HERITABILITY, GENETIC ADVANCE AND HETEROSIS IN LINE × TESTER CROSSES OF BASMATI RICE

Muhammad Yussouf Saleem[*], *Javed Iqbal Mirza*[**]
and Muhammad Ahsanul Haq[*]

ABSTRACT

The heritability, genetic advance and heterosis study was conducted on 27 F_1 hybrids along with their 12 Basmati rice (*Oryza sativa*) parents to know the pattern of inheritance of some morpho-physiological traits for selecting superior genotypes. The experiment was laid out according to line x tester mating design at Nuclear Institute for Agriculture and Biology (NIAB), Faisalabad during 2004-05. Analysis of variance revealed highly significant differences among treatments, parents, parents vs crosses and crosses for flag leaf area, plant height, panicle density, harvest index, biological yield per plant and yield per plant. Estimates of broad sense heritability and expected genetic advance in response to selection in next generation were high for all the traits. Heterosis and heterobeltiosis ranged -21.09 to 60.13 percent and -33.34 to 42.99 percent, respectively for flag leaf area, -3.94 to 12.28 percent and 3.25 to 32.21 percent for plant height, 17.88 to 53.10 percent and -25.90 to 23.97 percent for panicle density, -8.80 to 32.43 percent and -24.32 to 19.29 percent for harvest index, 7.54 to 58.77 percent and 12.88 to 104.37 percent for biological yield per plant and 12.50 to 95.33 percent and -6.97 to 66.38 percent for yield per plant. The results indicate that improvement in grain yield can be efficient through making some compromises within limits among morpho-physiological yield related traits. Based on higher mean performance and desirable heterosis and heterobeltiosis, three intermediate and six tall hybrids are recommended for exploitation of heterosis breeding. However, desirable transgressive segregants may also be selected in succeeding generations from the progenies of these crosses to develop potential varieties.

KEYWORDS: *Oryza sativa*, genotypes; heritability; hybrid vigour; agronomic characters; Pakistan.

INTRODUCTION

Rice (*Oryza sativa* L. 2n=2x=24) is one of the most important cereal crops of Pakistan. During 2005-06 it was sown on 2.62 million hectares with a production of 5.54 million tonnes and average yield of 2116 kg per hectare (1). Unlike other South Asian countries, rice is not sub-sistence crop and it is considered as cash crop in Pakistan. Pakistan earned 1143 million US $ by

---

[**]Nuclear Institute for Agriculture and Biology (NIAB), P. O. Box 128, Faisalabad, Pakistan.
[**]Institute of Pure and Applied Biology, Bahauddin Zakariya University, Multan, Pakistan.

exporting 3.69 million tonnes of rice in which aromatic premium rice shared 0.84 million tonnes worth 474 million US $ (1). Most of Basmati rice is produced in the 'Kalar' tract of Punjab province where the climatic conditions are sub-humid and sub-tropical with 400-700 mm rainfall mostly in July-August. The soil is either clayey with restricted drainage or loamy with good drainage. The predominantly grown cultivar is Super Basmati followed by Basmati-385.

Despite fair irrigation and other inputs, rice yields particularly of Basmati types are low as compared to these of major rice producing countries of the world (2) which is due to its narrow genetic base and scarcity of donor for grain quality. Moreover, progenies of Basmati rice with typical Indica lines exhibit some sterility and poor recombinations (5). It is, therefore, imperative to conduct intensive studies on extent of transmission of variations from parents to hybrids i.e heritability, improvement in the mean genotypic value of hybrids over the parental population i.e genetic advance and heterosis (midparent and high parent) on yield and various yield components in Basmati rice. Appreciable amount of literature is available on breeding – genetics of major yield components on Basmati rice. However, there is need to study various morpho-physiological traits to get better understanding of inheritance and select/identify superior genotypes without sacrificing quality traits. In rice, physiological traits (flag leaf area, harvest index and biological yield) associated with grain yield were discussed by Yoshida (22). Breeders prefer the plants with narrow dark green leaf, short height and stiff culms with long erect flag leaf. Semi dwarf plants are high yielder due to increased tillering ability, better responsiveness to nitrogen fertilizer and resistance to lodging.

Heritability values have been variable depending upon the genetic nature of genotypes for different morpho-physiological characters. Vivek *et al.* (21) observed high heritability coupled with high genetic advance for harvest index, biological yield per plant and grain yield per plant in evaluation of 39 tropical Japonica rice genotypes. Mishra and Verma (14) evaluated 16 rice genotypes alongwith 72 F_1 hybrids and noted high heritability with high genetic advance for flag leaf area and plant height indicating dominant role of additive gene action. The association of high heritability with high genetic advance was observed for plant height and grain yield per plant by Mahto *et al.* (13). Swati and Ramesh (17) reported high heritability for grain yield while moderate heritability for flag leaf area and plant height. Hosseini *et al.* (9) observed 61 percent broad sense heritability for grain yield in rice.

Surek and Korkut (16) reported 21.2 percent and mid-parent and15.2 percent high parent heterosis for yield and that the heterosis in yield was due to heterosis in harvest index, biological yield per plant and number of panicles per plant. Verma *et al.* (20) reported significant economic heterosis in 15 hybrids for flag leaf area, plant height and biological yield per plant. Heterosis estimates were attributed to both additive and high degree of dominance or epistatic interactions or both for one or more physiological traits. Biological yield, flag leaf area and harvest index were the major contributors to yield. Vanaja and Babu (19) pointed out that yield increase in rice was due to favourable heterosis in flag leaf area, number of spikelets per panicle and number of grains per panicle. Gnansekaran *et al.* (6) reported significant positive heterosis for harvest index and yield per plant over the standard varieties and recommended eight hybrids for commercial exploitation of heterosis breeding based on mean performance.

In this paper an attempt has been made to assess the heritability, genetic advance and heterosis for flag leaf area, plant height, panicle density, harvest index, biological yield per plant and yield per plant in Basmati rice. In this paper an attempt has been made to assess the heritability, genetic advance and heterosis for flag leaf area, plant height, panicle density, harvest index, biological yield per plant and yield per plant in Basmati rice.

MATERIALS AND METHODS

The present study was conducted in summer season at Nuclear Institute for Agriculture and Biology (NIAB), Faisalabad, Pakistan. Faisalabad is situated at latitude 31° 30N; longitude 73° 10E and altitude 213 meters from sea level. The breeding material comprised 12 pure Basmati rice genotypes, out of which 9 genotypes (Basmati-370, DM-2, DM-107-4, DM-16-5-1, Kashmir Basmati, Basmati-Pak, Basmati 2000, Super Basmati and Shaheen Basmati) were used as females (designated as lines) and 3 genotypes (Basamti-385, DM-25 and EL-30-2-1) designated as testers were used as males. These were crossed to produce 27 F_1 hybrids according to lines × tester mating design (11) during 2004. The hybrids were evaluated alongwith parents following RCBD with three replications during 2005. A replication comprised 39 entries (27 F_1s +12 parents). Each entry was planted in two rows of one meter each. The plant to plant and row to row spacing was 20 cm, each. N and P were applied @ 72.6 and 23.4 kg respectively. Half of N was applied at the time of transplanting while the remaining half into two splits: ¼ after 30 days of transplanting and other ¼ after 60 days of transplanting. Total amount of P was applied at the time of transplanting. Weeds were removed by weedicide Machette 60 EC (Butachlor) and Roanstar (Oxadiazon) @ 2.0 and 3.5 liter per hectare, respectively after 4 days of transplanting. The water level was kept at 2.5~4.0 cm at the time of transplanting and gradually increased to 8.0 cm for 25 days of transplanting. Irrigation was discontinued for few days to provide aeration and then recontinued. The plants were protected from insect pests, i.e. leaf roller and stem borer by application of insecticide Talstar 10 EC (biphenthrin) and Padan 4G (cartap) @ 500 ml per hectare and 20 kg per hectare, respectively. Measurements on flag leaf area (cm^2), plant height (cm), panicle density, harvest index (%), biological yield per plant (g) and yield per plant (g) were recorded according to standard evaluation system for rice (9, 23). Grain and straw yields were adjusted at 14 percent moisture content as suggested by Gomez (7).

Genotype means were used for analysis of variance. Heritability in broad sense and genetic advance were calculated according to Singh and Chaudhary (15). Standard error of broad sense heritability was calculated following the procedure of Lothrop *et al.* (12). Values of heritability and genetic advance were categorized according to standard scale (10). Mid-parent heterosis (Ht) and high-parent heterosis (Htb) or heterobeltiosis were determined as outlined by Falconar and Mackay (4).

RESULTS AND DISCUSSION

Mean performance of lines, testers and their hybrids (Table 1) indicated worth of genetic variability for the improvement of flag leaf area, plant height, panicle density, harvest index, biological yield per plant and yield per plant. Significant differences among various morpho-physiological traits have been observed earlier (16, 17). Four lines with flag leaf area of 47.54 to 62.93 cm^2, tester Basmati-385 (49.40 cm^2) and 8 hybrids (60.65 to 80.60 cm^2); 3 lines with plant height 92.83 to 116.07 cm, tester Basmati-385 (123.77 cm) and 11 hybrids (111.03 to 134.93 cm); 3 lines with panicle density of 5.45 to 5.76, 2 testers (5.68 to 5.86) and 14 hybrids (5.43 to 6.52); 3 lines with harvest index of 24.77 to 27.78, tester Basmati-385 (26.47) and 13 hybrids (27.06 to 32.20) and 3 lines with biological yield of 60.08 to 75.36 g per plant, tester DM-25 (84.48 g) and 10 hybrids (81.44 to 105.85 g) were found to be better than their representative grand means. Basmati-2000 (22.48 g/plant), Super Basmati (22.07), Shaheen Basmati (20.97), DM-16-5-1 (20.90) and Kashmir Basmati (20.87) showed significantly higher yield than grand mean yield (20.36) among lines. Among testers, Basmati-385 exhibited significantly higher yield (29.38) than grand mean (22.84). Of 27 F_1 hybrids, 9 hybrids viz. Basmati-Pak × Basmati-385 (44.21), Super Basmati × Basmati-385 (41.80 g/plant), DM-107-4 × Basmati-385 (41.27), Kashmir Basmati × Basmati-385 (39.74), Basmati 2000 × EL-30-2-1 (38.89), Basmati 2000 × DM-25 (37.41), DM-16-5-1 × Basmati-385 (37.20) Basmati 2000 × Basmati-385 (35.96) and Kashmir Basmati × DM-25 (35.32) were significantly higher yielder than grand mean (32.53 g/plant) and may be rated as desirable genotypes for improvement of yield and related traits (18).

Table 1. Mean performance of parents and hybrids for line x tester analysis in rice.

Parents/Hybrids	Flag leaf area (cm^2)	Plant height (cm)	Panicle density	Harvest index (%)	Biological yield/plant (g)	Yield/plant (g)
Lines						
Basmati-370	47.54**	170.50**	5.76**	20.29**	85.13**	20.03
DM-2	47.70**	92.83**	4.77^{NS}	27.55**	60.08**	19.22**
DM-107-4	49.93**	106.67**	3.87**	27.96**	61.38**	19.90^{NS}
DM-16-5-1	43.89**	140.43**	5.60**	23.47^{NS}	76.84^{NS}	20.90*
Kashmir Basmati	32.80**	156.00**	4.77^{NS}	21.41**	84.04**	20.87*
Basmati-Pak	39.24**	160.00**	3.49**	15.75**	91.92**	16.77**
Basmati-2000	62.93**	138.50**	4.69^{NS}	25.93**	75.36^{NS}	22.48**
Super Basmati	42.60**	116.07**	4.56*	24.25^{NS}	78.58^{NS}	22.07**
Shaheen Basmati	42.07**	134.53^{NS}	5.45**	24.77**	73.04*	20.97*
Grand Mean	45.41	135.06	4.77	23.49	76.26	20.36
S.E.	0.40	0.84	0.08	0.48	1.48	0.22
C.D. (0.05)	0.83	1.75	0.17	0.99	3.07	0.46
C.D. (0.01)	1.13	2.38	0.23	1.35	4.17	0.62
Testers						
Basmati-385	49.40**	123.77**	5.86**	26.47**	95.77**	29.38**
DM-25	41.74**	140.50**	5.68**	22.29^{NS}	84.48**	21.80*
EL-30-2-1	43.40^{NS}	145.43**	2.90**	15.66**	95.28*	17.33**
Grand Mean	44.85	136.57	4.81	21.47	91.84	22.84
S.E.	0.61	0.41	0.03	0.32	0.80	0.37
C.D. (0.05)	1.69	1.13	0.07	0.89	2.22	1.02
C.D. (0.01)	2.81	1.88	0.12	1.47	3.68	1.69
Hybrids						
Basmati-370×Basmati-385	63.40**	151.40**	6.52**	24.98^{NS}	115.93*	33.59^{NS}
Basmati-370×DM-25	59.82^{NS}	159.47**	5.10^{NS}	20.49**	113.45^{NS}	27.02**
Basmati-370×EL-30-2-1	57.73^{NS}	152.03**	5.26^{NS}	18.60**	106.85**	23.03**
DM-2×Basmati-385	69.25**	121.60**	4.80**	27.79**	85.04**	27.34**
DM-2×DM-25	59.22^{NS}	122.73**	4.65**	26.63^{NS}	81.44**	25.10**
DM-2×EL-30-2-1	53.31*	122.67**	4.48**	21.82**	122.79**	31.19^{NS}
DM-107-4×Basmati-385	62.40**	111.03**	6.14**	32.20**	110.57^{NS}	41.27**
DM-107-4×DM-25	60.65*	127.10**	5.43*	28.07**	99.48**	32.25^{NS}
DM-107-4×EL-30-2-1	57.05^{NS}	127.33**	4.60**	21.17**	117.10*	28.81**
DM-16-5-1×Basmati-385	68.96**	128.07**	6.37**	31.17**	102.95**	37.20**
DM-16-5-1×DM-25	54.41^{NS}	145.00**	5.79**	27.35**	86.74**	27.53**
DM-16-5-1×EL-30-2-1	50.06**	145.17**	4.29**	19.84**	114.07^{NS}	25.77**
Kashmir Basmati×Basmati-385	50.44**	135.40**	5.55**	27.06*	126.87**	39.74**
Kashmir Basmati×DM-25	59.68^{NS}	148.27**	5.44*	25.71^{NS}	120.00**	35.32*
Kashmir BasmatixEL-30-2-1	47.49**	161.77**	4.77**	18.84**	142.35**	31.07^{NS}
Basmati-Pak×Basmati-385	52.04**	142.67**	5.81**	27.96**	136.72**	44.21**
Basmati-Pak×DM-25	50.07**	155.13**	4.60**	21.69**	103.61**	25.69**
Basmati-Pak×EL-30-2-1	46.49**	153.60**	3.28**	18.16**	132.01**	27.73**
Basmati-2000×Basmati-385	80.60**	135.83**	6.22**	31.58**	98.46**	35.96**
Basmati-2000×DM-25	65.50**	146.27**	6.36**	29.25**	111.52^{NS}	37.41**
Basmati-2000×EL-30-2-1	41.95**	147.33**	5.81**	27.52**	122.91**	38.89**
Super Basmati×Basmati-385	64.04**	124.70**	5.68**	29.21**	123.93**	41.80**
Super Basmati×DM-25	44.58**	124.07**	4.21**	21.22**	105.85**	25.80**
Super Basmati×EL-30-2-1	51.66**	134.93**	3.54**	21.73**	135.94**	33.80^{NS}
Shaheen Basmati×Basmati-385	57.25^{NS}	124.07**	6.29**	30.62**	95.30**	33.67^{NS}
Shaheen Basmati×DM-25	57.79^{NS}	141.46**	6.11**	28.09**	103.77**	33.51^{NS}
Shaheen Basmati×EL-30-2-1	52.37**	146.60**	4.24**	26.60^{NS}	110.40^{NS}	33.57^{NS}
Grand Mean	56.97	138.36	5.24	25.38	112.08	32.53
S.E	1.62	0.99	0.08	0.67	1.91	1.24
C.D. (0.05)	3.25	1.81	0.16	1.35	3.83	2.50
C.D. (0.01)	4.27	2.38	0.21	1.77	5.04	3.28

*significant ($P < 0.05$), **Highly significant ($P < 0.01$).

C.D.= Critical difference

The analysis of variance revealed highly significant differences among treatments, parents, parents vs crosses, and crosses for flag leaf area, plant height, panicle density, harvest index, biological yield per plant and grain yield per plant (Table 2). Broad sense heritability was maximum (0.99) for plant height followed by 0.98 (for panicle density and biological yield per plant) and 0.94 (for flag leaf area and yield per plant). High estimates of broad sense heritability for all the characters revealed that variations were transmitted to the progeny. Expected genetic advance in response to selection in next generation was high for all traits. Maximum genetic advance (42.11) was noted for biological yield followed by 33.92 for plant height, 19.29 for flag leaf area, 14.65 for yield per plant, 8.62 for harvest index and 1.88 for panicle density. High heritability associated with high genetic advance indicated considerable potential for developing of high yielding varieties through selection of desirable plants in succeeding generations. The results were in line with those of various researchers (8, 14, 17, 22).

Table 2. Analysis of variance, heritability and genetic advance in Basmati rice genotypes.

Source	d.f	Flag leaf area (cm^2)	Plant height (cm)	Panicle density	Harvest index (%)	Biological yield /plant (g)	Yield/plant (g)
Replications	2.00	3.12^{NS}	0.29^{NS}	0.001^{NS}	0.39^{NS}	9.17^{NS}	1.18^{NS}
Treatments	38.00	285.67**	823.24**	2.59**	57.06**	1294.59**	164.85**
Parents	11.00	160.60**	1519.23**	2.76**	51.18**	412.32**	30.26**
Parents vs crosses	1.00	3412.49**	212.94**	5.10**	143.43**	25389.22**	3325.39**
Crosses	26.00	218.31**	552.25**	2.42**	56.23**	741.14**	100.24**
$\sigma^2 g$		93.26	273.58	0.86	18.62	428.03	53.81
$\sigma^2 p$		99.15	276.08	0.88	19.82	438.52	57.24
$\sigma^2 e$		5.90	2.49	0.02	1.20	10.49	3.43
$h^2_{(b.s)}$ ± S.E		0.94±0.01	0.99±0.01	0.98±0.14	0.94±0.03	0.98±0.01	0.94±0.02
G.A.		19.29	33.92	1.88	8.62	42.11	14.65

*Significant ($P < 0.05$), **Highly significant ($P < 0.01$).

The data on estimates of heterosis and heterobeltiosis revealed that mid-parent heterosis for flag leaf area ranged -21.09 to 60.13 percent and that of high-parent heterosis was -33.34 to 42.99 percent (Table 3). Twenty one hybrids indicated significantly positive heterosis as well as heterobeltiosis. Out of these seven hybrids viz. Basmati-370 × Basmati-385 (Ht = 30.80, Htb = 28.33), DM-2 × Basmati-385 (Ht = 42.64, Htb = 40.18), DM-107-4 × Basmati-385 (Ht = 25.65, Htb = 24.98), DM-107-4 ×DM-25 (Ht = 32.32, Htb = 21.47), DM-16-5-1 × Basmati-385 (Ht = 47.85, Htb = 39.60), Basmati 2000 × Basmati-385 (Ht = 43.50, Htb = 28.07) and Super Basmati × Basmati-385 (Ht = 39.21, Htb = 29.63) were important based on higher mean performance and highly significant heterosis of both types. Over-dominant type of gene action was suggested for them. Four hybrids (Kashmir Basmati × Basmati-

Table 3. Heterosis (Ht) and heterobeltiosis (Htb) estimates (%) in rice genotypes.

Hybrids	Flag leaf area		Plant height		Panicle density		Harvest index		Biological yield/plant		Yield/plant	
	Ht	Htb	Ht	Htb	Ht	Htb	Ht	Htb	Ht	Htb	Ht	Htb
Basmati-370 × Basmati-385	30.80**	28.33**	2.90**	22.33**	12.22**	11.26**	6.81*	-5.65^{NS}	28.17**	36.19**	35.95**	14.32**
Basmati-370 × DM-25	34.01**	25.83**	2.55**	13.50**	-10.81**	-11.46**	-3.77^{NS}	-8.08*	33.77**	34.28**	29.16**	23.93**
Basmati-370 × EL-30-2-1	26.96**	21.44**	-3.76**	4.54**	21.43**	-8.68**	3.47^{NS}	-8.34^{NS}	18.46**	25.52**	23.28**	14.98^{NS}
DM-2 × Basmati-385	42.64**	40.18**	12.28**	30.99**	-9.72**	-18.15**	2.89^{NS}	0.87^{NS}	9.13**	41.54**	12.50*	-6.97^{NS}
DM-2 × DM-25	32.44**	24.16**	5.20**	32.21**	-10.88**	-18.03**	6.88*	-3.34^{NS}	12.66**	35.54**	22.39**	15.14*
DM-2 × EL-30-2-1	17.02**	11.75**	2.97**	32.14**	16.73**	-6.08*	0.99^{NS}	-20.81**	58.08**	104.37**	70.65**	62.29**
DM-107-4 × Basmati-385	25.65**	24.98**	-3.63**	4.09**	26.16**	4.78*	18.31**	15.16**	40.71**	80.13**	67.47**	40.44**
DM-107-4 × DM-25	32.32**	21.47**	2.85**	19.16**	13.65**	-4.40*	11.71**	0.37^{NS}	36.39**	62.06**	54.68**	47.94**
DM-107-4 × EL-30-2-1	22.25**	14.27**	1.02^{NS}	19.38**	35.76**	18.76**	-2.96^{NS}	-24.31**	49.50**	90.77**	54.74**	44.76**
DM-16-5-1 × Basmati-385	47.85**	39.60**	-3.05**	3.47**	11.26**	8.76**	24.82**	17.73**	19.29**	33.98**	47.97**	26.61**
DM-16-5-1 × DM-25	27.09**	23.98**	3.23**	3.25**	2.66^{NS}	1.94^{NS}	19.55**	16.55**	7.54**	12.88**	28.93**	26.27**
DM-16-5-1 × EL-30-2-1	14.70**	14.07**	1.56*	3.37**	0.94^{NS}	-23.35**	1.43^{NS}	-15.44**	32.55**	48.44**	34.82**	23.32**
Kashmir Bas × Basmatu-385	22.72**	2.11^{NS}	-3.21**	9.40**	4.45*	-5.23*	13.02**	2.22^{NS}	41.12**	50.97**	58.16**	35.24**
Kashmir Bas × DM-25	60.13**	42.99**	0.01^{NS}	5.53**	4.11*	-4.17*	17.66**	15.35**	42.42**	42.79**	65.58**	62.03**
Kashmir Bas × EL-30-2-1	24.63**	9.41*	7.33**	11.23**	24.36**	0.00^{NS}	1.66^{NS}	-11.99**	58.77**	69.39**	62.65**	48.88**
Basmati-Pak × Basmati-385	17.42**	5.34^{NS}	0.55^{NS}	15.27**	24.28**	-0.85^{NS}	32.43**	5.62^{NS}	45.68**	48.73**	91.59**	50.46**
Basmati-Pak × DM-25	23.67**	19.97**	3.25**	10.42**	0.36^{NS}	-18.97**	14.02**	-2.69^{NS}	17.47**	22.64**	33.22**	17.84*
Basmati-Pak × EL-30-2-1	12.52**	7.12^{NS}	0.58^{NS}	5.62**	2.71^{NS}	-5.92^{NS}	15.60**	15.26**	41.04**	43.62**	62.64**	59.98**
Basmati 2000 × Basmati-385	43.50**	28.07**	3.58**	9.75**	18.02**	6.20**	20.53**	19.29**	15.07**	30.65**	38.66**	22.38**
Basmati 2000 × DM-25	25.16**	4.08^{NS}	4.85**	5.61**	22.68**	11.98**	21.33**	12.80**	39.53**	47.97**	68.94**	66.38**
Basmati 2000 × EL-30-2-1	-21.09**	-33.34**	3.78**	6.38**	53.10**	23.97**	32.32**	6.12^{NS}	44.06**	63.09**	95.33**	72.96**
Super Basmati × Basmati-385	39.21**	29.63**	3.99**	7.44**	9.09**	-3.01^{NS}	15.15**	10.32**	42.16**	57.71**	62.49**	42.26**
Super Basmati x DM-25	5.73^{NS}	4.66^{NS}	-3.29**	6.89**	-17.81**	-25.90**	-8.80*	-12.49**	29.83**	34.70**	17.63**	16.92*
Super Basmati × EL-30-2-1	20.13**	19.02**	3.20**	16.26**	-5.05^{NS}	-22.30**	8.90*	-10.39**	56.38**	72.99**	71.57**	53.17**
Shaheen Basmati × Basmati-385	25.17**	15.88**	-3.94**	0.24^{NS}	11.26**	7.34**	19.50**	15.65**	12.91**	30.48**	33.73**	14.58**
Shaheen Basmati × DM-25	37.93**	37.39**	2.87**	5.15**	9.86**	7.63**	19.41**	13.43**	31.75**	42.07**	56.70**	53.70**
Shaheen Basmati × EL-30-2-1	22.55**	20.66**	4.73**	8.97**	1.64^{NS}	-22.09**	31.61**	7.42*	31.18**	51.15**	75.28**	60.10**
S.E.	1.72	1.98	1.12	1.29	0.10	0.12	0.77	0.89	2.29	2.64	1.31	1.51

*Significant ($P<0.05$), **Highly significant ($P<0.01$)

significant positive heterobeltiosis manifesting partial dominant type of gene action, while Super Basmati × DM-25 indicated non-significant heterosis and heterobeltiosis displaying additive type of gene action. These results are in agreement with earlier findings (19, 20).

Negative heterosis for plant height is desirable for breeding short statured hybrids and varieties. None of the hybrids manifested significantly negative mid-parent and high-parent heterosis for plant height. The extent of heterosis over mid-parent was -3.94 to 12.28 percent and that of better parent was 3.25 to 32.21 percent. Ten hybrids indicated intermediate plant height (111.03 to 128.07 cm) out of which five hybrids viz. DM-2 × Basmati-385 (Ht = 12.28, Htb = 30.99), DM-2 × DM-25 (Ht = 5.20, Htb = 32.21), DM-2 × EL-30-2-1 (Ht = 2.97, Htb = 32.14), DM-107-4 × DM-25 (Ht = 2.85, Htb = 19.16) and Super Basmati × Basmati-385 (Ht = 3.99, Htb = 7.44) had significant positive mid-parent and high-parent heterosis; four hybrids viz. DM-107-4 × Basmati-385 (Ht = -3.63, Htb = 4.09), DM-16-5-1 × Basmati-385 (Ht = -3.05, Htb = 3.47), Super Basmati × DM-25 (Ht = -3.29, Htb = 6.89), Shaheen Basmati × Basmati-385 (Ht = -3.94, Htb = 0.24) possessed significantly negative heterosis and non-significant heterobeltiosis while one hybrid DM-107-4 × EL-30-2-1 (Ht = 1.02, Htb = 19.38) had non-significant heterosis and significant heterobeltiosis. Among these, three hybrids (Super Basmati x Basmati-385, DM-107-4 x Basmati-385 and DM-16-5-1 x Basmati -385) were high yielding. Other six high yielding hybrids were of tall stature (135.40 to 148.27).These were Kashmir Basmati × Basmati-385 (Ht = -3.21, Htb = 9.40), Kashmir Basmati × DM-25 (Ht = 0.01, Htb = 5.53), Basmati-Pak × Basmati-385 (Ht = 0.55, Htb = 15.27), Basmati 2000 × Basmati-385 (Ht = 3.58, Htb = 9.75), Basmati 2000 × DM-25 (Ht = 4.85, Htb = 5.61) and Basmati 2000 × EL-30-2-1 (Ht = 3.78, Htb = 6.38).

Mid-parent and high-parent heterosis ranged -17.81 to 53.10 percent and -25.90 to 23.97 percent respectively for panicle density. Nine hybrids namely Basmati-370 × Basmati-385 (Ht = 12.22, Htb = 11.26), DM-107-4 × Basmati-385 (Ht = 26.16, Htb = 4.78), DM-107-4 × EL-30-2-1 (Ht = 35.76, Htb = 18.76), DM-16-5-1 × Basmati-385 (Ht = 11.26, Htb = 8.76), Basmati 2000 × Basmati-385 (Ht = 18.02, Htb = 6.02), Basmati 2000 × DM-25 (Ht = 22.68, Htb = 11.98), Basmati 2000 × EL-30-2-1 (Ht = 53.10, Htb = 23.97), Shaheen Basmati × Basmati-385 (Ht = 11.26, Htb = 7.34), Shaheen Basmati × DM-25 (Ht = 9.86, Htb = 7.63) had significantly positive heterosis and heterobeltiosis manifesting over dominance type of gene action. Four hybrids viz. DM-107-4 × DM-25 (Ht = 13.65, Htb = -4.40), Kashmir Basmati × Basmati-385 (Ht = 4.45, Htb = -5.23), Kashmir Basmati × DM-25 (Ht = 4.11, Htb = -4.17) and Basmati-Pak × Basmati-385 (Ht = 24.28, Htb = -0.85) had significantly positive heterosis but significant or non-significant negative heterobeltiosis indicating partial dominance type of gene action for increased number of grains per panicle. Two hybrids viz. DM-16-5-1 × DM-25 (Ht = 2.66, Htb = 1.94) and Basmati-Pak × EL-30-2-1 (Ht = 2.71, Htb = -5.92) had non-significant heterosis and heterobeltiosis showing additive type of gene action. All these 15 hybrids can be regarded as promising based on higher mean performance and both types of heterosis for the improvement of panicle density. Five hybrids showed significantly positive mid-parent heterosis but significantly negative heterobeltiosis and three hybrids with significant heterosis and non-significant heterobeltiosis indicating partial dominance. For harvest index, minimum mid-parent heterosis (-8.80 %) was expressed by cross Super Basmati × DM-25 and maximum (32.43) by Basmati-Pak × Basmati-385. Similarly, minimum high-parent heterosis (-24.31) was shown by DM-107-4 × EL-30-2-1 and maximum (19.29) by Basmati 2000 × Basmati-385. Two hybrids DM-2 × Basmati-385 (Ht = 2.89, Htb = 0.87) and Basmati-370 × EL-30-2-1 (Ht = 3.47, Htb = -8.34) had non-significant heterosis and heterobeltiosis indicating additive type of gene action. Based on higher mean performance and desirable heterosis and heterobeltiosis, 11 hybrids were found to be the potential hybrids for higher harvest index. These were: DM-2 × Basmati-385 (Ht = 2.89, Htb = 0.87), DM-107-4 × Basmati-385 (Ht = 18.31, Htb = 15.16), DM-107-4 × DM-25 (Ht = 11.71, Htb = 0.37), DM-16-5-1 × Basmati-385 (Ht = 24.82, Htb = 17.73), Kashmir Basmati × Basmati-385 (Ht = 13.02, Htb = 2.22), Basmati-Pak × Basmati-385 (Ht = 32.43, Htb = 5.62), Basmati 2000 × Basmati-385 (Ht = 20.53, Htb = 19.29), Basmati 2000 × DM-25 (Ht = 21.33, Htb = 12.80), Basmati 2000 × EL-30-2-1 (Ht = 32.32, Htb = 6.12), Super Basmati × Basmati-385 (Ht = 15.15, Htb = 10.32), Shaheen Basmati × Basmati-385 (Ht = 19.50, Htb = 15.65) and Shaheen Basmati × DM-25 (Ht = 19.41, Htb = 13.43). Gnansekaran *et al.* (6) reported similar results with two line rice hybrids.

Heterosis and heterobeltiosis ranged from 7.54 to 58.77 and 12.88 to 104.37, respectively for biological yield per plant. All hybrids indicated significantly positive heterosis of both types. Hybrids viz. DM-2 × Basmati-385 (Ht = 9.13, Htb = 41.54), DM-2 × DM-25 (Ht = 21.66, Htb = 35.54), DM-107-4 × DM-25 (Ht = 36.39, Htb = 62.06), DM-16-5-1 × Basmati-385 (Ht = 19.29, Htb = 33.98), DM-16-5-1 × DM-25 (Ht = 7.54, Htb = 12.88), Basmati-Pak × DM-25 (Ht = 17.47, Htb = 22.64), Basmati 2000 × Basmati-385 (Ht = 15.07, Htb = 30.65), Super Basmati × DM-25 (Ht = 29.83, Htb = 34.70), Shaheen Basmati × Basmati-385 (Ht = 12.91, Htb = 30.48), Shaheen Basmati × DM-25 (Ht = 31.75, Htb = 42.07) had comparatively low biological yield, and most of them were also low yielder. Alternatively the best approach would be simultaneous consideration of yield performance in relation to biological yield. It was observed that nine hybrids viz. Basmati-Pak × Basmati-385 (Ht = 45.68, Htb = 48.73), Super Basmati × Basmati-385 (Ht = 42.16, Htb = 57.71), DM-107-4 × Basmati-385 (Ht = 40.71, Htb = 80.13), Kashmir Basmati × Basmati-385 (Ht = 41.12, Htb = 50.97), Basmati 2000 × EL-30-2-1 (Ht = 44.06, Htb = 63.09), Basmati 2000 × DM-25 (Ht = 39.53, Htb = 47.97), DM-16-5-1 × Basmati-385 (Ht = 19.29, Htb = 33.98), Basmati 2000 × Basmati-385 (Ht = 15.07, Htb = 30.65) and Kashmir Basmati × DM-25 (Ht = 42.42, Htb = 42.79) with significantly positive heterosis and heterobeltiosis showing presence of over dominance could be rated as best ones (16). The mean value of biological yield ranged from 98.46 to 136.72g and grain yield from 35.32 to 44.21g per plant for these hybrids. There was no remarkable effect on grain yield below or beyond biological yield range (98.46 to 136.72) of remaining hybrids.

For grain yield per plant, heterosis and heterobeltiosis was 12.50 to 95.33 and -6.97 to 66.38, respectively. Twenty five hybrids manifested significantly positive heterosis and heterobeltiosis. Over dominant type of gene action was suggested for most of them. However, hybrids with significantly positive heterosis but negative or non-significant positive heterobeltiosis had partially dominant type of gene action as in Basmati-370 × EL-30-2-1 (Ht = 23.28, Htb = 14.98), DM-2 × Basmati-385 (Ht = 12.50, Htb = -6.97). While considering mean performance, heterosis and heterobeltiosis of 27 hybrids, it was observed that high heterotic hybrids were not essentially those showing higher mean performance. Since high yield performance with significant hybrid vigour is ultimate aim of this study, therefore, nine hybrids viz. Basmati-Pak × Basmati-385 (Ht = 91.59, Htb = 50.46), followed by Super Basmati × Basmati-385 (Ht = 62.49, Htb = 42.26), DM-107-4 × Basmati-385 (Ht = 67.47, Htb = 40.44), Kashmir Basmati × Basmati-385 (Ht = 58.16, Htb = 35.24), Basmati 2000 × EL-30-2-1 (Ht = 95.33, Htb = 72.96), Basmati 2000 × DM-25 (Ht = 68.94, Htb = 66.38), DM-16-5-1 × Basmati-385 (Ht = 47.97, Htb = 26.61), Basmati 2000 × Basmati-385 (Ht = 38.66, Htb = 22.38) and Kashmir Basmati × DM-25 (Ht = 65.58, Htb = 62.03) were top performers. Similar results were obtained by Gnansekaran *et al.* (6). The predominant role of dominant type of gene action was attributed to intrinsic nature of parents especially that of Basmati-385, since six high yielding hybrids had Basmati-385 as male parent.

In an ideal situation, hybrids with semi dwarf plant type, high panicle density and harvest index and reasonable biological yield per plant are preferable. As this situation hardly exists, compromises will have to be made among morpho-physiological traits while selecting superior genotypes. Keeping in view mean performance, heterosis and heterobeltiosis estimates, three intermediates (Super Basmati × Basmati-385 , DM-107-4 × Basmati-385 and DM-16-5-1 × Basmati-385) and six tall hybrids (Basmati-Pak × Basmati-385 , Kashmir Basmati × Basmati-385 , Basmati 2000 × EL-30-2-1 , Basmati 2000 × DM-25, Basmati 2000 × Basmati-385 and Kashmir Basmati × DM-25) having better mean yield performance over commercial varieties ; (Super Basmati and Basmati-385) are recommended for heterosis breeding. However, desirable transgressive segregants might be selected in succeeding generations to develop potential varieties from their progenies.

REFERENCES

1. Anon. 2005-06. Agricultural Statistics of Pakistan. Ministry of Food, Agriculture and Livestock, Government of Pakistan Islamabad.
2. Anon. 2006. FAO.STAT database. Food and Agricultural Organization of the United Nations, Rome, Italy.
3. Anon 1998. Standard Evaluation System for Rice. International Rice Testing Programme. The IRRI, Los Banos, Philippines.
4. Falconar, D. S. and T.F.C. Mackay 1996. Introduction to Quantitative Genetics. Chapman and Hall. London, U. K.
5. Glazman, J. C. 1985. A varietal classification of Asian cultivated rice (*Oryza sativa* L.) based on isozyme polymorphism. Proc. Int. Rice Genet. Symp. Manila. p. 83-90.
6. Gnansekaran, M., P. Vivekanandan and S. Muthuramu. 2006. Combining ability and heterosis for yield and grain quality in two line rice (*Oryza sativa* L.) hybrids. Indian. J. Genet. 66(1): 6-9.
7. Gomez, K. A. 1972. Techniques for field experiments with rice. IRRI. Los Banos, Philippines.
8. Hasib, K. M. 2005. Genetic variability, interaction and path analysis for panicle characters in scented rice. Crop Res. Hisar. 30 (1): 37-39.
9. Hosseini, M., R. H. Nejad and A. R. Tarang. 2005. Gene effects, combining ability of quantitative characteristics and grain quality in rice. Iranian J. Agric. Sci. 36(1): 21-32.
10. Johnson, H. W., H.F. Robinson and R.E. Comstock. 1955. Estimates of genetic and environmental variability in soybean. Agron J. 47: 314-318.
11. Kempthorne, O. 1957. An Introduction to Genetic Statistics. John Willey and Sons, New York, USA.

12. Lothrop, J. E., R.E. Arkins and O.S. Smith. 1985 Variability for yield and yield components in IAPIR grain sorghum mating population. I. Means. Variance components and heritabilities. Crop Sci. 25: 235-240.
13. Mahto, R. N., M. S. Yadava and K. S. Mohan. 2003. Genetic variation, character association and path analysis in rainfed upland rice. Ind. J. Dryland Agric. Res. Dev. 18(2): 196-198.
14. Mishra, L. K. and R. K. Verma. 2002. Genetic variability for quality and yield traits in non-segregating populations of rice (*Oryza sativa* L.). Plant Archives. 2(2): 251-256.
15. Singh, R. K. and B.D. Chaudhary. 1985. Biometrical Methods in Quantitative Genetics. Kalayani Publ. New Delhi.
16. Surek, H. and K. Z. Korkut. 2002. Heterosis for yield and its components under temperate conditions. Proc. Euro Rice-2001 Symp. Krasnodar, Russia, Sep. 3-8 p: 1-10.
17. Swati, P. G. and B. R. Ramesh. 2004. The nature and divergence in relation to yield traits in rice germplasm. Annals. Agric. Res. 25(4): 598-602.
18. Thirumeni, S., M. Subramanian and K. Paramasivam. 2000. Combining ability and gene action in rice. Theor. Agric. Res. 12: 375-385.
19. Vanaja, T. and L. C. Babu. 2004. Heterosis for yield and yield components in rice (*Oryza sativa* L.). J. Trop. Agri. 42 (1/2): 43-44.
20. Verma, O. P., U. S. Shanthi and H. K. Srivastava. 2002. Heterosis and inbreeding depression for yield and certain physiological traits in hybrids involving diverse ecosystem of rice (*Oryza sativa* L.). J. Genet. Breed. 56 (3): 267-278.
21. Vivek, S., S. Surendra, S. K. Singh and H. Singh. 2000. Analysis of variability and heritability in new plant type tropical japonica rice (*Oryza sativa* L.). Environ. Ecol. 22(1): 43-45.
22. Yoshida, S. 1981. Fundamentals. of rice crop science. Int. Rice Res. Inst., Manila, Philippines.
23. Yoshida, Y., D.A. Forono, T.H. Cock and K.A. Gomez. 1975. Laboratory Manual for Physiological Studies of Rice. 3rd Ed. IRRI, Los Banos, Philippines.