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Genetic Analysis of Grain Yield and Quality Traits Regarding Heterosis in Rice (*Oryza sativa* L.)

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Abstract The present experiment was carried out to study the heterosis for grain yield and quality traits involving 10 parents and their 45 F_1s excluding reciprocals during 2012-13 and 2013-14. The cross (Vallabh Basmati 21 × CSR 13) exhibited highest significant heterosis over better parent (24.22**), standard parent (10.24**) and mid parent (5.41**) for grain yield whereas the cross (Vallabh Basmati 21 × CSR 30) showed significant heterosis over standard check for grain yield, kernel breath, kernel length, L/B ratio and hulling percent. These crosses could be exploited for getting desirable recombinants from the segregating populations. Inclusion of lines with good combining ability in a national hybrid rice program may offer genetic improvements in breeding for higher yield and some other quality traits in rice.

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Introduction

Rice (*Oryza sativa* L.) is an important staple food for two-third of the Indian population whereas about half of the world's population depends on rice for their survival. Rice is being cultivated in about 155 m ha globally over a wide range of agro-ecological conditions with varying temperature, water regime and soil texture. With the ever increasing population, rice production must be increased by about 40% by 2025 to satisfy the growing demand without adversely affecting the resource base (Khush 2004). This objective may be achieved by using heterosis breeding. Venkanna et al. (2014) also reported that heterosis breeding is an important tool which can enhance the yield and also enrich some other desirable quantitative traits in rice. The magnitude and direction of heterosis provides a basis for determining genetic diversity and also helps in the selection of desirable parents. Market value is determined largely by grain appearances and color, while percentage of hulling, milling and head rice recovery are the principal indices from traders' point of view. Therefore grain shape and size, milling and cooking characters are important criteria of rice quality that breeder consider in developing new varieties of rice. For the acceptance of rice variety both by farmers and traders, it should possess, not only high yield but also good acceptable quality. The main objective of present investigation is to identifying the best heterotic cross for yield and quality traits and also known about the type of gene action responsible for controlling these traits.

Materials and Methods

The experimental material consisted of ten diverse genotypes (Vallabh Basmati 21, Vallabh Basmati 22, MAUB 57, Pusa 1121, CSR 30, Pusa Basmati 1, Basmati 370, Pusa 1401, CSR 13 and CSR 10) were sown during *rabi* 2012-2013 for attempting crossing program in a 10 × 10 diallel fashion excluding reciprocals. In the next crop season (*rabi* 2013-2014), experimental material consisted 55 genotypes (10 parents and 45 F_1s) was sown in a randomized block design with three replications. Observations were recorded on five randomly selected plants from each genotype (Parents and F_1s) in each replication for grain yield per plant (g), kernel length (mm), kernel breadth (mm), L/B ratio, kernel length after cooking (mm), elongation ratio, amylose content (%) and hulling per cent. Heterosis was estimated over mid parent, better parent and standard parent and tested for significance as suggested by Snedecor and Cochran (1967). The mean values of parents and F_1s cross combinations were used for the estimation of heterosis for the traits under study. The magnitude of heterosis was estimated by commonly used statistical software (INDOSTAT 7.5). The percent increase or decrease of F_1 hybrids over parent was calculated by using the formulae of Fonseca and Patterson (1968).

$$\text{Heterosis (\%)} = \frac{F_1 \text{ mean value} - \text{Parental mean value}}{\text{Parental mean value}} \times 100;$$

F_1 mean = Mean value of F_1 hybrid, Parental mean =Mean value of parent.

Results and Discussion

The analysis of variance was highly significant among the treatments, parents and crosses for grain yield, kernel length, kernel breadth, L/B ratio, kernel length after cooking, elongation ratio, amylose content and hulling per cent. This indicated that considerable amount of variability is present among the parents and their F_1s derived by all possible single cross combination. The understanding of variability and genetic architecture of population is essential for the implementation of suitable breeding method. The general mean of F_1s crosses were greater than their corresponding parents for all the characters except L/B ratio and hulling %. The range of variability among material gives high chance of selection for desirable types for different characters under study. The magnitude of heterosis is a prerequisite for development of any F_1s hybrid. Before selecting a cross on the basis of *per se* performance it would be worthwhile to evaluate them for hybrid vigor for various characters. Knowledge about magnitude and direction of heterosis would help in selecting the best crosses for commercial exploitation. Mean performance of parents and crosses are presented in Table 1 and magnitude and range of heterosis over better parent, standard parent and mid parent for all the 12 characters are presented in Table 2.

Vallabh Basmati 22 × CSR 10 and MAUB 57 ×

Table 1. The pedigree and origin of the parental lines are as follows.

Name of varieties	Parentage	Source/Origin
Vallabh Basmati-21	Khalasa-7/Type-3	SVPUA&T, MEERUT
MAUB-162 (Vallabh Basmati-22)	Pusa-1121 × Type-3	SVPUA&T, MEERUT
MAUB-57 (Vallabh Basmati-23)	Pusa-1121 × Type-3	SVPUA&T, MEERUT
Pusa-1121	Traditional Basmati	IARI New Delhi
CSR-30	BR4-10/Basmati 370	CSSRI-Karnal, Haryana
Pusa Basmati-1	Pusa-150/Karnal Local	IARI, New Delhi
Basmati-370	Traditional Basmati	Rice Research Station Kaul, Haryana
PUSA-1401	Pusa Basmati-1/Pusa 1121-92-8-2-7-1	IARI New Delhi
CSR-13	CSR-1/Basmati-370/CSR-5	CSSRI-Karnal, Haryana
CSR-10	M40-431-24-114/jaya	CSSRI-Karnal, Haryana

Table 2. Analysis of variance for grain yield and some quality traits of rice (*Oryza sativa* L.).

Characters	Replication (df=2)	Treatments (df=54)	Parents (df=9)	Hybrids (df=44)	Parents vs hybrids (df=1)	Error (df=108)	Total (df=164)
Kernel Length	0.014	0.671**	1.356**	0.546**	0.007	0.006	0.221
Kernel Breadth	0.009	0.006**	0.011**	0.005**	0.003	0.002	0.002
L/B Ratio	0.011	0.360**	0.728**	0.293**	0.006	0.004	0.119
Kernel Length After Cooking	0.018	3.653**	6.259**	3.199**	0.149**	0.021	1.217
Elongation Ratio	0.022	0.028**	0.041**	0.025**	0.005**	0.001	0.009
Amylose Content	0.261	3.073**	5.811**	2.398**	8.089**	0.359	1.252
Hulling %	0.041	4.774**	8.554**	4.086**	1.052**	0.061	1.613
Grain Yield	0.045	64.453**	118.646**	54.784**	2.115**	0.248	21.386

CSR 10 were the most promising cross combinations which showed highly significant negative heterobeltiosis whereas Vallabh Basmati 21 × CSR 10 showed highly significant negative heterosis over standard parent for days to 50% flowering (Table 3). However there is no any cross combination which showed negative significant heterosis over mid parent for this trait. Negative heterosis is useful and desirable for days to 50% flowering as it is essential for early maturity. The importance of negative heterosis for was also reported by Selvaraj et al. (2011), Utharasu and Anandakumar (2013), Patil and Mehta (2014), Yogameenakshi and Vivekanandan (2015), Balakrishna and Satyanarayana (2015), Bhatti et al. (2015). The parent CSR 10 involved in above cross combinations showed good *per se* performance for this trait.

CSR 30 × CSR 10 and MAUB 57 × CSR 10 were best heterotic crosses which showed highly significant negative heterobeltiosis whereas Basmati 370 × CSR 10 showed highly significant economic heterosis for days to maturity. Among the mentioned above cross combinations CSR 30 × CSR 10 and among the parents CSR 10 also showed better *per se* performance for days to maturity.

Table 3. *Per se* performance of 10 parents and 45 crosses for grain yield and quality traits in rice (*Oryza sativa* L.).

Parents	Kernel length	Elongation ratio	Amylose content	Hulling %	Kernel length after cooking	L/B ratio	Kernel breadth	Grain yield
Vallabh Basmati 21	7.76	1.57	21.67	76.89	12.24	4.35	1.78	34.79
Vallabh Basmati 22	7.54	1.53	21.33	79.11	11.58	4.37	1.72	25.44
MAUB 57	7.36	1.53	21.00	78.41	11.29	4.23	1.74	22.07
Pusa 1121	7.94	1.47	21.67	75.74	11.69	4.80	1.65	24.93
CSR 30	7.18	1.47	19.67	78.67	10.59	4.02	1.79	38.95
PUSA Basmati 1	6.97	1.76	22.67	76.55	12.33	3.94	1.75	33.66
Basmati 370	6.95	1.38	20.67	79.91	9.65	4.15	1.67	27.67
Pusa 1401	7.98	1.48	21.33	76.41	11.85	4.85	1.64	21.98
CSR 13	6.28	1.33	18.33	80.37	8.37	3.56	1.76	35.73
CSR 10	5.98	1.45	18.67	80.00	8.72	3.28	1.82	23.68
Crosses								
Vallabh Basmati 21 × MAUB 57	7.57	1.56	21.67	77.28	11.83	4.27	1.77	29.45
Vallabh Basmati 21 × Pusa 1121	7.84	1.64	22.67	75.74	12.86	4.55	1.72	32.42
Vallabh Basmati 21 × CSR 30	7.48	1.55	21.33	77.34	11.64	4.21	1.77	37.96

Table 3. Continued.

Parents	Kernel length	Elongation ratio	Amylose content	Hulling %	Kernel length after cooking	L/B ratio	Kernel breadth	Grain yield
Vallabh Basmati 21 × Pusa Basmati 1	7.37	1.72	22.67	76.45	12.71	4.17	1.76	35.40
Vallabh Basmati 21 × Basmati 370	7.36	1.45	21.67	78.23	10.72	4.26	1.73	32.00
Vallabh Basmati 21 × Pusa 1401	7.84	1.65	21.33	76.24	12.72	4.57	1.71	28.99
Vallabh Basmati 21 × CSR 13	6.98	1.50	20.00	78.35	10.50	3.92	1.78	37.17
Vallabh Basmati 21 × CSR 10	6.87	1.51	20.67	78.39	10.40	3.79	1.81	29.97
Vallabh Basmati 22 × MAUB 57	7.45	1.57	21.67	78.42	11.71	4.33	1.72	24.20
Vallabh Basmati 22 × Pusa 1121	7.75	1.52	22.00	77.37	11.79	4.60	1.68	25.00
Vallabh Basmati 22 × CSR 30	7.37	1.46	20.67	78.51	10.78	4.20	1.75	32.20
Vallabh Basmati 22 × Pusa Basmati 1	7.27	1.63	22.67	78.25	11.85	4.19	1.73	28.01
Vallabh Basmati 22 × Basmati 370	7.24	1.47	21.33	79.34	10.66	4.27	1.69	26.56
Vallabh Basmati 22 × Pusa 1401	7.79	1.51	21.67	77.56	11.78	4.63	1.68	23.66
Vallabh Basmati 22 × CSR 13	6.88	1.42	20.00	79.50	9.84	3.94	1.74	31.17
Vallabh Basmati 22 × CSR 10	6.76	1.61	20.67	79.55	10.86	3.80	1.78	24.43
MAUB 57 × Pusa 1121	7.66	1.53	21.67	76.49	11.74	4.51	1.70	23.94
MAUB 57 × CSR 30	7.27	1.47	20.67	78.34	10.78	4.08	1.77	30.87
MAUB 57 × Pusa Basmati 1	7.18	1.63	22.67	77.22	11.69	4.11	1.75	27.86
MAUB 57 × Basmati 370	7.14	1.52	21.33	78.52	10.86	4.18	1.71	24.72
MAUB 57 × Pusa 1401	7.67	1.52	22.00	77.30	11.74	4.54	1.69	21.96
MAUB 57 × CSR 13	6.79	1.44	20.00	79.32	9.84	3.88	1.75	29.67
MAUB 57 × CSR 10	6.67	1.45	20.67	79.22	9.69	3.73	1.78	22.66
Pusa 1121 × CSR 30	7.55	1.43	21.33	76.56	10.80	4.35	1.73	32.20
Pusa 1121 × Pusa Basmati 1	7.46	1.58	22.67	75.87	11.86	4.37	1.70	29.44
Pusa 1121 × Basmati 370	7.45	1.44	21.33	77.32	10.71	4.44	1.68	26.49
Pusa 1121 × Pusa 1401	7.95	1.51	22.00	75.61	11.73	4.79	1.66	23.38
Pusa 1121 × CSR 13	7.14	1.47	20.33	77.46	10.57	4.18	1.71	31.83
Pusa 1121 × CSR 10	6.95	1.53	21.33	79.47	10.65	3.97	1.75	24.44
CSR 30 × Pusa Basmati 1	7.07	1.58	21.67	77.37	11.18	3.97	1.78	36.39
CSR 30 × Basmati 370	7.06	1.37	20.33	78.82	9.74	4.04	1.75	33.43
CSR 30 × Pusa 1401	7.59	1.42	21.33	77.22	10.85	4.39	1.73	29.94
CSR 30 × CSR 13	6.75	1.45	19.67	79.13	9.81	3.78	1.78	37.28
CSR 30 × CSR 10	6.58	1.47	20.33	79.09	9.73	3.65	1.80	31.09
Pusa Basmati 1 × Basmati 370	6.97	1.53	22.33	78.17	10.71	4.06	1.71	30.24
Pusa Basmati 1 × Pusa 1401	7.48	1.57	22.67	76.40	11.77	4.42	1.69	28.51
Pusa Basmati 1 × CSR 13	6.67	1.57	21.33	78.25	10.53	3.79	1.75	35.92
Pusa Basmati 1 × CSR 10	6.49	1.67	21.67	78.25	10.87	3.63	1.78	28.73
Basmati 370 × Pusa 1401	7.48	1.43	21.33	78.01	10.76	4.52	1.65	24.93
Basmati 370 × CSR 13	6.61	1.29	20.00	79.87	8.61	3.85	1.71	31.61
Basmati 370 × CSR 10	6.47	1.36	20.67	79.84	8.83	3.70	1.74	25.89
Pusa 1401 × CSR 13	7.16	1.36	20.33	78.21	9.74	4.20	1.70	28.55
Pusa 1401 × CSR 10	6.98	1.53	21.33	78.17	10.72	4.03	1.73	22.99
CSR 13 × CSR 10	6.19	1.43	19.33	80.11	8.87	3.45	1.79	29.47
Grand mean	8.17	1.70	22.83	80.58	13.15	4.87	1.83	38.61

The best cross combinations which showed significant and negative heterosis over better parent were Basmati 370 × CSR 10, Basmati 370 × CSR 13, Basmati 370 × Pusa 1401 whereas crosses CSR 13 × CSR 10, Pusa 1401 × CSR 10 and MAUB 57 × CSR 10 showed significant negative economic heterosis for plant height. Similar findings on negative heterosis for plant height were also reported by Selvaraj et al. (2011), Utharasu and Anandakumar (2013), Patil and Mehta (2014), Yogameenakshi and Vivekanandan (2015), Balakrishna and Satyanarayana (2015), Bhatti et al. (2015). Negative heterosis for plant height is an important feature in rice breeding because short stature has ability to resistance against lodging and produce higher yield.

For grain yield nine crosses showed significant positive relative heterosis while fourteen crosses exhibited significant positive heterobeltiosis (Table 4). The best cross combinations which showed significant and positive heterosis over better parent were Vallabh Basmati 21 × CSR 13, CSR 30 × Pusa 1401,

Table 4. Average heterosis, heterobeltiosis and standard heterosis in 45 crosses for grain yield and quality traits in rice (*Oryza sativa* L.).

Crosses	Kernel length			Elongation ratio		
	MP	BP	SP	MP	BP	SP
Vallabh Basmati 21 × Vallabh Basmati 22	0.17	1.25	10.00**	7.96**	6.36**	-5.10**
Vallabh Basmati 21 × MAUB 57	0.11	2.49**	8.61**	0.32	-1.06	-11.72**
Vallabh Basmati 21 × Pusa 1121	-0.19	1.30	12.43**	7.68**	4.03**	-7.18**
Vallabh Basmati 21 × CSR 30	0.04	3.69**	7.27**	1.97	-1.48	-12.10**
Vallabh Basmati 21 × Pusa Basmati 1	0.12	-5.11	5.69**	3.10**	-2.46*	-2.46*
Vallabh Basmati 21 × Basmati 370	0.11	-5.15	5.64**	-1.69	-7.63**	-17.58**
Vallabh Basmati 21 × Pusa 1401	-0.36	1.71	12.53**	8.30**	5.08**	-6.24**
Vallabh Basmati 21 × CSR 13	-0.64*	-10.13**	0.10	3.56**	-4.45**	-14.74**
Vallabh Basmati 21 × CSR 10	0.02	-11.46**	-1.39**	-0.44	-4.24**	-14.56**
Vallabh Basmati 22 × MAUB 57	-0.07	1.28	6.84**	2.73*	2.61*	-10.96**
Vallabh Basmati 22 × Pusa 1121	0.06	2.43**	11.14**	1.34	-0.66	-13.99**
Vallabh Basmati 22 × CSR 30	0.09	2.30	5.74**	-2.67*	-4.59**	-17.39**
Vallabh Basmati 22 × Pusa Basmati 1	0.18	3.62**	4.30**	-1.11	-7.75**	-7.75**
Vallabh Basmati 22 × Basmati 370	-0.07	4.02**	3.87**	1.26	-3.49**	-16.45**
Vallabh Basmati 22 × Pusa 1401	0.41	2.34	11.81**	0.44	-1.09	-14.37**
Vallabh Basmati 22 × CSR 13	-0.41	-8.75**	-1.24**	-0.35	-6.77**	-19.28**
Vallabh Basmati 22 × CSR 10	-0.07	-10.43**	-3.06**	7.83**	5.24**	-8.88**
MAUB 57 × Pusa 1121	0.13	3.53**	9.90	2.11	0.32	-13.23**
MAUB 57 × CSR 30	0.02	1.18	4.35**	-1.67	-3.70**	-16.45**
MAUB 57 × Pusa Basmati 1	0.21	2.45	3.01**	-1.21	-7.75**	-7.75**
MAUB 57 × Basmati 370	-0.19	2.99**	2.44**	4.35**	-0.65	-13.80**
MAUB 57 × Pusa 1401	0.04	3.84**	10.09**	1.22	-0.44	-13.61**
MAUB 57 × CSR 13	-0.49	-7.79**	-2.63**	0.93	-5.66**	-18.15**
MAUB 57 × CSR 10	0.13	-9.38**	-4.30**	-3.02**	-5.45**	-17.96**
Pusa 1121 × CSR 30	-0.15	4.91**	8.32**	-2.50*	-2.50	-18.90**
Pusa 1121 × Pusa Basmati 1	0.02	-6.09	6.98**	-2.17*	-10.40**	-10.40**
Pusa 1121 × Basmati 370	0.09	-6.17	6.89**	1.05	-1.82	-18.34**
Pusa 1121 × Pusa 1401	-0.13	0.38	14.06**	2.26	1.80	-14.56**
Pusa 1121 × CSR 13	0.47	-10.03**	2.49**	5.36**	0.45	-16.45**
Pusa 1121 × CSR 10	-0.19	-12.51**	-0.33	4.57**	4.09**	-13.42**
CSR 30 × Pusa Basmati 1	-0.09	1.58	1.43**	-2.37**	-10.59**	-10.59**
CSR 30 × Basmati 370	-0.12	1.76	1.24**	-3.63**	-6.36**	-22.12**
CSR 30 × Pusa 1401	0.11	4.89**	8.90**	-3.39**	-3.83**	-19.28**
CSR 30 × CSR 13	0.32	-5.99	-3.11**	3.46**	-1.36	-17.96**
CSR 30 × CSR 10	0.03	-8.35**	-5.55**	0.91	0.45	-16.45**
Pusa Basmati 1 × Basmati 370	0.12	0.05	-1.78**	-2.54*	-13.04**	-13.04**
Pusa Basmati 1 × Pusa 1401	0.11	-6.22	7.36**	-3.39**	-11.15**	-11.15**
Pusa Basmati 1 × CSR 13	0.63*	4.35**	-4.35**	1.72	-10.78**	-10.78**
Pusa Basmati 1 × CSR 10	0.18	-6.93	-6.93**	4.04**	-5.10**	-5.10**
Basmati 370 × Pusa 1401	0.18	-6.31	7.27**	0.12	-3.15*	-18.71**
Basmati 370 × CSR 13	0.12	4.80**	-5.12**	-4.67**	-6.51**	-26.65**
Basmati 370 × CSR 10	0.05	-6.91	-7.22**	-3.88**	-6.19**	-22.68**
Pusa 1401 × CSR 13	0.37	-10.32**	2.68**	-3.44**	-8.33**	-23.06**
Pusa 1401 × CSR 10	0.23	-12.53**	0.14	4.32**	3.38*	-13.23**
CSR 13 × CSR 10	0.98**	1.43	-11.19**	2.51*	-1.83	-19.09**

Table 4. Continued.

Crosses	Amylose content MP	BP	SP	Kernel length after cooking MP	BP	SP
Vallabh Basmati 21 × Vallabh Basmati 22	3.88	3.08*	-1.47	8.02**	5.09**	4.30**
Vallabh Basmati 21 × MAUB 57	1.56	0.43	-4.41*	0.52	-3.38**	-4.11**
Vallabh Basmati 21 × Pusa 1121	4.62*	4.62*	0.38	7.51**	5.09**	4.30**
Vallabh Basmati 21 × CSR 30	3.23	-1.54	-5.88**	1.96*	-4.93**	-5.65**
Vallabh Basmati 21 × Pusa Basmati 1	2.26	2.23	0.78	3.47**	3.08**	3.08**
Vallabh Basmati 21 × Basmati 370	2.36	1.59	-4.41*	-2.03*	-12.39**	-13.05**
Vallabh Basmati 21 × Pusa 1401	-0.78	-1.54	-5.88**	5.59**	3.92**	3.14**
Vallabh Basmati 21 × CSR 13	0.00	-7.69**	-11.76**	1.88	-14.24**	-14.89**
Vallabh Basmati 21 × CSR 10	2.48	-4.62*	-8.82**	-0.76	-15.03**	-15.68**
Vallabh Basmati 22 × MAUB 57	2.36	4.56*	-4.41*	2.42**	1.15	-5.05**
Vallabh Basmati 22 × Pusa 1121	2.33	4.78*	-2.94	1.38	0.88	-4.38**
Vallabh Basmati 22 × CSR 30	0.81	-3.13	-8.82**	-2.75**	-6.91**	-12.62**
Vallabh Basmati 22 × Pusa Basmati 1	3.03	1.12	0.56	-0.85	-3.89**	-3.89**
Vallabh Basmati 22 × Basmati 370	1.59	4.54*	-5.88**	0.41	-7.95**	-13.59**
Vallabh Basmati 22 × Pusa 1401	1.56	1.56	-4.41*	0.55	-0.62	-4.49**
Vallabh Basmati 22 × CSR 13	0.84	-6.25**	-11.76**	-1.29	-14.97**	-20.19**
Vallabh Basmati 22 × CSR 10	3.33	-3.13	-8.82**	6.98**	-6.22**	-11.97**
MAUB 57 × Pusa 1121	1.56	0.98	-4.41*	2.18*	0.43	-4.81**
MAUB 57 × CSR 30	1.64	-1.59	-8.82**	-1.48	-4.55**	-12.62**
MAUB 57 × Pusa Basmati 1	3.82	1.23	0.23	-1.00	-5.19**	-5.19**
MAUB 57 × Basmati 370	2.40	4.59*	-5.88**	3.72**	-3.81**	-11.95**
MAUB 57 × Pusa 1401	3.94	3.12*	-2.94	1.43	-0.98	-4.84**
MAUB 57 × CSR 13	1.69	-4.76*	-11.76**	0.12	-12.84**	-20.22**
MAUB 57 × CSR 10	4.20	-1.59	-8.82**	-3.18**	-14.20**	-21.46**
Pusa 1121 × CSR 30	3.23	-1.54	-5.88**	-3.01**	-7.58**	-12.41**
Pusa 1121 × Pusa Basmati 1	2.26	1.36	0.34	-1.29	-3.86**	-3.86**
Pusa 1121 × Basmati 370	0.79	-1.54	-5.88**	0.34	-8.41**	-13.19**
Pusa 1121 × Pusa 1401	2.33	1.54	-2.94	-0.33	-1.01	-4.86**
Pusa 1121 × CSR 13	1.67	-6.15**	-10.29**	5.37**	-9.61**	-14.32**
Pusa 1121 × CSR 10	5.79**	-1.54	-5.88**	4.36**	-8.90**	-13.65**
CSR 30 × Pusa Basmati 1	2.36	-4.41*	-4.41*	-2.44**	-9.35**	-9.35**
CSR 30 × Basmati 370	0.83	-1.61	-10.29**	-3.74**	-8.00**	-21.03**
CSR 30 × Pusa 1401	4.07	3.89*	-5.88**	-3.27**	-8.44**	-12.00**
CSR 30 × CSR 13	3.51	1.43	-13.24**	3.55**	-7.30**	-20.43**
CSR 30 × CSR 10	6.09**	3.39*	-10.29**	0.76**	-8.12**	-21.14**
Pusa Basmati 1 × Basmati 370	3.08	-1.47	-1.47	-2.59**	-13.19**	-13.19**
Pusa Basmati 1 × Pusa 1401	3.03	2.67	0.56	-2.67**	-4.57**	-4.57**
Pusa Basmati 1 × CSR 13	4.07	-5.88**	-5.88**	1.71**	-14.65**	-14.65**
Pusa Basmati 1 × CSR 10	4.84*	-4.41*	-4.41*	3.26**	-11.86**	-11.86**
Basmati 370 × Pusa 1401	1.59	1.98	-5.88**	0.11	-9.20**	-12.73**
Basmati 370 × CSR 13	2.56	-3.23	-11.76**	-4.38**	-10.74**	-30.16**
Basmati 370 × CSR 10	5.08*	2.67	-8.82**	-3.86**	-8.50**	-28.41**
Pusa 1401 × CSR 13	2.52	-4.69*	-10.29**	-3.66**	-17.83**	-21.03**
Pusa 1401 × CSR 10	6.67**	3.14*	-5.88**	4.21**	-9.56**	-13.08**
CSR 13 × CSR 10	4.50	3.57*	-14.71**	3.78**	1.68	-28.11**

Table 4. Average heterosis, heterobeltiosis and standard heterosis in 45 crosses for grain yield and quality traits in rice (*Oryza sativa* L.).

Crosses	Hulling % MP	BP	SP	L/B ratio MP	BP	SP
Vallabh Basmati 21 × Vallabh Basmati 22	-0.26	-1.66**	1.64**	-0.08	0.38	10.48**
Vallabh Basmati 21 × MAUB 57	-0.48*	-1.13	0.96	-0.47	1.76	8.28**

Table 4. Continued.

Crosses	Hulling % MP	BP	SP	L/B ratio MP	BP	SP
Vallabh Basmati 21 × Pusa 1121	-0.75**	-1.22	-1.05**	-0.40	5.07**	15.47**
Vallabh Basmati 21 × CSR 30	-0.56*	-1.68**	1.04**	0.68*	3.14**	6.76**
Vallabh Basmati 21 × Pusa Basmati 1	-0.35	0.57*	-0.12	0.68*	3.99**	5.83**
Vallabh Basmati 21 × Basmati 370	-0.22	-2.10**	2.20**	0.31	1.99	8.03**
Vallabh Basmati 21 × Pusa 1401	-0.54*	0.85**	-0.40	-0.58*	5.77**	15.98**
Vallabh Basmati 21 × CSR 13	-0.36	-2.52**	2.36**	-0.72*	-9.74**	-0.51
Vallabh Basmati 21 × CSR 10	-0.07	-2.01**	2.41**	-0.48	-12.73**	-3.80**
Vallabh Basmati 22 × MAUB 57	-0.43	0.87**	2.45**	0.70*	0.91*	9.89**
Vallabh Basmati 22 × Pusa 1121	-0.07	-2.20**	1.08**	0.25	4.17**	16.57**
Vallabh Basmati 22 × CSR 30	-0.48*	0.75**	2.57**	0.12	3.96**	6.51**
Vallabh Basmati 22 × Pusa Basmati 1	0.54*	-1.09	2.23**	0.76*	4.19**	6.26**
Vallabh Basmati 22 × Basmati 370	-0.21	0.70**	3.65**	0.16	2.44	8.20**
Vallabh Basmati 22 × Pusa 1401	-0.26	-1.96**	1.32**	0.29	4.67**	17.33**
Vallabh Basmati 22 × CSR 13	-0.30	-1.04	3.86**	-0.63	-9.91**	-0.08
Vallabh Basmati 22 × CSR 10	-0.01	0.56*	3.92**	-0.65	-13.11**	-3.63**
MAUB 57 × Pusa 1121	-0.75**	-2.44**	-0.07	-0.11	-5.98	14.37**
MAUB 57 × CSR 30	-0.26	0.42	2.34**	-1.09**	3.62**	3.47**
MAUB 57 × Pusa Basmati 1	-0.33	-1.23	0.88	0.45	2.99	4.14**
MAUB 57 × Basmati 370	-0.81**	-1.74**	2.57**	-0.32	1.34	5.92**
MAUB 57 × Pusa 1401	-0.15	-1.16	0.98**	-0.07	-6.46	15.13**
MAUB 57 × CSR 13	-0.09	-1.01	3.62**	-0.30	-8.27**	-1.52**
MAUB 57 × CSR 10	0.01	0.98**	3.49**	-0.58	-11.81**	-5.33**
Pusa 1121 × CSR 30	-0.84**	-2.68**	0.01	-1.29**	-9.31**	10.31**
Pusa 1121 × Pusa Basmati 1	-0.36	0.88**	-0.88**	0.08	-8.83**	10.90**
Pusa 1121 × Basmati 370	-0.64**	-3.23**	1.01**	-0.71*	-7.44**	12.60**
Pusa 1121 × Pusa 1401	-0.61**	-1.04	-1.22**	-0.66*	1.24	21.56**
Pusa 1121 × CSR 13	-0.77**	-3.63**	1.19**	0.08	-12.86**	6.00**
Pusa 1121 × CSR 10	2.05**	0.67**	3.81**	-1.57**	-17.16**	0.76*
CSR 30 × Pusa Basmati 1	-0.30	-1.64**	1.08**	-0.34	1.24	0.59
CSR 30 × Basmati 370	-0.59**	-1.19	2.97**	-1.10**	2.65	2.37**
CSR 30 × Pusa 1401	-0.41	-1.83**	0.88**	-1.01**	-9.55**	11.33**
CSR 30 × CSR 13	-0.49*	-1.55**	3.37**	-0.09	5.81	-4.06**
CSR 30 × CSR 10	-0.31	-1.11	3.32**	0.12	-9.21**	-7.52**
Pusa Basmati 1 × Basmati 370	-0.07	-2.17**	2.13**	0.37	2.09	2.96**
Pusa Basmati 1 × Pusa 1401	-0.11	0.120	-0.20	0.42	-9.00**	12.00**
Pusa Basmati 1 × CSR 13	-0.27	-2.64**	2.23**	1.16**	3.80**	-3.80**
Pusa Basmati 1 × CSR 10	-0.03	-2.18**	2.23**	0.65	-7.86**	-7.86**
Basmati 370 × Pusa 1401	-0.19	-2.37**	1.92**	0.37	-6.94	14.54**
Basmati 370 × CSR 13	-0.33	0.62*	4.35**	0.04	-7.07**	-2.28**
Basmati 370 × CSR 10	-0.14	0.26	4.31**	-0.22	-10.69**	-6.09**
Pusa 1401 × CSR 13	-0.24	-2.70**	2.17**	-0.20	-13.53**	6.42**
Pusa 1401 × CSR 10	-0.04	-2.29**	2.12**	-0.94**	-17.03**	2.11**
CSR 13 × CSR 10	-0.10	0.33	4.66**	0.88*	3.09**	-12.60**

Table 4. Continued.

Crosses	Kernel breath MP	BP	SP	Grain yield MP	BP	SP
Vallabh Basmati 21 × Vallabh Basmati 22	0.19	-1.50**	0.19	0.49	-9.15**	-10.08**
Vallabh Basmati 21 ×MAUB 57	0.57*	0.77**	0.95**	3.58**	19.35**	-12.51**
Vallabh Basmati 21 × Pusa 1121	-0.10	-3.74**	-2.09**	8.58**	-2.79	-3.66**
Vallabh Basmati 21 × CSR 30	-0.65**	0.87**	1.14**	2.95**	-4.56**	12.78**
Vallabh Basmati 21 × Pusa Basmati 1	-0.28	-1.12	0.57*	3.44**	-1.76	5.18**

Table 4. Continued.

Crosses	Kernel breath MP	BP	SP	Grain yield MP	BP	SP
Vallabh Basmati 21 × Basmati 370	-0.10	-3.18**	-1.52**	2.47*	8.02	-4.93**
Vallabh Basmati 21 × Pusa 1401	0.13	-3.93**	-2.28**	2.13	22.67**	13.88**
Vallabh Basmati 21 × CSR 13	0.19	0.37	1.33**	5.41**	24.22**	10.43**
Vallabh Basmati 21 × CSR 10	0.37	0.73**	3.23**	2.53*	-6.84**	-10.94**
Vallabh Basmati 22 × MAUB 57	-0.77**	-1.15	-2.09**	1.86	4.89	-28.10**
Vallabh Basmati 22 × Pusa 1121	-0.30	-2.32**	-3.99**	-0.76	-1.89	-25.73**
Vallabh Basmati 22 × CSR 30	-0.09	-1.87**	0.18	0.02	21.33**	-4.32**
Vallabh Basmati 22 × Pusa Basmati 1	-0.29	-1.14	-1.14**	-5.22**	18.79**	-16.79**
Vallabh Basmati 22 × Basmati 370	-0.29	-1.74**	-3.42**	0.03	-3.99	-21.08**
Vallabh Basmati 22 × Pusa 1401	0.18	-2.32**	-3.99**	-0.20	7.57	-29.69**
Vallabh Basmati 22 × CSR 13	0.14	-1.13	-0.57*	1.90	-8.77**	-7.40**
Vallabh Basmati 22 × CSR 10	0.19	-2.56**	1.33**	-0.52	3.97	-27.40**
MAUB 57 × Pusa 1121	0.10	-2.30**	-3.23**	1.84	` 4.23	-28.88**
MAUB 57 × CSR 30	0.66**	0.75**	1.14**	1.18	20.74**	-8.27**
MAUB 57 × Pusa Basmati 1	0.10	0.38	-0.38	-0.02	17.22**	-17.22**
MAUB 57 × Basmati 370	0.10	-1.73**	-2.66**	-0.62	9.66	-26.56**
MAUB 57 × Pusa 1401	-0.20	-2.88**	-3.80**	-0.30	-1.51	-34.75**
MAUB 57 × CSR 13	-0.19	0.95**	-0.38	2.66*	16.96**	-11.85**
MAUB 57 × CSR 10	0.19	-2.19**	1.71**	-0.93	-8.29**	-32.66**
Pusa 1121 × CSR 30	0.78**	-2.99**	-1.14**	0.79	17.35**	-4.34**
Pusa 1121 × Pusa Basmati 1	0.15	-2.85**	-2.85**	0.51	9.52	-12.52**
Pusa 1121 × Basmati 370	0.80**	0.13	-4.37**	0.71	-7.27**	-21.30**
Pusa 1121 × Pusa 1401	0.51	0.20	-5.51**	-0.34	6.24	-30.54**
Pusa 1121 × CSR 13	-0.10	-3.21**	-2.66**	4.95**	9.87	-5.42**
Pusa 1121 × CSR 10	0.48	-4.20**	-0.38	0.53	-1.99	-27.39**
CSR 30 × Pusa Basmati 1	0.75**	0.22	1.71**	0.23	6.58	8.12**
CSR 30 × Basmati 370	0.96**	-2.24**	-0.38	0.35	-0.55	-0.68
CSR 30 × Pusa 1401	0.68**	-3.36**	-1.52**	-1.73	23.14**	-11.04**
CSR 30 × CSR 13	0.47	0.19	1.71**	-0.17	4.30	10.76**
CSR 30 × CSR 10	-0.09	-1.10	2.85**	-0.71	20.18**	-7.62**
Pusa Basmati 1 × Basmati 370	0.13	-2.28**	-2.28**	-1.39	9.16	-10.16**
Pusa Basmati 1 × Pusa 1401	-0.29	-3.42**	-3.42**	2.47	19.57**	-15.30**
Pusa Basmati 1 × CSR 13	-0.28	0.57*	0.67	3.55**	-1.54	6.73**
Pusa Basmati 1 × CSR 10	-0.28	-2.19**	1.71**	0.22	-11.64**	-14.64**
Basmati 370 × Pusa 1401	-0.30	-1.20	-5.70**	0.44	9.88	-25.92**
Basmati 370 × CSR 13	-0.29	-2.84**	-2.28**	-0.29	-11.54**	-6.09**
Basmati 370 × CSR 10	-0.29	-4.39**	-0.57*	0.84	6.42	-23.08**
Pusa 1401 × CSR 13	0.32	-3.40**	-2.85**	-1.05	20.09**	-15.16**
Pusa 1401 × CSR 10	0.18	-4.94**	-1.14**	0.72	2.90	-31.68**
CSR 13 × CSR 10	0.23	-1.65	2.28**	-0.78	17.51**	-12.43**

Vallabh Basmati 21 × Pusa 1401, Vallabh Basmati 22 × Pusa 1121, MAUB 57 × CSR 30, CSR 30 × CSR 10, Pusa 1401 × CSR 13, Pusa Basmati 1 × Pusa 1401, Vallabh Basmati 21 × MAUB 57, Vallabh Basmati 22 × Pusa Basmati 1, Pusa 1121 × CSR 30, MAUB 57 × Pusa Basmati 1, MAUB 57 × CSR 13, CSR 13 × CSR 10.The best cross combinations which showed significant and positive heterosis over mid parent were Vallabh Basmati 21 × CSR 30, Vallabh Basmati 21 × Pusa Basmati 1, CSR 30 × Pusa Basmati 1, Vallabh Basmati 21 × CSR 13, CSR 30 × CSR 13, Pusa Basmati 1 × CSR 13. The best cross combinations which showed significant and positive heterosis over mid parent were Vallabh Basmati 21 × Pusa 1121, Vallabh Basmati 21 × CSR 13, Pusa 1121 × CSR 13, Pusa Basmati 1 × CSR 13, Vallabh Basmati 21 × MAUB 57, Vallabh Basmati 21 × Pusa Basmati 1, Vallabh Basmati 21 × CSR 30, MAUB 57 × CSR 13, Vallabh Basmati 21 × Basmati 370. Only one cross Vallabh Basmati 21 × CSR 13 was best heterotic cross for grain yield over better parent, standard parent and mid parent whereas two crosses namely Vallabh Basmati 21 × MAUB 57 and MAUB 57 × CSR 13 showed positive and significant heterosis over better parent and mid parent for grain yield. Similar results for this trait were also reported by Venkanna et al. (2014), Utharasu and Anandakumar (2013), Patil and Mehta (2014), Yogameenakshi and Vivekanandan (2015), Balakrishna and Satyanarayana (2015), Bhatti et al. (2015), Kumari et al. (2014).

This might be due to additive × dominance type of gene interaction with epistasis gene action and non fixable genetic components for grain yield. To obtained early desirable segregants, the appropriate breeding method would be bi-parental mating reciprocal recurrent selection. Best exploitation of heterosis for non-additive gene action has been done through the development of hybrids rice using cytoplasmic genetic male sterility in China. In conventional breeding approach which operates on additive gene action and additive × additive type of gene interactions, the breeder's interest is in the recombinants exhibiting transgressive segregants, which may produce promising genotypes as commercial cultivars in self-pollinated crops including rice. The promising crosses expressed significant and positive heterosis over standard check for grain yield indicating that these crosses have the capability for hybrid rice genotypes. These crosses having the parents with good general combining ability for grain yield. Similar findings on desirable heterosis were also reported by Utharasu and Anandakumar (2013), Yogameenakshi and Vivekanandan (2015), Bhatti et al. (2015), Kumari et al. (2014). All six promising crosses for higher grain yield having both parents with good × good GCA effects which could be due to additive gene action which is fixable in nature and may be exploited further using pedigree method of breeding for the development of pure lines.

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