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Estimation and Association of Genetic Diversity and Heterosis in Basmati Rice

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Abstract

A representative group of 38 improved basmati lines including maintainers of sterile lines were studied for genetic diversity utilizing Mahalanobis D^2 statistics. A wide diversity was observed having ten clusters with high intra- and inter-cluster distance. Heterosis was estimated utilizing the cytoplasmic male sterile lines from the clusters having high intra- and inter-cluster distance. Highly heterotic hybrids were obtained from the hybridization programme. Cross combinations IR68281A/Pusa 1235-95-73-1-1, IR 68281A/RP 3644-41-9-5, Pusa 3A/UPR 2268-4-1, IR 68281A/Pusa Basmati-1, IR68281A/BTCE 10-98, and IR58025A/HKR 97-401 were found to be highly heterotic for grain yield/plant with other agronomic and quality traits. Additionally, a positive association of intra-cluster distance with heterosis was observed, which could be utilized as a guideline for predicting heterosis in basmati hybrid rice breeding program. Also, a positive association between inter-cluster distance and heterosis was observed.

Key words: genetic diversity, heterosis, cluster, basmati rice

Introduction

Basmati rice occupies a prominent place in the species of *Oryza sativa* L. with unique quality features, pleasant aroma, long slender grains, remarkable linear elongation, and soft texture on cooking. However, this group of rice is losing its popularity due to low yield potential and susceptibility to disease and insect pests. The successful development of rice hybrids in the country and abroad has inspired the basmati breeders as well to develop basmati hybrid. To develop improved heterotic hybrid, we need to get genetically diverse parental lines. Genetically diverse parents are, to a certain extent, more likely to give heterotic hybrids than those genetically related. Heterosis is associated with maintainer and restorer having greater genetic distance and vice versa. Genetically speaking, heterosis refers to the significant increase or decrease in the F1 value over mid-parent value. However, from a plant breeders' view point, increase over better parent (heterobeltiosis) and standard variety (standard heterosis) is more relevant (Virmani 1994). It is reported that a positive correlation exists of genetic distance with heterosis (Xiao et al. 1996; Sun et al. 2002; Kwon et al. 2002). Genetic diversity has been suggested, and is being used, as an indirect parameter of moderate effectiveness in selecting parental lines to produce high-yielding progenies (Gopal et al. 1997). With this view, genetic diversity, mid-parent heterosis, heterobeltiosis, and standard heterosis were estimated in a set of basmati crosses.

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Materials and Methods

The experimental material for the study of genetic diversity consisted of three maintainer lines (B lines) of their cytoplasmic genetic male sterile line (A lines) and thirty-five new basmati breeding lines generated at different breeding centres of the country. These materials were grown in a randomized block design with three replications during the 2003 wet season. Five rows per entry were planted with two-meter row length and row-to-row spacing of 20 cm with plant to plant spacing of 15 cm was maintained. The practices normally adopted and need-based plant protection measures were followed. Ten plants were randomly selected for recording of twelve morphological and quality parameters, viz. days to 50% flowering, plant height, number of panicles per plant, number of grains per panicle, spikelet sterility, panicle length, 1000-grain weight, total dry matter at harvest, harvest index, length of brown rice, breadth of brown rice, and grain yield per plant. The genetic divergence was estimated using Mahalanobis D^2-statistics (Rao 1952). The genotypes were grouped into clusters on the basis of D2 values as suggested by Tocher (Rao 1952). During the 2004 wet season, three CMS lines were used as female parents and ten different improved lines as male parents and hybridized in a line x tester mating design. The parents were chosen to estimate the heterosis from mating design possessing higher intra- and inter-cluster genetic distances. During the 2005 wet season, all thirty hybrids and their parents along with standard check (Pusa basmati-1) were raised in randomized block design with three replications. Three rows per hybrid with 20 plants per row and eight rows of parents and standard variety were planted. Similar observations and procedure were followed as for the diversity study. The magnitude of average heterosis (over mid-parent), heterobeltiosis (over better parents), and standard heterosis (over standard variety) were calculated.

Results

The different basmati genotypes were grouped into ten clusters based on the twelve quantitative traits studied (Table 1). Cluster I was largest group which accommodated twenty-one genotypes studied for genetic diversity. It was followed by cluster V which accommodated four genotypes. Clusters VI to X consisted of only one genotype each. Clusters II and IV contained three genotypes each, while cluster III contained only two genotypes. This indicated that a wide diversity existed among the genotypes for different studied traits.

Table 1. Clustering of basmati rice genotypes using Tocher's method

Cluster	Genotypes	No of Genotypes
I	Pusa 3B, Pusa Basmati, RP 3392-32-8-3-3, RP 3364-36-15-8-4, UPRI 93-63-2, Type-3, RP 3392-75-5-11-1, IET 13549, UPR 1840-31-1-1, IET 15391, IET 15392, UPR 1840-31-1-1, IET 15391, IET 15392, UPR 2268-5-2, RP 3644-41-9-5, RP 3644-121-112-4, RP 3135-17-12-88, BTCE 10-98, HKR 97-401, RP 3644-41-9-5-5	21
II	IR 58025B, IET 17251, UPR 2268-4-1	3
III	IR 68281B, Pusa 1235-95-73-1	2
IV	Pusa 2504-1-26, Pusa 2512-97-83-98-4, TM 96140	3
V	Pusa 1280-1-2-1, UPR 2268-3-3, NDR 6111, IET 14131	4
VI	Pusa 2504-1-31	1
VII	Pusa 2511-97-107	1
VIII	Taraori Basmati	1
IX	TM 970267	1
X	Hasan Sarai	1

Table 2. Average intra and inter-cluster D2 values

Cluster	a	II	III	IV	V	VI	VII	VIII	IX	X
I	107.8	1066.51	600.5	2303.9	145.1	3085.6	794.5	425.6	2710.3	3125.5
II		134.4	220.2	408.0	757.6	871.9	236.4	2272.1	561.7	754.7
III			151.3	712.6	416.7	1127.6	130.4	1527.0	1024.4	1244.0
IV				78.2	1867.6	208.5	501.3	3375.8	178.1	167.5
V					139.7	2610.6	597.5	649.5	2187.6	2588.2
VI						0.0	883.2	4756.7	383.1	330.1
VII							0.0	1663.6	795.7	966.85
VIII								0.0	4375.8	4660.4
IX									0.0	150.4
X										0.0

Table 2 showed that cluster III exhibited maximum intra-cluster D^2 value (151.3) followed by cluster V (139.7) and cluster II (134.4). The highest inter-cluster divergence was observed in clusters VI and VIII (4756.7). This was followed by clusters VII and X (4660.4), clusters IV and VII (3775.8), clusters I and X (3125.5), and cluster I with VI (3085.6), respectively.

The cluster means of various traits are presented in Table 3. It is observed from the Table that no cluster exhibited superiority for all the traits studied. For earliness, cluster VI was found to be good, and cluster VIII for spikelet fertility, number of grains per panicle, and plant height. Cluster VII contained genotypes possessing a high harvest index, panicle length, and 1000-grain weight. Cluster VI contained genotypes having a high grain yield per plant, total dry matter per plant, and earliness. The relative contribution of different characters to genetic divergence is presented in Table 4. It is observed that days to 50% flowering was the major contributor to genetic diversity followed by grain length, grain yield/plant, grain breadth, number of spikelets/panicle, total dry matter /plant, and harvest index.

The estimation of heterosis is presented in Tables 5 to 7. The extent of heterosis (%) for plant height ranged from -18.1 to 19.8 for average heterosis, -11.2 to 27.5 for heterobeltiosis, and -20.3 to 22.7 for standard heterosis. Results indicated that cross combination Pusa 3A/Pusa 2504-1-26 and Pusa 3A/Pusa 2512-97-83-98-4 exhibited significant negative standard heterosis, heterobeltiosis, and standard heterosis for plant height which is important in basmati breeding as traditional basmati lines are tall. Out of the 30 hybrids, nine hybrids showed significant average heterosis, heterobeltiosis, and standard heterosis for earliness. The promising hybrids showing heterosis for earliness were

Table 3. Cluster means of 12 agromorphological traits in 38 basmati rice genotypes

Clusters	Plant Height (cm)	Daysto 50% Flowering	Spikelet Fertility (%)	Panicles / Plant	Panicle Length (cm)	Spikelets / Panicle	1000-Seed Weight	Grain Yield /Plant (gm)	Grain Length (mm)	Dry Matter /Plant (gm)	Grain Breadth (mm)	Harvest Index (%)
I	111.78	104.56	81.97	13.21	28.83	183.25	22.11	25.02	8.33	33.49	2.00	42.78
II	102.33	91.11	84.22	13.56	26.30	203.56	21.06	23.44	7.92	29.89	1.89	43.53
III	104.50	94.56	79.34	12.83	29.67	221.00	23.32	24.00	8.79	33.33	1.97	42.10
IV	115.45	83.89	82.78	13.45	26.83	165.78	25.97	23.00	8.61	26.67	2.01	46.41
V	113.08	102.08	85.50	12.75	28.33	198.50	21.30	24.50	8.01	34.84	2.00	39.76
VI	117.00	80.00	75.67	14.67	28.93	214.67	28.47	30.33	9.80	36.67	2.17	45.27
VII	136.67	93.00	89.00	13.00	30.70	158.67	29.43	26.67	8.73	28.33	2.07	48.47
VIII	153.67	110.00	89.67	16.33	27.07	84.33	24.67	12.33	8.90	28.67	2.03	30.07
IX	129.67	83.00	77.67	12.67	26.70	132.33	25.50	26.00	7.03	34.67	2.17	42.83
X	117.33	80.33	80.00	10.67	23.30	77.33	23.20	14.00	8.13	28.00	2.00	33.33

Table 4. Contribution of different characters towards genetic divergence

Sl. No.	Characters	% Contribution
1	Plant height	0.00
2	Days to 50% flowering	67.85
3	Spikelet fertility	0.14
4	Number of panicles/plant	0.28
5	Panicle length	0.00
6	Number of spikelets/panicle	3.13
7	1000-seed weight	0.71
8	Single plant yield	9.82
9	Grain length	9.96
10	Total dry matter per plant	2.99
11	Grain breadth	3.98
12	Harvest index	1.14

IR58025A/Pusa1235-95-73-1, IR58025A/UPR 2268-4-1, IR58025A/HKR97-401, and Pusa3A/Pusa 1235-95-73-1. In the present study, only two hybrids, i.e. Pusa 3A/RP 3644-95-73-1, and Pusa 3A/Pusa Basmati-1 exhibited more heterosis for spikelet fertility and the rest showed higher sterility. Twenty-five hybrids exhibited significant and positive heterosis for number of panicles/plant. The hybrids with high heterosis for this trait were Pusa 3A/UPR 2268-5-2, Pusa 3A/RP 3644-41-9-5, Pusa 3A/RP 3392-75-5-11-1, Pusa 3A/HKR 97-401, Pusa 3A/Pusa Basmai-1, IR58025A/RP3392-75-5-11-1, IR58025A/UPR2268-5-2, IR68281A/Pusa Basmati-1, IR68281A/UPR2268-4-1, and IR68281A/ RP3644-41-9-5.

The magnitude of heterosis (%) for panicle length ranged from -4.3 to 18.2 for mid parent heterosis, -8.3 to 10.9 for heterobeltiosis, and -10.1 to 13.2 for standard heterosis over variety Pusa basmati-1. Fifteen hybrids manifested for longer panicle showing significant heterosis value. Cross combinations highly heterotic for this trait were Pusa 3A/UPR2268-4-1, Pusa 3A/RP3644-41-9-5, Pusa 3A/ Pusa Basmati-1, IR68281A/HKR 97-401, IR68281A Pusa3A/ RP3644-41-9-5. In the present investigation, six hybrid combinations were found to show significant negative mid-parent heterosis, heterobeltiosis, and standard heterosis for 1000-seed weight; negative heterosis for this trait is desirable in basmati rice. The very good combinations for this trait were IR68281A/Pusa2512-97-83-98-4, IR68281A/Pusa 2504-1-26, IR68281A/UPR2268-4-1, and IR58025A/RP3644-41-9-5. Results indicated that only four hybrids exhibited mid parent heterosis, heterobeltiosis, and standard heterosis for the trait kernel length. The promising hybrids were Pusa 3A/HKR97-401, IR58025A/Pusa2512-97-83-98-4, IR58025A/Pusa2504-1-26, and IR68281A/HKR97-401. From the heterosis table, it is clear that only six hybrids manifested for significant negative heterosis for kernel breadth. The very good combinations for the trait were IR68281A/RP3644-41-9-5, IR68281A/RP 3392-75-5-11-1, Pusa3A/RP 3644-41-9-5, and IR58025A/RP3392-75-5-11-1. From the present study, it is observed that ten hybrids exhibited significant heterosis for harvest index. The range of average heterosis (%), heterobeltiosis (%), and standard

Table 5. Heterosis (%) for plant height, days to 50% flowering, spikelet fertility and panicles / plant

Cross Combination	Plant Height			Days to 50 % Flowering			Spikelet Fertility			Panicles/Plant		
	MP	HB	SH	MP	HB	SH	MP	HB	SH	MP	HB	SH
Pusa 3A / HKR 97-401	0.3	27.1**	7.7	6.5**	8.4**	6.4**	-65.8**	-62.9**	-66.1**	80.3**	53.7**	13.4**
Pusa 3A / Pusa basmati-1	19.8**	22.7**	22.7**	8.2**	9.2**	8.9**	.3	1.2	-2.9	48.4**	40.5**	46.7**
Pusa 3A / UPR 2268-4-1	3.0	6.8	2.3	1.8**	-1.0**	-3.2**	-17.1**	-17.6**	-18.4**	29.4**	34.5**	29.7**
Pusa 3A / UPR 2268-5-2	-18.1**	-8.9	-4.5	-2.8**	-1.9**	-2.2**	-76.4**	-66.3**	-67.5**	56.7**	58.9**	30.3**
Pusa 3A / RP 3392-75-5-11-1	-2.2	0.9	-0.6	-2.9**	-1.9**	-2.5**	-5.6*	-8.8**	-8.4**	52.9**	56.0**	23.3**
Pusa 3A / RP 3644-41-9-5	-5.0	-2.6	-2.8	-2.1**	-0.3	-2.2**	2.5	0.4	0.8	48.1**	37.8**	26.7**
Pusa 3A / Pusa 1235-95-73-1	-6.7	5.6	-9.6	-2.5**	-5.8**	-7.3**	-10.1**	-12.6**	-13.3**	12.6**	2.4	31.4**
Pusa 3A / Pusa 2504-1-26	-10.5*	-8.6	-10.2*	-8.1**	24.1**	-2.2**	-7.1**	-13.9**	-13.6**	7.5**	4.8**	23.3**
Pusa 3A / Pusa 2512-97-83-98-4	-6.7	-1.8	-5.9	2.5**	16.8**	-7.3**	-21.9**	-22.4**	-22.9**	34.2**	24.7**	40.3**
Pusa 3A / BTCE 10-98	-14.9**	-11.2**	-14.5**	-2.2**	-1.0**	-2.5**	-72.3**	-67.4**	-54.5**	47.4**	43.3**	53.3**
IR 6828A / HKR 97-401	13.8**	27.5**	13.0**	1.8**	5.2**	-3.5**	-37.6**	-39.2**	-41.6**	36.9**	28.6**	41.3**
IR 6828A / Pusa Basmati-1	3.0	9.6	-2.8	0.7	5.2**	-3.8**	-21.8**	-22.1**	-25.2**	42.8**	47.7**	53.3**
IR 6828A / UPR 2268-4-1	-0.3	2.6	-9.1	6.8**	8.6**	-3.8**	-5.8**	-4.5*	-6.4**	40.6**	67.9**	66.4**
IR 6828A / UPR2268-5-2	-10.2*	9.9*	-2.6	4.3**	9.4**	-0.3	-46.3**	-45.8**	-57.2**	24.9**	22.2**	53.3**
IR 6828A / RP 3392-75-5-11-1	-5.6	-0.3	-11.6*	1.3**	5.2**	-3.5**	-4.4*	-4.5*	-8.4**	31.1**	41.2**	46.7**
IR 6828A / RP 3364-41-9-5	3.5	9.9*	-2.5	6.2**	10.4**	0.6*	-10.7**	-8.6**	-9.2**	42.9**	48.2**	56.7**
IR 6828A / Pusa 1235-95-73-1	1.8	1.9	-9.6*	4.7**	6.5**	-5.7**	-23.6**	-24.2**	-21.7**	37.6**	39.7**	53.3**
IR 6828A / Pusa 2504-1-26	-4.2	-0.3	-11.6*	10.1**	19.3**	-6.1**	-18.9**	-22.5**	-25.6**	35.3**	36.7**	53.3**
IR 6828A / Pusa 2572-97-83-98-4	-3.3	1.3	-10.2*	10.4**	19.3**	-5.7**	-21.1**	-20.0**	-23.2**	39.5**	32.8**	43.3**
IR 6828A / BTCE 10-98	2.6	7.1	-5.1	3.7**	7.3**	-1.9**	-7.7**	-8.1**	-10.6**	38.7**	41.8**	63.3**
IR58025 / HKR97-401	2.8	22.9**	-2.8	-10.2**	-3.3**	-17.5**	-24.7**	-27.4**	-22.3**	15.3**	3.2	63.3**
IR58025 / Pusa basmati -1	-6.1	6.5	-15.9	5.1**	13.3**	-2.5**	-42.5**	-41.9**	-40.5**	15.2**	5.6**	26.7**
IR58025 / UPR2268-4-1	0.3	9.6	-13.3**	-7.1**	-5.5**	-19.1**	-31.1**	-31.3**	-29.1**	11.6**	15.5**	16.7**
IR58025 /UPR2268-5-2	-8.5	20.1**	-5.1	6.5**	15.6**	-1.3**	-60.8**	-76.1**	-60.0**	40.7**	35.7**	30.3**
IR58025 / RP3392-75-5-11-1	-1.7	10.4*	-12.7*	-7.6**	0.0	-14.6**	-27.9**	-28.9**	-26.8**	47.3**	38.3**	50.0**
IR58025 / RP3644-41-9-5	-0.8	12.2*	-11.3*	-0.9*	6.7**	-8.9**	-26.2**	-36.1**	-24.0**	-18.8**	-22.3**	-4.7**
IR58025 / Pusa1235-95-73-1	1.9	8.2	-14.4**	-2.4**	-1.1**	-14.9**	-30.9**	-32.3**	30.2**	-12.3**	-11.7**	-0.8
IR58025 / PUSA2504-1-26	0.2	10.7*	-12.5**	4.2**	8.4**	-13.9**	-15.6**	-13.9**	-17.6**	-9.4**	-10.8**	11.3**
IR58025 / Pusa2512-97-83-98-4	3.7	15.4**	-8.8	0.4	4.8**	-17.1**	-5.9**	-5.9**	-2.9	-7.8**	-8.1**	6.7**
IR58025 / BTCE10-98	-8.8	1.1	-20.1**	3.1**	10.1**	-5.4**	-63.1**	-65.4**	-68.2**	6.6**	2.5	15.3**

*& ** significant at 5% & 1% level of probability; MP-Mid parent heterosis (%); HB-Heterobeltiosis (%) & SH-Standard heterosis (%)

heterosis (%) for grain yield/plant varied from -74.0 to 86.1, -77 to 91.5, and -81.8 to 76.1, respectively. Seventeen hybrids showed positive significant heterosis for this trait. The promising hybrids for this trait were IR68281A/Pusa1235-95-73-1, IR68281A/RP3644-41-9-5, Pusa 3A/UPR 2268-4-1, IR68281A/Pusa Basmat-1, IR68281A/BTCE 10-98, and IR58025A/HKR97-401.

Discussion

There is a need to access the genetic diversity among the newly developed parental lines to get superior basmati hybrids. Different genotypes were grouped into ten clusters indicating wide diversity in the material under study for all the characters. This wide diversity observed in elite basmati genotypes was due to the involvement of diverse parental lines on the hybridization program at different research centers and selection under different environmental situations of the country. Clusters III, II, and I exhibited high intra-cluster D^2 value. Genotypes from this cluster could be utilized as parental lines for hybrid breeding programs owing to their higher within group distance. The clusters showing higher inter-cluster D^2 values were between clusters VI & III, VIII and X, VII and IX, VI and VIII, and with clusters I and VI. Parental lines selected from these individual groups showing high inter cluster distances are likely to produce superior progenies and hybrids. Similar results of Pradhan and Ray (1990) indicated that selection of parents for hybridization should be done from two clusters having wider inter-cluster distances to get maximum variability in the segregating generations (Pradhan & Ray 1990). Clusters III and IV exhibited minimum genetic distances between them which showed that genotypes in these two clusters were some what similar in genetic constitution, and hybridization between these groups may not generate sufficient variability.

Cluster means table indicated that no cluster contained genotypes possessing all superior traits under study. Therefore, none of the clusters could be directly selected and utilized. The hybridization between genotypes of different clusters was necessary for the development of desirable genotypes. Recombination breeding between genotypes of different clusters has also been suggested by Sinha et al. (1991) and Singh et al. (1996). Days to 50% flowering was the major contributor to the genetic diversity. This was followed by grain length and grain yield/plant. These observations are closely in agreement with the findings of Murty and Arunachalam (1996), indicating that greatest contributors to the genetic diversity in grain crops were flowering time, plant height, and tillers/plant.

The dwarf and medium plant height is preferred in basmati rice. For this purpose, highly significant negative heterosis is desirable for this trait along with other desirable features in the progenies. From the experiment, it is revealed that cross combi-

Table 6. Heterosis (%) for panicle length, spikelets / panicle, 1000-seed weight and single plant yield

Cross combination	Plant Height			Spikelets / Panicle			1000-Seed Weight			Single Plant Yield		
	MP	HB	SH	MP	HB	SH	MP	HB	SH	MP	HB	SH
Pusa 3A / HKR 97-401	7.6**	3.1**	6.7**	-9.3	-12.1	-11.1	22.8**	21.6**	24.8**	-63.1**	-64.5**	-65.2**
Pusa 3A / Pusa basmati-1	9.5**	7.7**	11.5**	34.7**	33.9**	35.5**	-5.8**	-6.1**	-5.5**	-11.6**	-13.6**	-13.6**
Pusa 3A / UPR 2268-4-1	11.7**	9.3**	13.2**	17.4	6.4	26.6*	9.3**	6.7**	7.4**	34.9**	37.8**	30.2**
Pusa 3A / UPR 2268-5-2	9.7**	7.9**	11.7**	56.4**	34.2**	35.8**	14.8**	15.3**	18.4**	-45.1**	-49.1**	-50.4**
Pusa 3A / RP 3392-75-5-11-1	2.8**	0.6	4.1**	42.1**	35.2**	51.5**	9.2**	16.2**	19.3**	76.5**	66.7**	34.6**
Pusa 3A / RP 3644-41-9-5	12.7**	8.7**	12.5**	59.5**	44.5**	46.2**	3.3*	10.6**	13.5**	17.9**	15.1**	13.6**
Pusa 3A / Pusa 1235-95-73-1	1.5**	-0.4	3.1**	11.3	11.4	12.7	20.3**	28.5**	31.9**	20.5**	17.4**	16.6**
Pusa 3A / Pusa 2504-1-26	-4.2**	-8.3**	-5.1**	-1.7	10.2	-9.1	-6.3**	3.8*	6.6**	14.8**	1.2	-3.4
Pusa 3A / Pusa 2512-97-83-98-4	0.2	-3.8**	-0.3	1.1	7.6	-0.5	72.4**	93.1**	98.2**	30.5**	32.1**	26.1**
Pusa 3A / BTCE 10-98	5.6**	3.4**	7.1**	64.2**	55.7**	75.8**	0.8	2.3	5.1**	-65.7**	-66.8**	-57.1**
IR 6828A / HKR 97-401	11.2**	5.8**	11.2**	22.4*	6.5	36.1**	-5.1**	-5.9**	-3.2	21.3**	22.7**	3.2
IR 6828A / Pusa Basmati-1	-4.3**	-6.7**	-1.9**	28.1*	14.4	45.5**	4.5**	3.8*	5.2**	30.8**	33.8**	21.6**
IR 6828A / UPR 2268-4-1	-3.9**	-6.7**	-1.9**	5.8	0.4	27.8**	-17.2**	-19.4**	-18.4**	37.7**	38.6**	18.2**
IR 6828A / UPR2268-5-2	1.2*	-1.2*	3.9**	-4.1	-24.6*	-4.1	7.3**	8.1**	10.9**	-20.2**	-25.7**	-28.8**
IR 6828A / RP 3392-75-5-11-1	4.4**	1.3*	6.6**	5.6	-0.7	26.4*	-0.6	6.1**	8.9**	45.1**	47.1**	17.1**
IR 6828A / RP 3364-41-9-5	6.9**	2.3**	7.6**	14.8	-5.7	20.1	-8.7**	2.1	0.6	53.5**	84.3**	76.1**
IR 6828A / Pusa 1235-95-73-1	-4.2**	-6.7**	-1.9**	24.4*	11.8	42.8**	-10.5**	-4.1*	-1.6	86.1**	91.5**	52.3**
IR 6828A / Pusa 2504-1-26	-0.6	-5.6**	-0.7	-2.5	-19.1	2.9	-19.7**	-10.8**	-8.5**	16.7**	10.1**	-12.4**
IR 6828A / Pusa 2572-97-83-98-4	-2.2**	-6.6**	-1.7**	-8.1	-23.1*	-2.1	-23.5**	-15.1**	-12.7**	35.2**	32.8**	19.5**
IR 6828A / BTCE 10-98	9.5**	6.4**	11.9**	44.3**	36.2**	73.3**	-8.3**	-6.6**	4.1*	56.3**	51.2**	36.6**
IR58025 / HKR97-401	15.9**	7.5**	1.9**	71.1**	-7.6	1.7	5.9**	-2.2	0.5	36.3**	27.2**	36.8**
IR58025 / Pusa basmati -1	-0.6	-5.1**	-10.1**	7.9	0.5	10.7	3.5*	-5.8**	-3.3	-34.3**	-34.3**	-47.7**
IR58025 / UPR2268-4-1	11.5**	5.9**	0.5	22.5*	17.9	34.8**	7.3**	-4.5*	-1.9	12.2**	10.7**	13.9**
IR58025 /UPR2268-5-2	16.1**	10.9**	5.2**	9.4	3.4	13.9	15.3**	8.1**	10.9**	-66.1**	-69.9**	-64.1**
IR58025 / RP3392-75-5-11-1	13.9**	8.2**	2.6**	-0.3	-7.5	3.6	1.2	1.1	3.7*	3.1*	-4.2*	-23.8**
IR58025 / RP3644-41-9-5	1.6**	-5.1**	-9.9**	3.0	3.9	14.5	-9.9**	-9.6**	-7.2**	-10.3**	-7.1**	-16.1**
IR58025 / Pusa1235-95-73-1	10.3**	5.1**	-0.4	15.4	1.6	11.9	6.3**	6.4**	9.3**	29.3**	28.6**	22.1**
IR58025 / PUSA2504-1-26	18.2**	9.5**	3.8**	-13.6	-12.5	-3.6	15.9**	20.7**	23.9**	18.3**	12.6**	7.6**
IR58025 / Pusa2512-97-83-98-4	17.8**	9.8**	4.1**	26.5*	22.2*	34.6**	16.8**	21.7**	25.0**	19.8**	15.8**	21.6**
IR58025 / BTCE10-98	0.6	-4.4**	-9.3**	-11.4	-24.6*	-14.8	-0.7	-5.8**	-3.3	-74.0**	-77.2**	-81.8**

*& ** significant at 5% & 1% level of probability; MP-Mid parent heterosis (%); HB-Heterobeltiosis (%) & SH-Standard heterosis (%)

nation like Pusa3A/Pusa2504-1-26 and Pusa3A/Pusa 2512-97-83-98-4 were very good for plant height exhibiting negative mid-parent heterosis, heterobeltiosis, and standard heterosis. Earliness is required in basmati breeding programs. Cross combination which showed high negative heterosis for days to maturity were IR58025A/UPR2268-5-2, IR58025A/UPR2268-4-1, and Pusa 3A/Pusa1235-95-73-1. Spikelet sterility is a major cause of low yield in hybrids. Emphasis should be given to select hybrids with high fertility %. In the present study, only two hybrids, i.e. Pusa 3A/RP3644-41-9-5 and Pusa 3A/Pusa Basmati-1 showed more heterosis for spikelet fertility. Twenty-five hybrids exhibited significant positive heterosis for number of panicles/plants. From the present study, it is also revealed that high heterosis is obtained for the other component traits like panicle length, number of spikelet/panicle, harvest index, grain yield per plant, grain length, and low grain breadth. Results on heterosis for these component traits were also reported (Sharma & Mani 1989; Hariprasanna et al. 2001). The heterotic crosses for grain yield /plant manifested with high heterosis for some component traits but not for all. The best hybrid IR68281A/Pusa1235-95-73-1, manifested high grain yield due to high heterosis for single plant yield, more panicles/plant, more spikelets /panicle, more straw yield, and high harvest index. The next best hybrid IR68281A/RP 3644-41-9-5 expressed high grain yield with more panicles/plant, high harvest index, straw yield, and long panicle along with low kernel breadth. High heterosis for grain yield in hybrid IR68281A/Pusa 2504-1-26 was due to more panicles/plant, long panicle, more spikelets/panicle, more dry matter/plant, and high harvest index along with earliness. Similar conclusion on the increased yield in tropical rice has been found to be due to heterosis in total biomass, harvest index, and best combination of factors for bigger sink size and better grain filling (Virmani et al. 1993; Bobby & Nadarajan 1994).

From the heterosis and genetic distance table, it is observed that cross combination of IR68281A with Pusa 1235-95-73-1 from cluster III possessing high intra-cluster distance exhibited high heterosis for grain yield and also components traits like harvest index, panicles/plant, and spikelet/panicle. Also, the hybrid of IR58025A with UPR 2268-4-1 from cluster II manifested higher heterosis. But members of cluster I in combination with the CMS of the same cluster produced heterosis but relatively less compared to many combinations of members of cluster III which showed high intra-cluster distance. When heterosis is compared with combination of members from inter-cluster having higher genetic distance, it is difficult to predict heterosis on the basis of estimated genetic distance. Cross combination of Pusa 3A from cluster I with Pusa 2504-1-26 and Pusa 2512-97-83-98-4 from cluster IV manifested higher heterosis for grain yield. However, members of cluster III which showed lower inter-cluster distance with cluster I also exhibited high heterosis. For example, CMS line Pusa 3A with members of cluster III

Table 7. Heterosis (%) for kernel length, kernel breadth, straw yield / plant and harvest index

Cross Combination	Kernel Length			Kernel Breadth			Straw Yield / Plant			Harvest Index		
	MP	HB	SH	MP	HB	SH	MP	HB	SH	MP	HB	SH
Pusa 3A / HKR 97-401	5.7**	4.7**	5.6**	9.2**	6.5**	8.1**	114.7**	91.2**	139.6**	-58.5**	-47.3**	-46.5**
Pusa 3A / Pusa basmati-1	-4.8**	-5.2**	-4.4**	-3.4*	-6.5**	-5.1**	85.5**	46.5**	83.5**	-35.9**	-35.3**	-24.7**
Pusa 3A / UPR 2268-4-1	5.2**	-1.2**	-0.3	6.5**	13.7**	0.0	62.5**	33.3**	67.1**	2.8	-0.3	15.9**
Pusa 3A / UPR 2268-5-2	-2.1**	3.6**	2.4**	-2.5	-5.0**	-3.5*	185.7**	128.1**	185.7**	59.7**	-52.4**	-48.1**
Pusa 3A / RP 3392-75-5-11-1	-4.1**	0.8**	-0.3	4.9**	1.5	3.1*	108.7**	80.7**	126.4**	14.8**	7.8**	25.4**
Pusa 3A / RP 3644-41-9-5	-1.2**	2.6**	1.5**	-6.6**	-5.0**	-3.5*	17.7**	7.9*	35.2**	-1.9	-6.4**	8.8**
Pusa 3A / Pusa 1235-95-73-1	0.6**	8.1**	6.8**	10.4**	8.5**	10.2**	-2.2	-22.8**	-3.3	14.6**	13.7**	22.3**
Pusa 3A / Pusa 2504-1-26	-2.2**	2.8**	1.6**	1.9	0.0	-3.6**	31.3**	20.2**	17.6**	-8.2**	-8.3**	6.7**
Pusa 3A / Pusa 2512-97-83-98-4	0.9**	-1.5**	4.4**	5.3**	3.5*	5.1**	38.6**	26.9**	24.2**	1.5	-0.9	13.3**
Pusa 3A / BTCE 10-98	-6.8**	-9.5**	-8.7**	6.9**	3.5*	5.1**	92.1**	50.0**	87.9**	-56.9**	-57.4**	-55.4**
IR 6828A / HKR 97-401	3.6**	3.6**	2.4**	-2.6	-5.0**	-3.6**	79.0**	64.2**	96.7**	14.2**	11.9**	3.5
IR 6828A / Pusa Basmati-1	-0.2	-4.8**	-7.1**	-1.8	-3.6**	-3.6**	44.7**	32.1**	58.3**	-13.1**	-11.8**	-9.9**
IR 6828A / UPR 2268-4-1	-3.9**	-8.2**	-10.4**	11.9**	10.7**	5.1**	57.5**	49.5**	79.1**	-7.1**	-7.4**	-6.2**
IR 6828A / UPR2268-5-2	-5.2**	-1.2**	-2.3**	1.1	-1.5	0.0	65.4**	53.2**	83.5**	-35.5**	-38.5**	-9.9**
IR 6828A / RP 3392-75-5-11-1	-9.1**	-6.0**	-7.1**	-8.5**	-11.5**	-10.1**	32.9**	33.9**	60.5**	5.3**	0.8	0.4
IR 6828A / RP 3364-41-9-5	-2.7**	-0.4	-1.5**	-8.1**	-6.5**	-5.1**	34.5**	41.3**	69.2**	40.1**	29.6**	36.1**
IR 6828A / Pusa 1235-95-73-1	-5.5**	0.0	-1.2**	5.3**	3.5*	5.1**	36.0**	24.7**	49.5**	17.9**	4.9**	19.5**
IR 6828A / Pusa 2504-1-26	-13.8**	-10.8**	-11.9**	7.2**	6.9**	1.5	31.5**	10.1**	31.8**	-7.9**	-18.5**	-5.9**
IR 6828A / Pusa 2572-97-83-98-4	-12.3**	-9.6**	-10.7**	5.3**	3.5*	5.1**	72.7**	49.4**	73.6**	-3.5	-6.1**	0.9
IR 6828A / BTCE 10-98	-0.4**	-1.6**	-3.9**	1.6	0.0	1.5	18.8**	-11.4**	11.1**	-29.5**	-36.3**	-24.6**
IR58025 / HKR97-401	-12.7**	-15.3**	-16.3**	-1.8	-5.0**	-3.5*	33.7**	13.2**	41.8**	45.1**	42.6**	36.4**
IR58025 / Pusa basmati -1	1.2**	-1.2**	-2.4**	4.2**	0.0	1.5	18.8**	-11.4**	11.1**	29.5**	36.3**	24.6**
IR58025 / UPR2268-4-1	-3.1**	0.9**	-6.3**	-0.3	-3.7**	-7.1**	2.8	-20.2**	0.0	-16.2**	-22.7**	-12.5**
IR58025 /UPR2268-5-2	-5.3**	-3.6**	-4.8**	12.1**	8.5**	10.1**	73.6**	30.9**	63.8**	-68.9**	-69.3**	-70.0**
IR58025 / RP3392-75-5-11-1	-6.9**	-6.1**	-7.1**	-6.3**	-10.0**	-8.6**	37.3**	13.2**	41.8**	-16.2**	-18.2**	-19.8**
IR58025 / RP3644-41-9-5	-2.8**	-2.8**	-3.9**	-0.8	-1.5	0.0	-34.6**	-42.9**	-28.5**	9.5**	9.5**	7.4**
IR58025 / Pusa1235-95-73-1	-2.5**	0.8**	-0.4	11.3**	8.5**	10.1**	25.9**	-6.1*	17.6**	23.8**	13.8**	29.7**
IR58025 / PUSA2504-1-26	4.6**	5.7**	4.4**	9.7**	6.8**	3.1*	1.9	-1.2	-14.3**	17.5**	7.4**	15.3**
IR58025 / Pusa2512-97-83-98-4	5.4**	6.0**	4.8**	2.6	0.0	1.5	24.2**	20.3**	4.4	18.2**	6.0**	27.6**
IR58025 / BTCE10-98	-0.9**	-5.7**	-6.8**	-4.7**	-8.5**	-7.1**	36.9**	0.8	26.4**	-0.8	52.4**	-40.5**

*& ** significant at 5% & 1% level of probability; MP-Mid parent heterosis (%); HB-Heterobeltiosis (%) & SH-Standard heterosis (%)

(Pusa 1235-95-73-1) exhibited higher standard heterosis. It may be possible that some of the estimates may be biased due to the inclusion of complex character such as yield. Besides, many of the genetic traits are highly influenced by environment and genotype x environment as well. Therefore, precision of the genetic distance can be obtained by estimating genetic distance through molecular techniques. But intra-cluster distance can be utilized as a reliable parameter for predicting heterosis in basmati rice. In the case of inter-cluster genetic distance, there also exists a good trend of association of genetic distance with levels of heterosis in basmati rice. It is reported that a significant positive correlation exists with genetic distance in *indica* x *indica* and *japonica* x *japonica* crosses (Xiao et al. 1995; Sun et al. 2002; Kwon et al. 2002).

From this study, we concluded that in the case of basmati rice, heterotic hybrids can be obtained for grain yield per plant along with other component traits. It is revealed that cross combinations IR68281A/Pusa 1235-95-73-1-1, IR 68281A/RP 3644-41-9-5, Pusa 3A/UPR 2268-4-1, IR 68281A/Pusa Basmati-1, IR68281A/BTCE 10-98, and IR58025A/HKR 97-401 were found to be highly heterotic for grain yield/plant with other agronomic and quality traits. It is observed that there was a wide diversity among the newly-developed basmati lines for grain yield and other traits as evidenced by genetic distance and clustering pattern. Also, we concluded that intra-cluster distance can be utilized as a reliable parameter for predicting heterosis. There is a positive trend of association of inter-cluster distance with level of heterosis in basmati rice.

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