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Research Article

Heterosis and combining ability analysis for grain quality and physico-chemical traits involving fertility restorers with basmati background in Rice (*Oryza sativa L.)*

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Abstract
A study was undertaken to explore possibility of developing hybrids and analyze them for heterosis and combining ability for basmati grain and physico-chemical attributes. Initially 45 improved germplasm lines of aromatic and non-aromatic genotypes were test crossed with four cytoplasmic male sterile (CMS) lines viz; IR 58025A, IR62829A, PMS10A and PMS 3A of wild abortive cytosterile source to identify basmati pollen parents restoring fertility. Ninteen pollen restorers of basmati background were identified and crossed with 4 CMS lines in line x tester design and analysed for heterosis and combining ability. Observations were recorded for grain quality characteristics viz; hulling percentage, milling percentage and head rice recovery per cent and physico-chemical traits viz; aroma, grain length and breadth before and after cooking, grain length and breadth ratio, kernel elongation ratio, water uptake ratio, volume expansion ratio and gelatinization temperature. Analysis of variance indicated significant difference ($p<0.05$) among genotypes exhibiting wealth of variability. No heterosis for hulling and milling percentage, kernel length and length breadth ratio was observed. Hybrids were characterized as intermediate between the parents for grain quality and physico-chemical traits. Therefore both the parents need to possess aroma, long slender grains with intermediate gelatinization temperature (GT) to develop aromatic, long grain basmati hybrids. The restorers Basmati 385 was characterized as good general combiner for all grain quality and physico-chemical traits while Karnal Local for grain quality and HKR 241 for physico-chemical attributes. These restorers in combination with basmati CMS lines could be utilized for developing basmati hybrids. Heterotic hybrids for grain yield IR 58025A x Basmati 385 and IR 58025A x Karnal Local with significant SCA effects were identified as specific combinations for grain quality and physico-chemical traits, respectively.

Key words
Rice, basmati hybrids, grain quality, heterosis , combining ability

Introduction:

Quality of rice is quite complex. It is determined by indices of market, milling, cooking, eating and nutritional quality characteristics. Market value is determined largely by grain appearances and colour, while percentage of hulling, milling and head rice recovery are the principal indices from traders' point of view. Physico-chemical properties of starch like amylose content, water absorption, volume expansion, alkali spreading score as a measure of gelatinization temperature and gel consistency, etc., constitute the cooking-eating qualities. Considerable research work has been done to understand the chemistry, genetics and breeding behaviour of various quality features of rice varieties. Such a study, however is scanty in respect of basmati hybrids. Indian Agricultural Research Institute, New Delhi for the first time developed and released basmati rice hybrid Pusa RH 10 in 2001. Cultivation of this hybrid in about 7.0 lakh hectare led to an overall increase in hybrid rice area to nearly 2.0 million hectares (Anonymous, 2010). Hybrid rice technology thus is likely to play a major role in increasing rice production. The government of India has set a target of expanding the cultivation of hybrid rice to 25 % of the area occupied by the crop by 2015 thereby contributing significantly towards national food security (Spielman el at, 2013). With the identification and availability of fertility restorers and sterility maintainers possessing basmati characteristics (Sarial et. al. 1994, Sarial and Singh, 2000) development of basmati rice hybrids has been a reality. This paper focuses on basmati restorer parents for heterosis and combing ability for grain and physico-chemical quality attributes.

Material and methods

Initially.four CMS lines viz., IR 58025A, IR 62829A, PMS 10A and PMS 3A and 45 improved basmati germplasm developed at IARI, New Delhi and non-aromatic disease resistant collections from the Rice Research Station CCS, Haryana Agricultural University, Kaul were used to screen pollen parents for fertility restoration. The pollen parents were screened for pollen fertility restoration following procedure of Sarial and Singh (2000). Based on pollen fertility 19 restorers (11 basmati and 8 non-basmati type) were selected and crossed with 4 CMS lines in line x tester design. Seventy six hybrids, their parents and three checks viz., Pusa 169, Pusa 44-33 and PR-110, representing medium-early, medium and late growth duration were grown in 2.0 x 0. 20 x 0. 15 m^2 plot size with two replications in RBD at

IARI New Delhi. Nursery raising and transplanting was carried out like as reported in Sarial and Singh (2000). Hybrids and checks were grown together followed by parents in contiguous plots in a RBD randomizing hybrids and parents separately. At maturity hybrids were evaluated for spikelet fertility restoration and pollen parents were categorised as effective restorers and partial restorers based on criteria as cited by Sarial and Singh, (2000).

Data were recorded for grain quality and physico-chemical attributes viz; hulling (%) milling (%), head rice recovery (%), presence of aroma, water uptake ratio(WUR), volume expansion ratio (VER), kernel length (KL) and breadth (KB) before and after cooking, kernel length and breadth ratio (KL/B) and gelatinization temperature (GT) as a measure of alkali spreading score. For physico-chemical traits observations on 11 pollen parents of basmati origin and their hybrids were recorded except aroma which was recorded for all 19 restorers and their hybrids. Presence of aroma was evaluated by the method suggested by Sood and Siddiq (1978). Alkali spreading score (GT) was recorded on a 7 point numerical scale proposed by Jenning *et al.* (1979). Remaining traits were recorded as per standard method. The magnitude of heterosis was calculated over mid parent (Ha), better parent (Hb) and superiority over check variety (Sc). The combining ability analysis and general (GCA) and specific (SCA) effects were estimated following Line x Tester (L x T) design proposed by Kempthorne (1957).

Results and discussion

The analysis of variance revealed significant ($p<0.01$) differences among parents and hybrids for all traits studied except water uptake (hybrids non-significant), hulling and milling percentage (parents non-significant). Partitioning of parents mean sum of squares indicated that females were significant for all physico-chemical traits except water uptake. Variances due to males differed significantly for head rice recovery percentage, all physico-chemical traits except volume expansion. The comparison of females vs males revealed that they differed significantly for hulling percentage, milling percentage, kernel length, breadth and their ratio and volume expansion. Parents vs hybrids mean sum of squares was significant for milling percentage, head rice recovery percentage, kernel length, kernel length breadth ratio and volume expansion.

Mean performance of hybrids in comparison to parents: Out of total 76 hybrids, mean performance of 20 hybrids and their 5 basmati restorers parents and 4 non-basmati CMS lines are given in Table 1.

Grain quality traits: Hybrids were higher in range than parents for all traits. However, majority of the hybrids fall within the parental range, for hulling percentage (50%), milling percentage (55%), head rice recovery percentage (95%), kernel length (90%), kernel breadth (80%), kernel length/breadth ratio (95%), water uptake (85%), volume expansion (75%) and alkali spreading score (75%). Hybrids of restorers Basmati 385 and Karnal Local with all CMS lines exhibited higher hulling, milling and head rice recovery percentage while those of P 1031-8-5-1-1 for head rice recovery showed consistent higher percentage. In case of aroma all the hybrids of line IR 58025A and aromatic restorers possessed strong aroma, while all hybrids involving aromatic testers and non-aromatic lines emitted moderate to mild aroma. The findings are in conformity to those of Khush *et al.* (1988) who reported that in crosses between an aromatic male sterile line and non-aromatic testers the bulk grain sample had moderately weak to slightly strong aroma. Among parents 9 out of 23 and among hybrids 44 out of 76 had strong to moderate aroma while remaining non-aromatic. Hybrids possessing strong aroma were IR 58025A x Basmati 385, IR 58025A x Karnal Local and IR 58025A x HKR 241.These hybrids also had significant heterobeltiosis ranged from 59.61 to 150.66 % and superiority over check 76.64 to 284.55 % for grain yield per plant (Sarial, 1995). Aroma is single recessive gene inherited trait and hence to develop heterotic aromatic basmati hybrids both the parents need to be aromatic.

Physico-chemical traits: For kernel length, breadth, L/B ratio, water uptake and volume expansion parental mean were higher than hybrids. More than 75% of the hybrids for all the characteristics studied were within the parental range. HKR 241 and Basmati 385 restorers hybrids have intermediate (3-5) alkali spreading score, high volume expansion (>3.0) and water uptake (>2.0) with all CMS lines except IR 62829A. HKR 241 produced hybrids involving CMS lines IR 58025A, PMS 10A and PMS 3A with desirable kernel dimensions qualifying as basmati type *i.e.*, kernel length >6.5mm, breadth <1.75mm kernel l/b ratio > 3.50. Hybrids of Basmati 385 with IR58025A and P1031-8-5-1-1 with PMS 10A were also found to possess desirable basmati type grains.

Heterosis: Heterosis, heterobeltiosis and superiority over check in per cent of 20 hybrids involving basmati restorers for different traits are given in table 2.

Grain quality traits: Of the 76 hybrids studied none recorded significant heterosis over mid and better parent for hulling percentage, milling percentage and only 2 had significant mid parental heterosis for head rice recovery percentage. The range of significant superiority over check varied from 5.61 to 10.83 % observed for 29 hybrids for hulling percentage and 6.63 to 9.98% among 10 hybrids for milling percentage. These findings are in conformity with those of Gravois (1994) who in a diallel analysis of head rice percentage and total milled rice percentage observed no heterosis. Hybrid PMS 3A x P1031-8-5-1-1 and PMS 3A x HKR 241 among 15 significant crosses showed positive heterosis for head rice recovery percentage. Hybrid IR 58025A x Karnal Local had the highest superiority for hulling percentage over check followed by PMS3A x Basmati 385. For milling percentage hybrids of Basmati 385 and Karnal Local recorded significant superiority over standard check.

Hulling, milling and head rice recovery are inherent varietal characteristics. Unless hybrids have milling quality equal to or higher than either parent, the full advantage of their high yielding ability cannot be realized. Head rice recovery is an important character from miller point of view. If a hybrid has a higher broken grain percentage its marketability will be reduced. High head rice recovery is also associated with hardness, absence of chalkiness and grain size and shape (Khush *et al.* 1988). Rutger and Shinjyo, (1980) reported low milling recovery as the most significant deficiency of rice hybrids introduced in China and USA. They attributed this deficiency to cytoplasmic male sterility (CMS) lines.

Physico-chemical traits: None of the hybrids recorded significant heterobeltiosis for kernel length, kernel length/breadth ratio, water uptake and volume expansion while 12 showed significant heterobeltiosis for kernel breadth . This is in agreement with Khush *et al.* (1988) and Viraktamath (1987) who reported that length and shape of grains borne on F_1 plants were in between the respective parents. Negative heterosis for kernel length and positive for kernel breadth was also observed by Sahai *et al.* (1986). In general, the length and shape of F_1 grains are between those of parents and the grains borne on F_1 plants did not exceed the long slender parent. Therefore, to develop medium grain hybrids, parents having long and short grains may be used. To produce long grain basmati hybrids, both parents should possess long slender grains. Three hybrids exhibited mid parental heterosis for kernel length. Significant superiority over check was observed for 10 hybrids for kerenl length, 25 for kerenel breadth, 22 for length/ breadth ratio and 3 for water uptake. Sahai *et al.* (1986) have also observed negative heterosis for water uptake in the hybrids involving CMS lines as female parents. On the contrary, Zaman (1981) reported significant heterosis for water uptake in a set of 15 hybrids. Heterosis for water uptake upto a limit that does not make the cooked rice too sticky is desirable. In case of volume expansion predominantly negative heterosis was reported by Virkathmath (1987). However, high magnitude of positive heterosis was observed by Sahai *et al.* (1986). High volume expansion is generally associated with high amylose but Sood and Siddiq (1980) demonstrated that some of the low and intermediate amylose types also have high volume expansion comparable to those of high amylose rices. As sterility inducing cytoplasm and maternal nuclear components affects several other characteristics it would be worth while to make in depth study of their influence on water uptake and volume expansion. Hybrids with higher superiority over check were PMS 10A x P1031-8-5-1-1, IR 58025A x HKR 241, IR 58025A x Basmati 385 for kerenl length; IR58025A x Karnal Local and IR58025A x SAF Khalsa 7 for kernel breadth; PMS 3A x HKR 241, PMS 10A x HKR 241 and IR58025A x Basamati 385 for kernel length / breadth ratio ; IR58025A x HKR 241 for water uptake and PMS 10A x Basmati 385 for volume expansion.

Alkali spreading score as a measure of GT revealed that of the 44 hybrids, 14 had medium, 5 low and remaining had high gelatinization temperature. In general, crosses involving HKR 241 and Basmati 385 as male parent and IR 58025A, PMS 10A , PMS 3A as female parent exhibited medium alkali spreading score. Gelatinization temperature, a physical property of starch is the range of temperature within which the starch granules start swelling irreversibly in hot water. Rices with high GT take longer time to cook and expand very little (Juliano *et al.*, 1965). From consumers' point of view rices with intermediate GT are preferred. In general, crosses involving restorers Basmati 385, HKR 241 and CMS lines IR 58025A, PMS 10A and PMS 3A as one of the parent had medium alkali spreading score hence, medium GT. Thus, in hybrid breeding programme select parents with intermediate GT to have intermediate basmati rice hybrids.

Combining ability analysis: Analysis of variance for combining ability revealed significant ($p<0.05$) variance due to lines for head rice percentage, kernel breadth, kernel L/B ratio, volume expansion . The variance due to testers was significant for all grain quality and physico-chemical traits . The L x T component of variance was significant for milling percentage and volume expansion for all other characteristics except water uptake indicating that lines interacted considerably with the testers. However, relatively small magnitude of variances due to L x T interactions as compared to that of lines and testers indicated that both additive and non-additive gene effects contributed to the hybrids. The estimates of variances due to GCA (σ^{-2} GCA) and SCA (σ^{-2} SCA) indicated the predominance of SCA variances for all traits studied except kernel breadth, kernel L/B ratio which was further corroborated with average degree of dominance ≥ 1.00. Similar findings were made for milled rice (Ajmer *et al.,* 1990). The preponderance of additive gene action has also been observed for grain length and L/B ratio by Mahapatra and Mohant (1986) and for head rice recovery percentage by Gravois (1994). Presence of aroma and GT being qualitative were not subjected to combining ability analysis.

General combining ability effects of parents: With increasing interest in the exploitation of heterosis in rice, there is a need to subject various CMS lines and restorers to combining ability test, so as to identify the most potential parents to develop heterotic hybrids. Even though, there are many studies conducted on combining ability in rice following diallel and L x T analysis, the studies pertaining to crosses involving CMS lines and restorers are very limited (Virkathmath, 1987) . Most of the studies reported earlier pertained to traditional varieties as parents. This study report on combining ability of the restorers with basmati background (Sarial *et al.,* 1994; Sarial, 1995). GCA and SCA effects of 4 CMS lines and 5 basmati restorers an their 20 hybrids are presented in Table 3.

Grain quality traits: Basmati 385 and Karnal Local had significant positive GCA effects for hulling and milling and found to be good combiners for these traits while average combiners for head rice recovery. Among CMS lines, PMS 3A with significant positive GCA was found to begood general combiners for three grain quality traits.

Physico-chemical traits: Restorer HKR 241 had significant positive GCA for kernel length, length/ breadth ratio and volume expansion and hence identified as good combiner for these traits. While Basmati 385 and Karnal Local for length/breadth ratio and P1031-8-5-1-1 for kernel length and kernel breadth found to be good combiners. Among CMS lines, IR 58025A exhibited significant positive GCA for kernel length and volume expansion and PMS 10A for kernel length/breadth ratio. Hence IR58025 A and PMS 10A were ranked as good general combiners for these traits, respectively.

Specific combining ability effects: Among 11 significant crosses, a hybrid involving basmati restorer viz; IR 62829A x HKR 241 had positive SCA for hulling ; out of 9, two viz; IR62829A x p1031-8-5-1-1 and IR 58025A x Karnal Local for milling percentage and among 14, three viz; PMS 3A x P1031-8-5-1-1, PMS 3A x HKR 241 and IR 62829A x Karnal Local showed positive SCA for head rice recovery percentage.

Physico-chemical traits: Out of 10 hybrids with significant SCA effects, cross combinations involving basmati restorer viz; PMS 10A x P1031-8-5-1-1 and IR 58025A x Basmati 385 showed positive effects for kernel length; PMS 3A x P1031-8-5-1-1 for kernel breadth, PMS 10A x P1031-8-5-1-1, IR 58025A x Basmati 385, PMS 3A x HKR 241 and PMS 10A x HKR 241 for kernel length/ breadth ratio; PMS 10A x Basmati 385 for water uptake and PMS 3A x Karnal Local for volume expansion.

To conclude, the restorers Basmati 385 was characterized as good general combiner for all grain quality and physico-chemical traits while Karnal Local for grain quality and HKR 241 for physico-chemical attributes. These restorers in combination with basmati CMS lines could be utilized for developing basmati hybrids. In addition yield heterotic hybrids IR 58025A x Basmati 385 and IR 58025A x Karnal Local with significant SCA effects were identified as specific combinations for grain quality and physico-chemical traits, respectively and were recommended for further large scale testing and evaluation over locations and years for release for cultivation.

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Table 1. Mean performance of hybrids and parents for different grain quality traits.

Sl No.	*Hybrids / Parents*	*Hulling (%)*	*Milling (%)*	*HRR (%)*	*Aroma*	*KL (mm)*	*KB (mm)*	*KL/B (ratio)*	*WU (ratio)*	*VE (ratio)*	*ASS*
1.	IR58025A/P1031-8-5-1-1	71.00	61.50	50.00	1.50	6.10	1.85	3.30	1.90	2.57	2.0
2.	IR 62829A/ "	76.75	67.55	54.20	1.50	6.20	2.00	3.10	2.02	2.57	2.0
3.	PMS 10A / "	74.15	67.15	53.75	1.00	7.20	1.80	3.94	2.10	2.57	2.0
4.	PMS 3A / "	76.60	69.75	64.25	2.00	5.60	2.00	2.80	2.00	2.45	4.0
5.	IR 58025A / HKR 241	74.30	65.30	49.00	1.00	6.80	1.80	3.78	2.32	3.29	5.5
6.	IR 62829A / "	77.45	67.85	43.85	1.50	5.80	1.90	3.05	2.26	2.75	2.0
7.	PMS 10A / "	68.40	61.20	46.00	2.00	6.80	1.70	4.00	2.19	3.28	5.3
8.	PMS 3A / "	76.15	69.00	61.80	2.00	6.70	1.70	3.94	2.31	3.17	3.5
9.	IR58025A/ Basmati 385	80.30	71.10	54.65	1.00	6.70	1.70	3.94	2.20	3.17	4.5
10.	IR 62829A / "	81.80	71.80	58.70	1.50	5.70	1.85	3.08	2.12	2.57	2.0
11.	PMS 10A / "	82.30	72.70	58.25	1.50	6.00	1.70	3.53	2.07	3.53	3.0
12.	PMS 3A / "	82.50	72.40	54.10	1.50	6.05	1.70	3.56	2.28	2.60	3.0
13.	IR58025A/SAFKhalsa 7	80.10	69.75	43.70	1.00	5.85	1.65	3.55	2.16	3.12	3.5
14.	IR 62829A/ "	79.10	67.95	47.25	1.50	5.75	1.75	3.28	2.12	2.13	1.0
15.	PMS 10A / "	80.40	67.60	34.90	1.00	5.80	1.70	3.50	2.23	1.99	7.0
16.	PMS 3A / "	80.65	71.00	49.70	1.50	6.05	1.70	3.56	2.03	2.40	6.5
17	IR58025A/Karnal Local	82.40	74.40	54.90	1.00	5.85	1.65	3.70	1.98	2.13	3.5
18.	IR 62829A / "	80.25	73.05	60.35	1.50	5.75	1.75	3.47	1.72	1.90	1.0
19.	PMS 10A / "	79.65	70.20	55.05	1.50	5.80	1.70	3.50	1.75	1.89	1.0
20.	PMS 3A / "	79.95	71.55	49.30	1.50	6.05	1.70	3.59	2.20	3.64	7.0
21.	P1031-8-5-1-1	79.60	72.00	48.20	1.00	8.20	1.75	4.69	2.20	3.53	5.0
22.	HKR 241	80.00	70.30	38.30	1.00	7.30	1.70	4.30	2.36	3.57	4.0
23.	Bas 385	78.45	69.30	51.00	1.00	6.55	1.70	3.85	2.77	4.00	4.0
24.	SAF Khalsa 7	80.90	71.10	43.25	1.00	6.85	1.75	3.91	2.04	4.00	4.0
25.	Karnal Local	77.10	68.50	53.90	1.00	6.85	1.75	4.10	2.11	4.00	4.0
26.	IR 58025A	82.00	73.40	56.50	1.50	6.50	1.70	3.84	1.98	3.00	6.0
27.	IR 62829A	80.20	71.80	61.25	3.00	5.75	1.90	3.04	2.20	2.25	6.0
28.	PMS 10A	80.50	72.45	62.40	3.00	6.00	1.75	3.43	2.11	2.80	2.0
29.	PMS 3A	80.40	71.65	62.25	3.00	5.80	1.75	3.32	1.98	3.04	2.0
30.	PUSA 169	76.70	68.55	57.20	2.50	6.30	2.00	3.15	1.72	2.95	6.0
31.	PR 110	75.50	67.10	60.30	3.00	6.00	1.90	3.16	1.80	2.68	6.0
32.	PUSA 44-33	74.35	67.65	61.80	2.00	6.00	2.00	3.00	1.95	3.06	6.0

HRR = Head rice recovery; KL = Kernel length; LB = Kernel breadth; L/B = Length breadth ratio; WA = Water uptake; VE = Volume expansion and ASS = Alkali spreading score.

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Table 2. Heterosis (upper) Heterobeltiosis (middle), superiority over check (lower) in % of hybrids for different grain quality traits

Sl. No.	*Hybrids*	*Hulling (%)*	*Milling (%)*	*HRR (%)*	*KL (mm)*	*KB (mm)*	*KL/B (ratio)*	*WU (ratio)*	*VE (ratio)*
1.	IR58025A / P1031-8-5-1-1	-12.13**	-15.41**	-4.49	-17.01**	7.25*	-22.70**	-8.98	-21.29
		-13.41**	-16.21**	-11.50	-25.61**	5.71	-29.74**	-13.44	-27.20*
		-7.43**	-10.28**	-12.59	-3.17	-7.50*	4.76	10.47	-12.88
2.	IR 62829A / "	-3.94	-6.05*	-0.96	-11.11**	9.59**	-19.74**	-8.20	-3.66
		-4.30	6.18	-11.51	-24.39**	5.26	-33.90**	-8.20	-27.20*
		-0.06	-1.46	-5.24	-1.59	0.00	-1.59	17.44	-12.88
3.	PMS 10A / "	-7.37**	-7.03*	2.80	0.00	2.86	-2.96	-2.67	-18.74
		-7.89**	-7.32	-13.86	-13.41**	2.86	-15.99**	-4.56	-27.20
		-1.79	0.07	-10.86	18.33**	-5.26	24.68**	16.67	-4.10
4.	PMS 3A / "	-4.24	-2.89	16.34*	-20.00	14.29**	-30.09**	-4.08	-25.42*
		-4.73	-3.12	3.21	-31.71**	14.29**	-40.30**	-8.88	-30.59*
		-0.13	1.75	12.32	-11.11**	0.00	-11.11*	16.28	-16.95
5.	IR 58025A / HKR 241	-8.27**	-9.12**	3.38	-1.45	5.88	-7.01	6.81	0.23
		-9.39**	-11.04**-	-13.27	-6.85*	5.88	-11.99**	-1.70	-7.71
		-1.59	-2.68	-18.74**	13.33**	-5.26	19.62**	28.89*	22.76
6.	IR 62829A / "	-3.31	-4.50	-11.90	-11.11**	5.56	-16.78**	-0.44	2.42
		-3.43	-5.50	-28.41**	-20.55**	0.00	-28.99**	-3.82	-22.86
		2.58	1.12	-27.28**	-3.33	0.00	-3.48	25.56	2.61
7.	PMS 10A / "	-14.77**	-14.26**	-8.64	2.26	-1.45	3.56	-1.68	3.30
		-15.03**	-15.53**	-26.28**	-6.85*	-2.86	-6.87	-6.79	-7.85
		-9.40**	-8.79*	-23.71**	13.33**	-10.53**	26.58**	21.67	22.39
8.	PMS 3A / "	-5.05*	2.78	22.92**	2.29	-1.45	3.48	6.70	-4.01
		-5.29*	-3.70	-0.72	-8.22*	-2.86	-8.27*	-1.91	-11.08
		2.42	1.99	0.00	11.67**	-15.00**	31.33**	18.46	3.59
9.	IR 58025A / Basmati 385	0.09	-0.35	1.67	2.68	0.00	2.54	-7.37	-9.43
		-2.07	-3.13	-3.27	2.29	0.00	2.34	-20.58*	-20.75
		6.36**	5.96	-9.37	11.67**	-10.53**	24.68**	22.22	18.28
10	IR 62829A / "	3.12	1.77	-4.59	-7.32*	2.78	-10.53**	-14.80	-11.46
		2.00	0.00	-4.16	-12.98**	-2.63	-20.00**	-23.65*	-35.75**
		8.34**	7.00*	-2.65	-5.00	-2.63	-2.53	17.78	-4.10
11	PMS 10A / "	3.55	2.57	2.73	-4.38	-1.45	-3.02	-15.16	3.75
		2.24	0.35	-6.65	-8.40*	-2.86	-8.31	-25.27**	-11.87
		9.01**	8.34**	-3.39	0.00	-10.53**	11.71*	15.00	31.72

Table 2. Contd..

Sl. No.	Hybrids	Hulling (%)	Milling (%)	HRR (%)	KL (mm)	KB (mm)	KL/B (ratio)	WU (ratio)	VE (ratio)
12	PMS 3A / "	3.87	2.73	-4.46	-2.02	-1.45	-0.70	3.69	-26.14*
		2.61	1.05	-13.09	-7.63*	-2.86	-7.53	-17.51	-35.00**
		9.27**	7.89**	-10.28	0.83	-10.53**	12.66**	26.67	-2.99
13	IR58025A / SAFKhalsa 7	-1.66	-3.46	-12.38	-12.36**	-4.35	-8.33*	7.46	-11.00
		-2.32	-4.97	-22.65**	-14.60**	-5.71	-9.21*	5.88	-22.12
		7.73**	3.10	-29.29**	2.50	-17.50**	18.33**	10.77	1.96
14	IR 62829A / "	-1.80	-4.90	-9.57	-8.73**	-4.11	-5.40	-0.12	-26.61
		-2.22	-5.36	-22.86**	-16.06**	-7.89*	-15.98**	-3.64	-46.75**
		4.77	1.27	-21.64**	-4.17	-7.89*-	3.80	17.78	-20.52
15	PMS 10A / "	-0.37	-4.42	-33.93**	-9.73**	-2.86	-4.63	7.47	-41.28**
		-0.62	-5.31	-44.07**	-15.33**	-2.86	-10.49*	5.69	-50.13**
		8.14**	1.40	-43.53**	-3.33	-15.50**	16.67**	14.36	-34.97**
16	PMS 3A / "	0.00	0.46	-5.78	-4.35	-2.86	-1.52	1.37	-31.82
		-0.31	0.07	-20.16	-11.68**	-2.86	-8.95*	-0.25	-40.00**
		8.47**	5.10	-19.58**	0.83	-15.00**	18.67**	4.10	-21.57
17	IR 58025A / Karnal Local	3.58	4.86	-0.54	-7.92**	-1.49	-6.68	-3.42	-39.14**
		0.49	1.36	-2.83	-9.63**	-2.94	-9.65*	-6.40	-46.75**
		10.83**	9.98**	-11.16	1.67	-17.50**	23.33**	1.54	-30.39*
18	IR 62829AA / "	2.03	4.13	6.56	-3.20	-1.41	-2.81	-20.09	-34.54*
		0.06	1.74	0.16	-10.37**	-7.89*	-15.38**	-21.64	-52.50**
		7.93**	7.98**	-0.73	0.83	-12.50**	15.67**	-4.44	-37.91**
19	PMS 10A / "	1.08	-0.39	-5.33	-6.67*	0.00	-6.98	-17.30	-44.37
		-1.06	-3.11	-11.78	-11.85**	-2.86	-14.53**	-17.30	-52.75**
		7.13**	3.77	-10.92	-0.83	-15.00**	16.67**	-10.26	-38.24**
20	PMS 3A / "	1.52	2.10	-15.11*	-2.79	0.00	-3.17	7.96	3.55
		-0.56	-0.14	-20.80**	-9.63**	-2.86	-12.33**	4.50	-8.88
		7.53**	5.71	-20.23**	1.67	-15.00**	19.67**	12.82	18.95
	S.E. (Ha)	+/-1.83	+/-1.95	+/-4.15	+/-0.18	+/-0.055	+/-0.146	+/-0.22	+/-0.40
	S.E. (Hb/Sc)	+/-2.11	+/-2.25	+/-4.79	+/-0.21	+/-0.064	+/-0.168	+/-0.25	+/-0.45

*, ** Significant at 5% and 1% level, respectively.
RR =Head rice recovery; KL= Kernel length; LB = Kernel breadth; L/B = Length breadth ratio; WA = Water uptake; VE = Volume expansion .

Table 3. Estimates of combining ability effects (SCA) of crosses and (GCA) parents for different grain quality traits

Sl No.	*Hybrids / Parents*	*Hulling (%)*	*Milling (%)*	*HRR (%)*	*KL (mm)*	*KB (mm)*	*KL/B (ratio)*	*WU (ratio)*	*VE (ratio)*
1.	IR58025A / P1031-8-5-1-1	-0.20*	-3.26**	-2.66	-0.26*	-0.03	-0.12	-0.13	-0.22
2.	IR 62829A/ "	0.13	2.09**	-0.07	0.12	0.04	0.01	0.02	0.29
3.	PMS 10A / "	0.00	0.19	-3.02	0.77**	-0.09**	0.57**	0.112	0.05
4.	PMS 3A / "	0.07	0.98	5.75*	-0.63**	0.08*	-0.46**	-0.02	-0.13
5.	IR 58025A / HKR 241	0.02	-0.10	1.73	0.16	0.06	-0.05	0.02	-0.08
6.	IR 62829A / "	0.21**	1.16	-5.03	-0.56**	0.08*	-0.45**	0.00	-0.11
7.	PMS 10A / "	-0.31**	-2.43**	-5.38*	0.19	-0.05	0.22**	-0.05	0.19
8.	PMS 3A / "	0.08	1.37	8.69*	0.20	-0.09**	0.27**	0.02	0.01
9.	IR58025A/ Basmati 385	-0.07	-0.31	1.12	0.47**	0.00	0.28	0.01	-0.04
10.	IR 62829A / "	0.01	-0.16	3.55	-0.24*	0.07*	-0.25**	0.04	-0.14
11.	PMS 10A / "	0.06	0.74	0.60	-0.19	-0.02	-0.08	-0.07	-0.25
12.	PMS 3A / "	0.00	-0.28	-5.28	-0.04	-0.05	0.06	0.10	0.09
13.	IR58025A/SAFKhalsa 7	0.01	0.40	2.71	-0.13	-0.02	-0.06	0.00	0.46*
14.	IR 62829A/ "	-0.05	-1.01	4.64	0.06	0.01	0.01	-0.01	-0.02
15.	PMS 10A / "	0.05	-0.25	-10.21*	-0.14	0.02	-0.06	0.12	-0.39
16.	PMS 3A / "	-0.01	0.86	2.86	0.21	-0.01	0.11	-0.11	-0.05
17	IR58025A/Karnal Local	0.10	1.64*	2.64	-0.06	-0.02	0.00	0.04	-0.51*
18.	IR 62829A / "	-0.01	0.42	7.48**	0.17	0.01	0.10	-0.18	-0.23
19.	PMS 10A / "	-0.02	-1.03	-1.32	-0.18	0.02	-0.15	-0.14	-0.48*
20.	PMS 3A / "	-0.08	-1.02	-8.80*	0.07	-0.01	0.05	0.28*	1.22**
21.	P1031-8-5-1-1	-0.21**	-1.24**	-0.23	0.15*	0.10**	-0.10	-0.05	-0.22
22.	HKR 241	-0.25**	-2.12**	-5.62**	0.43**	-0.04*	0.30**	0.02	0.36**
23.	Bas 385	0.19**	1.68**	0.64	0.02	-0.08**	0.14*	0.12	0.20
24.	SAF Khalsa 7	0.10	0.09	-17.89**	-0.23**	-0.13**	0.09	0.09	-0.35**
25.	Karnal Local	0.13**	1.87**	-0.63	-0.05	-0.12**	0.18**	-0.14*	-0.37**
26.	IR 58025A	-0.01	-0.26	-2.89**	0.11**	-0.03**	-0.13**	0.02	0.25**
27.	IR 62829A	-0.01	0.05	-1.28*	-0.17**	0.04**	-0.19**	-0.01	-0.26**
28.	PMS 10A	-0.03	-0.32	1.22	0.08	-0.02*	0.09**	-0.03	-0.02
29.	PMS 3A	0.04*	0.53*	2.95**	-0.02	0.01	-0.03**	0.01	0.04
	SE (s_{ij})	+/-0.068	+/-0.77	+/-2.70	+/-0.105	+/-0.030	+/-0.086	+/-0.117	+/-0.20
	SE $(g_i)_L$	+/-0.02	+/-0.18	+/-0.64	+/-0.033	+/-0.008	+/-0.027	+/-0.037	+/-0.063
	SE $(g_i)_T$	+/-0.04	+/-0.44	+/-1.56	+/-0.60	+/-0.016	+/-0.05	+/-0.166	+/-0.116

*, ** Significant at 5% and 1% level, respectively.

HRR = Head rice recovery; KL = Kernel length; LB = Kernel breadth; L/B = Length breadth ratio; WA = Water uptake; VE = Volume expansion .