasekaran *et al*.(2006)also reported the predominance of additive gene control of kernel l:b atio.

Predictability ratios were recorded higher than 0.50 for most of the characters so those traits with high predictability ratio will prove to be more reliable in selecting desired genotypes due to comparatively high influence of additive genetic component in the expression of this trait. The estimates of predictability ratio were reported low for amylose content, head rice recovery and Fe and Zn content. Low estimate of narrow sense heritability were found for almost all the traits except kernel length, kernel breadth, kernel l:b ratio, KLAC and GC which further indicated the predominance of non additive genetic variance in their expression and therefore heterosis breeding may be rewarding.

The gca effects for lines and testers in respect of all the quality traits are presented in the (Table 4). Patnai-23 followed by Jayasilet, Taraori Basmati and CN 1794-2 from female lines and Satabdi and IR 64 from male were found to be good general combiners for kernel length. Best combiner for kernel breadth in female was found in Jayasilet followed by Patnai-23 and among male, Swarna-Sub1 and Pankaj were the best combiners. Considering all the quality traits among the lines, Jayasilet followed by CN 1794-2 and among the testers IR 64 followed by Pankaj were the best general combiners. GC was significant in all the lines except Jayasilet and Kataribhog. Taraori Basmati and CN 1794-2 exhibited significant and positive gca effect whereas Seetabhog and Badshahbhog revealed negative effect. Among the testers Satabdi and Swarna-Sub 1 showed significantly negative effect while a positive and significant gca effect was shown by IR 64. Hulling percentage was significant among all the lines but Seetabhog, Taraori Basmati, Badshahbhog and Kataribhog exhibited significant but negative effect. All the lines were also significant for the trait but IR 64 and Swarna sub 1 exhibited negative effect. All the lines showed significant gca effects for milling percentage except Taraori Basmati. All the testers also exhibited significant gca effect but IR 64 and Swarna-Sub1 showed negative effect. Only Jayasilet and Seetabhog revealed significant gca effect for head rice recovery but Seetabhog showed negative effect among the lines. Three out of four testers exhibited significant gca effect. Pankaj showed positive effect while IR 64 and Swarna-Sub1 showed negative effect. The gca for Fe content were significant in all the lines except CN 1794-2. Jayasilet, Taraori Basmati, Badshahbhog and Kataribhog showed significant and positive effect while others showed negative effect. Among the testers

Table 4. General combining ability (gca) effects of parents for quality traits in Rice

Parents	KL (mm)	KB (mm)	Kernel L:b ratio	KLAC (mm)	KER	AC (%)	GT	GC	Hulling percentage	Milling percentage	HRR (%)	Fe content (mgkg^{-1})	Zn content (mg kg^{-1})
Lines(gi)													
Patnai 23	0.90 ***	0.15 ***	0.18*	0.82 ***	-0.05	-0.55 *	0.01	-3.87 **	3.06* **	2.39 **	0.80	-3.19 ***	-0.89 **
Jayasilet	0.30* *	0.18* **	-0.10	-0.07	-0.08 *	0.21	0.21 *	-0.45	6.54* **	5.46 * **	4.11 * **	1.26**	1.29 * **
Seetabhog	-0.98* **	0.00	-0.45* **	-1.02* **	0.04	1.47 * **	0.01	-9.62* **	-5.76*	-6.56 * **	-3.77 * **	-3.09* **	1.25 * **
Taraori Basmati	0.70 * **	-0.13* **	0.52* **	0.75 * **	-0.03	0.26	0.40* **	5.21* **	-2.46 * *	-1.46	-0.80	1.42* **	0.35 **
CN 1794-2	0.49* **	-0.16* **	0.44* **	0.52 * *	-0.02	-0.24	0.20 *	17.71 ***	5.83* **	5.90* **	1.42	-0.56	-2.28 * **
Badsh-ahbhog	-0.65 ***	0.11* **	-0.42* **	-0.51 **	0.05	-1.20* **	-0.50 ***	-10.45 ***	-1.75*	-2.27**	-0.07	2.15 * **	0.05
Katar-ibhog	-0.75 ***	-0.14 ***	-0.16*	-0.48* *	0.08 *	0.03	-0.34 ***	1.46	-5.46* **	-3.45* **	-1.68	2.01* **	0.22
SE (gi)	0.09	0.02	0.07	0.16	0.03	0.26	0.09	1.17	0.74	0.80	0.92	0.37	0.30
Tester (gj)													
Satabdi	0.18*	-0.10 * **	0.19**	0.33**	0.02	-0.01	0.18*	-4.20 * **	1.98* **	1.57*	1.11	-1.02***	-1.85 * **
IR 64	0.21**	-0.10 * **	0.24* **	0.10	-0.03	-0.24	-0.01	8.85* **	-2.63* **	-2.05**	-1.49*	1.16* **	-0.85* **
Pankaj	-0.01	0.09* **	-0.13 *	-0.13	-0.02	0.64 **	-0.19**	0.70	5.21***	5.53***	3.95***	-0.05	1.36* **
Swarna sub 1	-0.37* **	0.11* **	-0.30* **	-0.31*	0.03	-0.39	0.02	-5.35* **	-4.56***	-5.05* **	-3.58* **	-0.09	1.34 * **
SE (gj)	0.07	0.02	0.05	0.12	0.02	0.20	0.07	0.88	0.56	0.60	0.69	0.28	0.22

*Significant at 5% level ** Significant at 1% level *** Significant at 0.1% level

Satabdi exhibited significantly negative effect while IR 64 showed significant and positive effect. Among the lines Jayasilet and Seetabhog showed significantly positive gca effect for Zn content while Patnai-23 and CN 1794-2 showed significant but negative gca effect. All the testers were found to exhibit significant gca effect but Satabdi and IR 64 revealed negative effect.

The reflection of sca effect in superior specific combinations (Table 5) towards desirable direction for different quality characters highlighted that these superior crosses involved all the possible combination between parents like (high × high), (high × average), (high × low), (average × average), (average × low) and (low × low) gca effect. It was found that (high × high) combinations not always resulted in high sca effect which is probably due to internal cancellation of gene effect in parents as suggested by Jones (1958) or may be due to poor genetic diversity between the parents involved (Singh and Gupta 1969). Highly performed hybrids generated from (high × high) general combiners may be resulted from interactions of dominant gene actions contributed by both the parents and due to additive gene actions the character are fixable and these crosses can be exploited for obtaining early desirable segregants following simple breeding method following pedigree selection. Superior hybrids from combinations of (good × poor) parents may be resulted due to dominance × recessive type of interactions with non additive and non fixable genetic components. Random mating and selection among segregants could lead to identification of desirable segregants at later generations. The hybrids from parents with poor or average combiners could be resultant effect of interaction of gene at higher degrees and suggested for cyclic selection or biparental breeding programme for obtaining desirable segregants.

The sca effect were found superior in Taraori Basmati × Satabdi for kernel length, kernel length: breadth ratio, kernel length after cooking and Zn

Table 5. Specific combining ability (sca) effects of rice hybrids for quality traits in Rice

	KL (mm)	KB (mm)	Kernel L:b ratio	KLAC (mm)	KER	AC (%)	GT	GC	Hulling percentage	Milling percentage	HRR (%)	Fe content (mg kg-1)	Zn content (mg kg-1)
Patnai-23 × Satabdi	-0.15	0.06	-0.14	-0.12	0.00	1.32*	-0.18	9.87 ***	-0.52	-0.48	0.58	-0.81	-4.09***
Patnai-23 × IR 64	-0.47*	0.00	-0.22	-0.06	0.08	0.42	-0.40 *	-2.85	0.25	-0.51	0.91	-3.39 ***	-0.80
Patnai-23 × Pankaj	0.24	0.04	0.06	0.08	-0.03	-0.83	0.72***	-11.37 ***	-1.44	-0.14	-2.61	1.07	0.84
Patnai-2 3× Swarna sub	0.38	-0.10	0.30	0.10	-0.06	-0.90	-0.14	4.35	1.71	1.14	1.12	3.12 ***	4.05 ***
Jayasilet × Satabdi	0.07	0.01	0.01	0.02	-0.01	-0.46	-0.31	6.12 *	2.77	2.76	0.66	0.07	-0.28
Jayasilet × IR 64	-0.29	0.18**	-0.37 *	-0.10	0.04	-0.07	0.37	-2.60	3.39 *	4.57**	1.87	-3.26***	-1.79**
Jayasilet × Pankaj	0.10	0.04	0.02	-0.06	-0.03	0.38	0.08	-4.12	-3.54*	-4.19*	-1.85	-2.14**	0.62
Jayasilet × Swarna sub 1	0.12	-0.23***	0.34 *	0.14	-0.01	0.14	-0.14	0.60	-2.63	-3.13	-0.68	5.33***	1.45*
Seetabhog × Satabdi	0.25	-0.03	0.14	-0.30	-0.10	-0.91	0.12	4.62	0.81	-5.94***	-5.38**	2.97 ***	0.87
Seetabhog× R 64	-0.42*	-0.01	-0.23	-0.38	0.02	1.51 **	-0.67 ***	-3.76	-13.47 ***	-9.09***	-6.66***	2.70 ***	3.31 ***
Seetabhog × Pankaj	-0.08	-0.10	0.09	-0.12	-0.01	0.78	-0.15	-3.62	4.72 **	4.20 *	5.29 **	-2.69***	-1.69 **
Seetabhog × Swarna sub 1	0.24	0.14 *	0.00	0.81 *	0.09	-1.38 *	0.70***	2zz.76	7.94 ***	10.83 ***	6.76***	-2.98 ***	-2.48 ***
Taraori Basmati × Satabdi	0.47*	-0.06	0.36*	0.72*	0.01	-0.25	-0.23	-17.21 ***	-3.63 *	-4.63 **	-4.87*	-5.68***	4.65 ***
Taraori Basmati × IR 64	0.01	-0.11	0.20	0.07	0.02	-0.33	-0.37	13.07 ***	11.67***	7.63 ***	4.68 *	5.13***	-4.84 ***
Taraori Basmati × Pankaj	-0.02	0.03	-0.11	-0.06	-0.01	-0.19	-0.04	-3.12	2.21	6.01***	6.53***	7.12***	-0.77
Taraori Ba × Swarna sub	-0.46 *	0.15 *	-0.45 **	-0.74 *	-0.03	0.77	0.63 **	7.26**	-10.24***	-9.01 ***	-6.35 **	-6.57 ***	0.97
CN 1794-2 × Satabdi	0.18	0.18 **	-0.16	0.10	-0.02	-0.02	-0.12	-8.71 ***	-2.74	-2.08	-0.28	3.25 ***	1.46*
CN 1794-2 × IR 64	0.24	-0.07	0.26	0.35	0.01	-0.73	-0.03	5.90 *	4.41 **	4.00 *	3.62	4.57***	0.20
CN 1794-2 × Pankaj	-0.26	-0.04	-0.09	-0.41	-0.01	0.80	-0.10	15.38 ***	-1.27	-1.88	-4.01*	-4.07***	0.39
CN 1794-2 × Swarna sub 1	-0.15	-0.07	-0.01	-0.05	0.02	-0.05	0.25	-12.57***	-0.39	-0.04	0.67	-3.75***	-2.05**
Badshahbho × Satabdi	-0.05	-0.09	0.08	0.16	0.02	-0.10	0.60 **	4.45	8.85***	11.64***	9.52***	-5.05***	-4.74 ***
Badshahbho × IR 64	0.52 **	0.09	0.07	-0.12	-0.13	1.14*	0.52 **	-12.26 ***	-5.65***	-4.47**	-3.36	-1.84*	4.06 ***
Badshahbhog × Pankaj	-0.48 *	0.03	-0.20	-0.10	0.09	-1.75**	0.16	5.21 *	-1.91	-3.61*	-2.70	4.57***	1.90 **
Badshahbhog × Swarna sub 1	0.01	-0.03	0.06	0.06	0.01	0.71	-1.28 ***	2.60	-1.29	-3.56 *	-3.46	2.32**	-1.22*
Kataribhog× Satabdi	-0.78 ***	-0.06	-0.30	-0.59	0.09	0.42	0.11	0.87	-5.53 ***	-1.28	-0.24	5.25***	2.14***
Kataribhog × IR 64	0.40*	-0.07	0.29	0.24	-0.05	-1.94***	0.58 **	2.49	-0.61	-2.13	-1.05	-3.92***	-0.13
Kataribhog × Pankaj	0.50*	-0.01	0.24	0.66 *	-0.01	0.80	-0.67***	1.63	1.24	-0.37	-0.65	-3.86***	-1.29 *
Kataribhog × Swarna sub 1	-0.13	0.15 *	-0.23	-0.32	0.02	0.72	-0.02	-4.99 *	4.90**	3.78*	1.94	2.53**	-0.72
SE (ij) 0.193	0.058	0.154	0.323	0.060	0.532	0.188	2.343	1.486	1.609	1.846	0.753	0.604	

*Significant at 5% level ** Significant at 1% level *** Significant at 0.1% level content, Jayasilet × Swarna-Sub1 for kernel breadth, Seetabhog × IR 64 for amylose content and Zn content, Taraori Basmati × IR 64 for gel consistency, hulling percentage, Fe content and yield plant^{-1}, Taraori Basmati × Pankaj for milling percentage, head rice recovery, and yield plant^{-1}, Badshahbhog×Satabdi for hulling percentage, milling percentage, head rice recovery, Kataribhog × Satabdi for Fe content and Zn content. These hybrids would proved to be useful for development of early, high yielding and quality enriched lines by selecting early recombinant from those crosses and intermating of elite lines.

CONCLUSION

On the basis of combining ability studies for quality traits using line x tester analysis it was found that both additive and non additive gene actions played important roles in governing inheritance of most of the traits. Both the laboratory and field experiments had cumulative influences on studies related to genetic control of quality characters. Results derived from this study would be highly grateful in rice breeding program and may be used for further crop improvement by selecting early desirable recombinants which could be further enriched for micronutrients like Fe and Zn.

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