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Research Article

Heterosis Assessment for Yield Related Traits in F_1 Rice Hybrids

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Abstract

Realizing the genetic potential of hybrid rice for yield improvement, the present study was undertaken to study the performance of F_1 rice hybrids derived from 8 × 8 full diallel mating design. F_1 rice hybrids along with the parents were planted in randomized complete block design with three replications at The University of Agriculture-Peshawar during 2019 rice crop growing season. Significant ($P \leq 0.01$) differences among the parental genotypes and F_1 hybrids were observed for yield related traits. Most of the F_1 rice hybrids showed superior performance for yield related traits in comparison with the parental genotypes. Among F_1 cross combinations, Shaheen-Basmati × Shua-92 displayed maximum panicle length (33.7 cm), primary branches panicle^{-1} (12), secondary branches panicle^{-1} (35), grains panicle^{-1} (95), 100-grain weight (4.0 g) and grain yield plant^{-1} (44.7 g). F_1 cross combination, DR-82 × Shaheen-Basmati revealed the highest better-parent heterosis for panicle length (16.38%) and 100-grain weight (32.50%) while F_1 hybrid, Shaheen-Basmati × Shua-92 showed maximum better-parent heterosis for primary branches panicle^{-1} (24.44%) and secondary branches panicle^{-1} (21.35%). Maximum better-parent heterosis for grains panicle^{-1} (67.31%) was manifested by F_1 cross combination, DR-92 × Shaheen-Basmati whereas highest better-parent heterosis for grain yield plant^{-1} (157.88%) was displayed by F_1 rice hybrid, Shaheen-Basmati × Shua-92. On the basis of the superior performance for yield related traits, F_1 cross combinations, DR-82 × Shaheen-Basmati, Shaheen-Basmati × Shua-92 and DR-92 × Shaheen-Basmati are recommended for commercial use as rice hybrids after multi-locational trials. Additionally, segregating generations of these hybrids could be advanced to develop rice cultivars with desirable attributes.

Keywords: Rice; Heterosis; F_1 Rice Hybrids; Grain Yield; Yield Related Traits

Introduction

Rice is one of the most important cereal crops in the world and is the principal food for more than half of the world's population. We need to go for hybrid rice because demand for rice is rapidly increasing with the increase in population, especially in less developed countries. The need to increase grain yield of rice per unit area is considered as one of the primary goals of rice crop improvement programs. Considering the increasing requirements on account of population increase and decreasingly land/water assets, it is imperative to enhance rice yield for ensuring the food security. Conventional crop breeding approaches encompasses selection, identification and development of high yielding rice hybrids/cultivars and exploitation of their combining abilities in hybridization programs [1-3]. On account of exploitation of phenomenon of heterosis, hybrid rice could increase yield by 20-25% over inbred varieties. Heterosis breeding is a fundamental tool for the expression of commercial exploitation of heterosis with the desired characteristics [1]. The present study was, therefore performed to assess genetic variation among F_1 cross combinations and to estimate heterotic potential of F_1 rice hybrids. Heterosis breeding exploits the phenomenon of hybrid vigor has proven to be a practical method of crop improvement, especially for increasing yield potential. The term heterosis, often used synonymously with hybrid vigor, refers to the superiority of the F_1 hybrid over its parents. Expression of heterosis is confined to the first generation only and it could be positive or negative. Both positive and negative heterosis are useful in crop improvement, depending on the nature of trait. Positive heterosis is desired for yield and related traits while negative heterosis is desirable for maturity traits. Heterosis is expressed in different ways, depending on the reference which is used to compare the performance of a hybrid. Mid-parent heterosis is the increase or decrease in the performance of the hybrid in comparison with the mid-parental value whereas better parent heterosis is the increase or decrease in the performance level of the hybrid in comparison with the better parent of the cross combination (IRRI, 2020).

Materials and Methods

The study was conducted at the Research Farm of The University of Agriculture, Peshawar-Pakistan. Eight rice genotypes namely DR-82, Shaheen-Basmati, KS-282, Basmati-2000, DR-83, DR-92, Shua-92 and IR-8 obtained from National Agriculture Research Center (NARC) Islamabad-Pakistan. These genotypes were planted during 2018 rice crop growing season using multiple sowing and transplantation dates. The genotypes were then crossed in all possible combinations using 8 × 8 diallel mating system. Fifty-six F_1 rice hybrids along with parental genotypes were planted during 2019 rice crop growing season in a randomized complete block design with three replications. Three rows of each parent and F_1 hybrid was 1m measured with 30 x 40 cm, row to row and plant to plant spacing, respectively. Data were recorded on panicle length, primary branches panicle^{-1}, secondary branches panicle^{-1}, grains panicle^{-1}, grain yield plant^{-1} and 100-grain weight using ten randomly selected plants in each entry.

Statistical and Biometrical analysis

The data were analyzed using the procedure outlined by Steel and Torrie (1980) with the help of Statistx-8.1 computer software. Upon significant F-test for genotypes in analysis of variance (ANOVA), means of genotypes were separated using least significant difference (LSD) test at 1% probability level. The percent increase or decrease of F_1 hybrids over mid and better parents were calculated to estimate possible heterotic effects for all the traits, using following formulae [4].

Mid-parent heterosis % (MPH) = $(F_1 - MP)/MP \times 100$

Better-parent heterosis % (MPH) = $(F_1 - MP)/MP \times 100$

The significance of mid and better parent heterosis was determined following the "t" test suggested by [5].

MP (t) = $(F_1\text{-}MP)/(3/2r \times EMS)^{1/2}$ BP (t) = $(F_1\text{-} BP)/(3/2r \times EMS)^{1/2}$

Where

F_1 = Mean value of F_1 hybrid, MP = Average value of the two parents involved in a cross, BP = Mean value of better parent of the particular cross, EMS = Error mean square

Results and Discussion

Panicle length

Mean squares showed significant (P ≤ 0.01) differences among parents and their F_1 rice hybrids for panicle length (Table 1). Mean data among the parents for panicle length ranged from 28.3 to 30.2 cm. Parental genotype, Shua-92 (30.2 cm) showed longest panicles followed by Shaheen-Basmati (29.3 cm) and IR-8 (28.8). Panicle length among F_1 rice hybrids varied from 29.7 to 33.7 cm. F_1 cross combination, Shaheen-Basmati × Shua-92 showed maximum panicle length (33.7 cm) followed by DR-82 × Shaheen-Basmati (33.4) and DR-82 × Shua-92 (32.6) (Table 2). Generally, longer panicle is associated with higher number of grains panicle^{-1} resulting into higher productivity. Among the F_1 rice hybrids, forty-one hybrids showed significantly positive mid-parent heterosis while forty-five F_1 hybrids displayed significantly better-parent heterosis for this trait. Maximum positive mid-parent heterosis (41.81%) was observed for F_1 rice hybrid, Shaheen-Basmati × Basmati-2000 while better-parent heterosis (16.38%) was observed for F_1 rice hybrid, DR-82 × Shaheen-Basmati followed by Shua-92 × DR-82 (15.68%) and Shaheen-Basmati × Shua-92 (15.02%) (Table 4). Our findings are in agreement with those of [6,7].studied five rice genotypes and observed significant differences among genotypes for yield and related traits and observed significantly positive high parent heterosis while [7] manifested significant differences for grain yield and yield contributing traits using seven diversified elite lines of rice, four F_1 hybrids and their corresponding F_2 populations.

Primary branches panicle^{-1}

Significant (P ≤ 0.01) differences among parents and their F_1 cross combinations were observed for primary branches panicle^{-1} (Table 1). Mean values among parental genotypes for primary branches panicle-1 ranged between 9.0 and 11.0. Parental genotypes, Shua-92 (10.0) and IR-8 (11.0) produced maximum primary branches panicle-1. The mean values for this trait among F_1 rice hybrids ranged from 10.0 to 12.0. F_1 cross combination, Shaheen-Basmati × Shua-92 produced maximum primary branches panicle-1 (12.0) followed by IR-8 × Shaheen-Basmati (12.0) (Table 2). Forty-two F1 cross combinations showed significantly positive mid-parent heterosis while, 46 F_1 rice hybrids displayed significantly positive better parent heterosis for this trait. Highest positive mid-parent heterosis was displayed for F_1 cross combination, Shaheen-Basmati × Basmati - 2000 (58.84%). Maximum better-parent heterosis was manifested for F_1 cross combination, Shaheen-Basmati × Shua-92 (24.44%) followed by Shaheen-Basmati × DR-83 (22.22%) (Table 5). The present findings are in line with the results of [6,8]. studied five rice genotypes and observed significant differences among genotypes for primary branches panicle^{-1}. [8] displayed significantly positive heterosis for the corresponding trait.

Secondary branches panicle^{-1}

Analysis of variance revealed significant (P ≤ 0.01) variation among parents and their F_1 rice hybrids for secondary branches panicle^{-1} (Table 1). Among parental genotypes mean values for secondary branches panicle^{-1} varied between 28.7 and 32.0. Parental genotypes, Shua-92 (32.0), Basmati-2000 (31.9) and Shaheen-Basmati (29.7) produced maximum secondary branches panicle-^{1}. Secondary branches panicle-^{1} among F_1 rice hybrids ranged between 30.0 and 36.0. F_1 rice hybrid, Shaheen-Basmati × Shua-92 produced maximum secondary branches panicle-^{1} (36.0) followed by Shaheen-Basmati × Basmati-2000 (34.5) and Shua-92 × Basmati-2000 (34.4) (Table 2). Overall, 31 F1 cross combinations showed significantly positive heterosis over mid-parent while thirty-eight F_1 hybrids displayed significantly positive heterosis over better-parent. Maximum positive mid-parent heterosis was observed for F_1 cross combination, Shaheen-Basmati × Basmati-2000 (49.12%) whereas the highest better-parent heterosis was manifested for F1 cross combination, Shaheen-Basmati × Shua-92 (21.35%) followed by KS-282 × Shua-92 (19.32%) and DR-82 × Shua-92 (14.46%) (Table 6). Similar results also observed by [7,8]. They observed significant differences for grain yield and yield contributing traits and high estimates of heterosis.

Grains panicle^{-1}

The analysis of variance table displayed significant (P ≤ 0.01) differences among parents and their F_1 rice cross combinations (Table 1). Mean values among the parental genotypes for grains panicle^{-1} varied from 53 to 61. Parental genotypes, DR-82 (71), Shaheen-Basmati (69), IR-8 (61) and Shua-92 (59) revealed maximum grains panicle^{-1}. Mean values for this trait among F_1 rice hybrids ranged between 61 and 95 grains panicle^{-1}. F_1 cross combination, Shaheen-Basmati × DR-82 produced maximum grains panicle^{-1} (96.0) followed by Shaheen-Basmati × Shua-92 (95.0) and DR-82 × IR-8 (91.4) (Table 3). Forty-one F_1 rice hybrids showed significantly positive mid-parent heterosis whereas 44 F_1 rice hybrids revealed significantly positive better-parent heterosis for grains panicle^{-1}. F_1 cross combination, DR-92 × Shaheen-Basmati showed the highest positive mid-parent (72.82%) and better-parent (67.31%) heterosis for grains panicle^{-1} (Table 7). Our findings are in agreement with those of [6,7]. observed significantly positive high-parent heterosis for most of the yield related traits in population of five cross combinations which is compatible with the findings of present study.

100-grain weight

Significant (P ≤ 0.01) differences among the parents and their F_1 rice hybrids were found for 100-grain weight (Table 1). Mean values among parents for 100-grain weight ranged from 3.3 to 3.7 g. Parental genotype, IR-8 showed maximum 100-grain weight (3.7 g) followed by Shaheen-Basmati (3.6 g) and DR-82 (3.4 g). Among F_1 rice cross combinations for 100-grain weight means values were varied from 3.2 to 3.8 g. F_1 rice hybrid, Shaheen-Basmati × Shua-92 exhibited maximum 100-grain weight (4.0 g) followed by Shaheen-Basmati × IR-8 (4.0) and DR-82 × IR-8 (3.9 g) (Table 3). The 100-grain weight is one of the important traits which impact the grain yield. Significantly positive mid-parent heterosis was observed for 12 F_1 rice hybrids while 19 F_1 cross combinations recorded significantly positive better-parent heterosis for 100-grain weight. Maximum positive mid-parent heterosis was observed for F_1 cross combination, Shaheen-Basmati × Basmati-2000 (44.99%) while maximum better-parent heterosis was observed for F_1 cross combination, DR-82 × Shaheen-Basmati (32.50%) followed by Shaheen-Basmati × DR-82 (25.71%) and KS-282 × DR-82 (15.26%)

(Table 8). Our results are in line with those of [6,7]. They observed significantly positive high-parent heterosis for 100 grain weight.

Grain yield plant^{-1}

Mean squares revealed significant (P ≤ 0.01) variation among parents and their F_1 rice hybrids for grain yield (Table 1). For grain yield plant^{-1} mean values among parents were varied from 16.4 to 28.6 g. Parental genotype, Shua-92 (28.6 g) produced maximum grain yield plant^{-1} followed by Basmatti-2000 (27.7 g) and Shaheen-Basmati (26.3 g). Among F_1 cross combinations, mean values for grain yield plant^{-1} ranged between 22.1 and 44.7 g. F_1 rice hybrid, Shaheen-Basmati × Shua-92 (44.7 g) revealed maximum grain yield plant^{-1} followed by Shaheen-Basmati × Basmati-2000 (39.7 g) and Shua92 × Basmati-2000 (38.8 g) (Table 3). Significantly positive mid-parent heterosis for grain yield plant^{-1} was manifested for 52 F_1 cross combinations and significantly positive better-parent heterosis was recorded for 49 F_1 rice hybrids. Maximum positive mid-parent (148.56%) and better-parent (157.88%) heterosis was measured for F_1 cross combination, Shaheen-Basmati × Shua-92 (Table 9). Our findings are in line with the results of [6-8]. They also reported high heterotic values in hybrids for yield and its related traits [9-13].

Traits	Replications (d. f. = 2)	Genotypes (d. f. = 63)	Error (d. f. = 253)	CV%
Panicle length	141.29	7.30**	2.27	4.85
Primary branches panicle^{-1}	0.12	1.44**	0.68	7.75
Secondary branches panicle^{-1}	5.49	6.68**	3.53	5.66
Grains panicle^{-1}	7.84	419.92**	9.65	4.21
100-grain weight	0.17	0.09**	0.05	6.21
Grain yield plant^{-1}	103.16	91.13**	17.78	15.11

Table 1: Mean squares of eight parents and 56 F_1 rice hybrids for yield traits at Peshawar.

** = Significant at 1% probability level.

Genotypes	PL	PBP	SBP	F_1 Hybrids	PL	PBP	SBP
Parents							
DR-82	28.7	9.0	29.7	DR-83 x DR-82	31.0	10.0	31.0
ShaheenBasmati (SB)	29.3	9.0	29.7	DR-83 x SB	30.0	10.0	31.7
KS-282	28.3	9.8	29.3	DR-83 x KS-282	30.7	11.0	30.8
Basmati-2000 (B-2000)	27.9	9.7	31.9	DR-83 x B-2000	30.3	11.0	34.0
DR-83	28.3	9.0	28.7	DR-83 x DR-92	30.7	11.0	32.0
DR-92	28.3	10.0	30.7	DR-83 x Shua-92	29.7	11.0	33.2
Shua-92	30.2	10.0	32.0	DR-83 x IR-8	32.0	10.0	32.8
IR-8	28.8	11.0	30.7	DR-92 x DR-82	32.5	10.0	32.0
Parental Means	28.7	11.0	30.0	DR-92 x SB	30.3	10.0	31.0
F_1 Hybrids				DR-92 x KS-282	30.7	11.0	34.0
DR-82 x SB	33.4	11.0	32.0	DR-92 x B-2000	29.7	11.0	33.9
DR-82 x KS-282	32.6	11.0	33.0	DR-92 x DR-83	32.0	11.0	33.7
DR-82 x B-2000	32.4	11.0	33.1	DR-92 x Shua-92	29.5	10.0	30.0

DR-82 x DR-83	31.8	10.0	31.3	DR-92xIR-8	30.0	11.0	34.0
DR-82 x DR-92	30.8	10.0	31.2	Shua-92 x DR-82	30.5	11.0	31.7
DR-82 x Shua-92	32.6	10.0	34.0	Shua-92 x SB	30.0	11.0	33.3
DR-82 x IR-8	32.0	11.0	32.7	Shua-92 x KS-282	30.7	11.0	32.7
SB x DR-82	32.4	11.0	31.7	Shua-92 x B-2000	30.3	11.0	34.4
SB x KS-282	30.3	10.0	30.8	Shua-92 x DR-83	30.7	11.0	33.1
SB x B -2000	30.7	11.0	34.5	Shua-92 x DR-92	30.7	11.0	31.3
SB x DR-83	31.6	11.0	33.9	Shua-92 x IR-8	30.3	11.0	31.2
SB x DR-92	32.0	11.0	34.2	IR-8 x DR-82	32.0	11.0	34.0
SB x Shua-92	33.7	12.0	36.0	IR-8 x SB	29.6	12.0	33.0
SB x IR-8	30.0	11.0	32.7	IR-8 x KS-282	30.0	11.0	31.7
KS-282 x DR-82	31.6	11.0	32.8	IR-8 x B-2000	31.8	11.0	34.0
KS-282 x SB	30.0	10.0	34.0	IR-8 x DR-83	30.0	11.0	34.0
KS-282 x B-2000	30.7	11.0	33.9	IR-8 x DR-92	30.7	11.0	33.9
KS-282 x DR-83	30.3	11.0	33.0	IR-8 x Shua-92	30.3	10.0	34.2
KS-282 x DR-92	30.7	10.0	31.7	F_1 Hybrids Means	31.0	11.0	33.0
KS-282 x Shua-92	30.7	10.0	34.0	LSD $_{(0.05)}$ Genotypes	2.42	1.32	3.02
KS-282 x IR-8	30.3	11.0	31.7				
B-2000 x DR-82	32.2	11.0	32.7				
B-2000 x SB	31.3	11.0	33.0				
B-2000 x KS-282	32.0	10.0	34.5				
B-2000 x DR-83	29.7	11.0	33.1				
B-2000 x DR-92	30.0	10.0	31.3				
B-2000 x Shua-92	29.8	10.0	31.2				
B-2000 x IR-8	30.0	11.0	34.0				

Table 2: Mean values of eight parents and 56 F_1 rice hybrids for panicle length (PL), primary branches panicle^{-1} (PBP) and secondary branches panicle^{-1} (SBP) at Peshawar during 2019.

Genotypes	GP	HGW	GYP	F_1 Hybrids	GP	HGW	GYP
Parents							
DR-82	71.0	3.4	24.7	DR-83 x DR-82	61.0	3.5	38.1
ShaheenBasmati (SB)	69.0	3.6	26.3	DR-83 x SB	74.9	3.6	31.9
KS-282	58.0	3.3	16.4	DR-83 x KS-282	65.3	3.4	27.7
Basmati-2000 (B-2000)	53.0	3.3	27.7	DR-83 x B-2000	81.0	3.7	34.6
DR-83	55.0	3.3	21.7	DR-83 x DR-92	82.1	3.4	24.8
DR-92	53.3	3.3	21.3	DR-83 x Shua-92	65.7	3.6	26.1
Shua-92	59.0	3.4	28.6	DR-83 x IR-8	84.0	3.3	22.4
IR-8	61.0	3.7	20.0	DR-92 x DR-82	85.9	3.3	30.7
Parental Means	56.0	3.4	21.0	DR-92 x SB	90.1	3.6	29.0

F_1 Hybrids				DR-92 x KS-282	61.0	3.3	25.4
DR-82 x SB	73.0	3.9	30.2	DR-92 x B-2000	74.9	3.4	33.2
DR-82 x KS-282	81.0	3.4	27.5	DR-92 x DR-83	65.3	3.5	25.5
DR-82 x B-2000	82.1	3.7	31.3	DR-92 x Shua-92	81.0	3.4	29.1
DR-82 x DR-83	65.7	3.6	29.5	DR-92xIR-8	82.1	3.4	27.7
DR-82 x DR-92	84.0	3.4	28.7	Shua-92 x DR-82	65.7	3.7	26.8
DR-82 x Shua-92	85.9	3.4	28.2	Shua-92 x SB	84.0	3.6	25.4
DR-82 x IR-8	91.4	3.9	27.4	Shua-92 x KS-282	85.9	3.4	24.2
SB x DR-82	96.0	3.7	28.4	Shua-92 x B-2000	65.3	3.4	38.8
SB x KS-282	74.9	3.5	28.7	Shua-92 x DR-83	81.0	3.6	24.8
SB x B-2000	65.3	3.8	39.7	Shua-92 x DR-92	82.1	3.5	22.1
SB x DR-83	81.0	3.6	26.7	Shua-92 x IR-8	65.7	3.5	22.8
SB x DR-92	82.1	3.5	25.8	IR-8 x DR-82	84.0	3.3	27.8
SB x Shua-92	95.0	4.0	44.7	IR-8 x SB	85.9	3.6	28.7
SB x IR-8	84.0	4.0	24.7	IR-8 x KS-282	66.2	3.3	23.9
KS-282 x DR-82	85.9	3.8	35.2	IR-8 x B-2000	83.8	3.8	34.1
KS-282 x SB	65.3	3.7	32.6	IR-8 x DR-83	61.0	3.5	25.8
KS-282 x B-2000	81.0	3.5	36.1	IR-8 x DR-92	74.9	3.5	23.0
KS-282 x DR-83	82.1	3.6	32.3	IR-8 x Shua-92	65.3	3.6	22.1
KS-282 x DR-92	65.7	3.4	26.9	F_1 Hybrids Means	76.0	3.5	28.7
KS-282 x Shua-92	84.0	3.2	23.2	LSD $_{(0.05)}$ Genotypes	5.00	0.34	6.78
KS-282 x IR-8	85.9	3.2	27.2				
B-2000 x DR-82	66.2	3.4	33.6				
B-2000 x SB	83.8	3.7	29.0				
B-2000 x KS-282	61.0	3.6	29.4				
B-2000 x DR-83	74.9	3.4	35.3				
B-2000 x DR-92	65.3	3.4	31.8				
B-2000 x Shua-92	61.0	3.5	29.1				
B-2000 x IR-8	74.9	3.5	28.8				

Table 3: Mean values of eight parents and 56 F_1 rice hybrids for grains panicle^{-1} (GP), 100-grain weight (HGW) and grain yield plant^{-1} (GYP) at Peshawar during 2019.

S.NO.	F_1 Rice Hybrids	Panicle Length		S.NO.	F_1 Rice Hybrids	Panicle Length	
		MPH%	HPH%			MPH%	HPH%
1.	DR-82 x Shaheen-Basmati	15.17**	16.38**	29.	DR-83 x DR-82	8.84**	8.01**
2.	DR-82 x KS-282	14.32**	13.59**	30.	DR-83 x Shaheen-Basmati	4.23	6.13
3.	DR-82 x Basmati-2000	14.49**	12.89**	31.	DR-83 x KS-282	8.36**	8.49**
4.	DR-82 x DR-83	11.64**	10.80**	32.	DR-83 x Basmati-2000	8.01**	7.31*
5.	DR-82 x DR-92	14.45**	13.59**	33.	DR-83 x DR-92	8.49**	8.49**

6.	DR-82 x Shua-92	7.64**	10.45**	34.	DR-83 x Shua-92	1.48	4.95
7.	DR-82 x IR-8	11.30	11.50*	35.	DR-83 x IR-8	12.15**	13.21**
8.	Shaheen-Basmati x DR-82	11.72**	12.89**	36.	DR-92 x DR-82	14.10**	13.24**
9.	Shaheen-Basmati x KS-282	5.26	7.06*	37.	DR-92 x Shaheen-Basmati	5.39**	3.53*
10.	Shaheen-Basmati x Basmati-2000	41.81**	9.92**	38.	DR-92 x KS-282	8.36**	8.24**
11.	Shaheen-Basmati x DR-83	9.79**	11.79**	39.	DR-92 x Basmati-2000	5.64**	6.33**
12.	Shaheen-Basmati x DR-92	11.18**	9.22**	40.	DR-92 x DR-83	13.21**	13.21**
13.	Shaheen-Basmati x Shua-92	13.28**	15.02**	41.	DR-92 x Shua-92	1.48	4.95
14.	Shaheen-Basmati x IR-8	3.27*	2.39*	42.	DR-92xIR-8	5.14	6.13*
15.	KS-282 x DR-82	10.81**	11.53**	43.	Shua-92 x DR-82	12.73**	15.68**
16.	KS-282 x Shaheen-Basmati	4.11	5.88	44.	Shua-92 x Shaheen-Basmati	0.84	2.39
17.	KS-282 x Basmati-2000	9.07**	8.24**	45.	Shua-92 x KS-282	4.78**	8.24**
18.	KS-282 x DR-83	7.18*	7.31*	46.	Shua-92 x Basmati-2000	4.42**	8.72**
19.	KS-282 x DR-92	8.36**	8.24**	47.	Shua-92 x DR-83	4.90**	8.49**
20,	KS-282 x Shua-92	4.78**	8.24**	48,	Shua-92 x DR-92	4.90**	8.49**
21.	KS-282 x IR-8	6.18	7.06*	49.	Shua-92 x IR-8	2.82	0.44
22.	Basmati-2000 x DR-82	13.78**	12.20**	50.	IR-8 x DR-82	11.30**	11.50**
23.	Basmati-2000 x Shaheen-Basmati	9.56**	9.18**	51.	IR-8 x Shaheen-Basmati	2.24	1.37
24	Basmati-2000 x KS-282	13.81**	13.14**	52	IR-8 x KS-282	5.02**	5.88**
25.	Basmati-2000 x DR-83	5.64	6.24	53.	IR-8 x Basmati-2000	12.17**	13.98**
26.	Basmati-2000 x DR-92	6.82*	7.53*	54.	IR-8 x DR-83	5.14	6.13
27.	Basmati-2000 x Shua-92	2.12	6.33	55.	IR-8 x DR-92	7.48*	8.49**
28.	Basmati-2000 x IR-8	5.82	7.53*	56.	IR-8 x Shua-92	2.82	0.44

Table 4: Mid parent heterosis (MPH%) and high parent heterosis (HPH%) for panicle length of 56 F_1 rice hybrids at Peshawar during 2019.

S.NO.	F_1 Rice Hybrids	Primary branches panicle^{-1}		S.NO.	F_1 Rice Hybrids	Primary branches panicle^{-1}	
		MPH%	HPH%			MPH%	HPH%
1.	DR-82 x Shaheen-Basmati	22.22**	22.22**	29.	DR-83 x DR-82	11.11**	11.11**
2.	DR-82 x KS-282	17.02**	22.22**	30.	DR-83 x Shaheen-Basmati	11.11**	11.11**
3.	DR-82 x Basmati-2000	17.65**	22.22**	31.	DR-83 x KS-282	17.02**	22.22**
4.	DR-82 x DR-83	11.11**	11.11**	32.	DR-83 x Basmati-2000	17.65**	22.22**
5.	DR-82 x DR-92	5.26*	11.11**	33.	DR-83 x DR-92	15.79**	22.22**
6.	DR-82 x Shua-92	11.11**	11.11**	34.	DR-83 x Shua-92	22.22**	22.22**
7.	DR-82 x IR-8	10.00**	22.22**	35.	DR-83 x IR-8	6.00	11.11**
8.	Shaheen-Basmati x DR-82	22.22**	22.22**	36.	DR-92 x DR-82	5.26	11.11**
9.	Shaheen-Basmati x KS-282	6.74*	2.38	37.	DR-92 x Shaheen-Basmati	5.26	11.11**

10.	Shaheen-Basmati x Basmati-2000	58.84**	13.40*	38.	DR-92 x KS-282	11.11**	12.24**
11.	Shaheen-Basmati x DR-83	22.22**	22.22**	39.	DR-92 x Basmati-2000	11.68**	13.40**
12.	Shaheen-Basmati x DR-92	15.79**	22.22**	40.	DR-92 x DR-83	15.79**	22.22**
13.	Shaheen-Basmati x Shua-92	33.33**	24.44**	41.	DR-92 x Shua-92	5.26	0.00
14.	Shaheen-Basmati x IR-8	10.00**	22.22**	42.	DR-92xIR-8	4.76	10.00**
15.	KS-282 x DR-82	17.02**	12.24**	43.	Shua-92 x DR-82	22.22**	22.22**
16.	KS-282 x Shaheen-Basmati	6.38*	2.06	44.	Shua-92 x Shaheen-Basmati	22.22**	22.22**
17.	KS-282 x Basmati-2000	12.82**	12.24**	45.	Shua-92 x KS-282	17.02**	12.24**
18.	KS-282 x DR-83	17.02**	22.22**	46.	Shua-92 x Basmati-2000	17.65**	13.40**
19.	KS-282 x DR-92	1.01	2.04	47.	Shua-92 x DR-83	22.22**	22.22**
20,	KS-282 x Shua-92	6.39*	2.04	48,	Shua-92 x DR-92	15.79**	10.00**
21.	KS-282 x IR-8	5.77	12.24**	49.	Shua-92 x IR-8	10.00**	22.22**
22.	Basmati-2000 x DR-82	17.65**	22.22**	50.	IR-8 x DR-82	10.00**	22.22**
23.	Basmati-2000 x Shaheen-Basmati	17.65**	22.22**	51.	IR-8 x Shaheen-Basmati	20.00**	33.33**
24	Basmati-2000 x KS-282	2.56	2.06	52	IR-8 x KS-282	6.09	12.59**
25.	Basmati-2000 x DR-83	18.00**	13.61**	53.	IR-8 x Basmati-2000	6.28	13.40**
26.	Basmati-2000 x DR-92	1.52	3.09	54.	IR-8 x DR-83	10.00**	22.22**
27.	Basmati-2000 x Shua-92	6.95*	3.09	55.	IR-8 x DR-92	4.76	10.00**
28.	Basmati-2000 x IR-8	6.28	13.40**	56.	IR-8 x Shua-92	0.00	11.11

Table 5: Mid parent heterosis (MPH%) and high parent heterosis (HPH%) for primary branches panicle^{-1} of 56 F_1 rice hybrids at Peshawar during 2019.

S.NO.	F_1 Rice Hybrids	Secondary branches panicle^{-1}		S.NO.	F_1 Rice Hybrids	Secondary branches panicle^{-1}	
		MPH%	HPH%			MPH%	HPH%
1.	DR-82 x Shaheen-Basmati	7.74*	7.62*	29.	DR-83 x DR-82	6.16	4.26
2.	DR-82 x KS-282	11.74**	10.99**	30.	DR-83 x Shaheen-Basmati	8.69**	10.58**
3.	DR-82 x Basmati-2000	7.47*	11.32**	31.	DR-83 x KS-282	6.32	7.56*
4.	DR-82 x DR-83	7.31*	5.38	32.	DR-83 x Basmati-2000	12.33**	18.60**
5.	DR-82 x DR-92	3.31	4.93	33.	DR-83 x DR-92	7.87*	11.63**
6.	DR-82 x Shua-92	13.95**	14.46**	34.	DR-83 x Shua-92	16.59**	19.30**
7.	DR-82 x IR-8	8.17**	9.87**	35.	DR-83 x IR-8	10.45**	14.30**
8.	Shaheen-Basmati x DR-82	6.73*	6.61	36.	DR-92 x DR-82	5.96	7.62*
9.	Shaheen-Basmati x KS-282	4.52	5.11	37.	DR-92 x Shaheen-Basmati	2.76	4.49

10.	Shaheen-Basmati x Basmati-2000	49.12**	6.69*	38.	DR-92 x KS-282	13.33**	15.91**
11.	Shaheen-Basmati x DR-83	16.11**	18.14**	39.	DR-92 x Basmati-2000	8.32**	6.28
12.	Shaheen-Basmati x DR-92	13.37**	15.28**	40.	DR-92 x DR-83	13.48**	17.44**
13.	Shaheen-Basmati x Shua-92	20.67**	21.35**	41.	DR-92 x Shua-92	-1.10	-2.17
14.	Shaheen-Basmati x IR-8	8.40**	10.22**	42.	DR-92xIR-8	10.87**	10.87**
15.	KS-282 x DR-82	11.17**	11.93**	43.	Shua-92 x DR-82	6.25	6.73*
16.	KS-282 x Shaheen-Basmati	15.25**	15.91**	44.	Shua-92 x Shaheen-Basmati	11.73**	12.36**
17.	KS-282 x Basmati-2000	10.68**	15.45**	45.	Shua-92 x KS-282	10.11**	11.36**
18.	KS-282 x DR-83	13.79**	15.12**	46.	Shua-92 x Basma-ti-2000	11.42**	8.16**
19.	KS-282 x DR-92	5.56	7.95*	47.	Shua-92 x DR-83	12.84**	15.47**
20,	KS-282 x Shua-92	17.98**	19.32**	48,	Shua-92 x DR-92	3.30	2.17
21.	KS-282 x IR-8	5.78	8.18**	49.	Shua-92 x IR-8	2.86	4.00
22.	Basmati-2000 x DR-82	6.06	9.87**	50.	IR-8 x DR-82	12.69**	14.46**
23.	Basmati-2000 x Shaheen-Basmati	7.26	10.99**	51.	IR-8 x Shaheen-Bas-mati	9.39**	11.24**
24	Basmati-2000 x KS-282	12.64**	16.11**	52	IR-8 x KS-282	5.67	8.07**
25.	Basmati-2000 x DR-83	9.36**	4.20	53.	IR-8 x Basmati-2000	8.74**	6.69
26.	Basmati-2000 x DR-92	0.21	-1.67	54.	IR-8 x DR-83	14.61**	18.60**
27.	Basmati-2000 x Shua-92	0.86	-2.09	55.	IR-8 x DR-92	10.43**	10.43**
28.	Basmati-2000 x IR-8	8.85**	6.80*	56.	IR-8 x Shua-92	12.75**	14.00**

Table 6: Mid parent heterosis (MPH%) and high parent heterosis (HPH%) for secondary branches panicle^{-1} of 56 F_1 rice hybrids at Peshawar during 2019.

S.NO.	F_1 Rice Hybrids	Grains Panicle^{-1}		S.NO.	F_1 Rice Hybrids	Grains Panicle^{-1}	
		MPH%	HPH%			MPH%	HPH%
1.	DR-82 x Shaheen-Basmati	24.79*	21.67*	29.	DR-83 x DR-82	6.09	1.67
2.	DR-82 x KS-282	37.29**	35.00**	30.	DR-83 x Shaheen-Bas-mati	33.75*	36.18**
3.	DR-82 x Basmati-2000	45.31**	36.83**	31.	DR-83 x KS-282	15.58	18.73
4.	DR-82 x DR-83	14.20	9.44	32.	DR-83 x Basmati-2000	50.00**	47.27**
5.	DR-82 x DR-92	48.24**	40.00**	33.	DR-83 x DR-92	51.57**	49.27**
6.	DR-82 x Shua-92	50.76**	43.22**	34.	DR-83 x Shua-92	20.49*	19.39*
7.	DR-82 x IR-8	57.63**	58.94**	35.	DR-83 x IR-8	44.83**	52.73**
8.	Shaheen-Basmati x DR-82	64.10**	60.00**	36.	DR-92 x DR-82	51.65**	43.22**
9.	Shaheen-Basmati x KS-282	30.26*	29.14*	37.	DR-92 x Shaheen-Bas-mati	72.87**	67.31**
10.	Shaheen-Basmati x Basma-ti-2000	56.41**	23.21	38.	DR-92 x KS-282	9.58	5.17

11.	Shaheen-Basmati x DR-83	44.64**	47.27**	39.	DR-92 x Basmati-2000	40.88**	41.32**
12.	Shaheen-Basmati x DR-92	48.82**	44.04**	40.	DR-92 x DR-83	20.55*	18.73*
13.	Shaheen-Basmati x Shua-92	71.17**	66.67**	41.	DR-92 x Shua-92	50.93**	51.88**
14.	Shaheen-Basmati x IR-8	42.37**	47.37**	42.	DR-92xIR-8	43.62**	53.94**
15.	KS-282 x DR-82	45.65**	48.16**	43.	Shua-92 x DR-82	15.20	9.44
16.	KS-282 x Shaheen-Basmati	13.57	12.59	44.	Shua-92 x Shaheen-Basmati	51.35**	47.37**
17.	KS-282 x Basmati-2000	45.95**	39.66**	45.	Shua-92 x KS-282	53.45**	48.16**
18.	KS-282 x DR-83	45.31**	49.27**	46.	Shua-92 x Basmati-2000	22.06*	23.21*
19.	KS-282 x DR-92	17.96	13.22	47.	Shua-92 x DR-83	48.62**	47.27**
20,	KS-282 x Shua-92	50.00**	44.83**	48,	Shua-92 x DR-92	52.98**	53.94**
21.	KS-282 x IR-8	44.43**	48.16**	49.	Shua-92 x IR-8	14.20	21.60
22.	Basmati-2000 x DR-82	17.23	10.39	50.	IR-8 x DR-82	38.84**	40.00**
23.	Basmati-2000 x Shaheen-Basmati	52.30**	39.61**	51.	IR-8 x Shaheen-Basmati	45.65**	50.76**
24	Basmati-2000 x KS-282	9.91	5.66	52	IR-8 x KS-282	11.32	14.20
25.	Basmati-2000 x DR-83	38.70**	37.76**	53.	IR-8 x Basmati-2000	46.96**	58.05**
26.	Basmati-2000 x DR-92	22.82*	23.21*	54.	IR-8 x DR-83	5.17	10.91
27.	Basmati-2000 x Shua-92	14.02	15.09	55.	IR-8 x DR-92	31.02**	40.44**
28.	Basmati-2000 x IR-8	31.40	41.32**	56.	IR-8 x Shua-92	13.57	20.93*

Table 7: Mid parent heterosis (MPH%) and high parent heterosis (HPH%) for grains panicle^{-1} of 56 F_1 rice hybrids at Peshawar during 2019.

S.NO.	F_1 Rice Hybrids	100-grain weight		S.NO.	F_1 Rice Hybrids	100-grain weight	
		MPH%	HPH%			MPH%	HPH%
1.	DR-82 x Shaheen-Basmati	19.45*	32.50**	29.	DR-83 x DR-82	10.67	17.73
2.	DR-82 x KS-282	8.95	14.72**	30.	DR-83 x Shaheen-Basmati	4.65	8.86
3.	DR-82 x Basmati-2000	16.84**	24.12**	31.	DR-83 x KS-282	2.62	1.63
4.	DR-82 x DR-83	13.44**	20.68**	32.	DR-83 x Basmati-2000	12.83*	12.68*
5.	DR-82 x DR-92	8.87	15.89**	33.	DR-83 x DR-92	2.38	2.44
6.	DR-82 x Shua-92	6.35	14.21**	34.	DR-83 x Shua-92	7.10	8.06
7.	DR-82 x IR-8	17.44**	32.50**	35.	DR-83 x IR-8	-7.23	-1.93
8.	Shaheen-Basmati x DR-82	13.32**	25.71**	36.	DR-92 x DR-82	5.65	12.46*
9.	Shaheen-Basmati x KS-282	1.30	6.46	37.	DR-92 x Shaheen-Basmati	4.01	0.19
10.	Shaheen-Basmati x Basma-ti-2000	44.99**	14.80**	38.	DR-92 x KS-282	1.03	2.09
11.	Shaheen-Basmati x DR-83	4.26	8.46	39.	DR-92 x Basmati-2000	1.87	2.06
12.	Shaheen-Basmati x DR-92	2.05	-1.70	40.	DR-92 x DR-83	5.39	5.45
13.	Shaheen-Basmati x Shua-92	11.99**	8.74	41.	DR-92 x Shua-92	0.98	1.82
14.	Shaheen-Basmati x IR-8	-12.15**	-10.78**	42.	DR-92xIR-8	-3.81	1.62

15.	KS-282 x DR-82	21.05*	15.26*	43.	Shua-92 x DR-82	15.58*	24.12**
16.	KS-282 x Shaheen-Basmati	8.16	13.67*	44.	Shua-92 x Shaheen-Basmati	6.25	3.16
17.	KS-282 x Basmati-2000	6.63	7.53	45.	Shua-92 x KS-282	2.84	4.79
18.	KS-282 x DR-83	9.52**	8.46	46.	Shua-92 x Basmati-2000	0.52	1.56
19.	KS-282 x DR-92	2.72	3.79	47.	Shua-92 x DR-83	6.11	7.05
20,	KS-282 x Shua-92	-3.52	-1.69	48,	Shua-92 x DR-92	4.46	5.33
21.	KS-282 x IR-8	-7.95	-1.69	49.	Shua-92 x IR-8	-2.06	2.58
22.	Basmati-2000 x DR-82	8.00	14.72*	50.	IR-8 x DR-82	-0.12	12.68*
23.	Basmati-2000 x Shaheen-Basmati	5.94	24.12**	51.	IR-8 x Shaheen-Basmati	0.12	1.67
24	Basmati-2000 x KS-282	8.21	8.97	52	IR-8 x KS-282	-6.07	0.33
25.	Basmati-2000 x DR-83	2.91	3.10	53.	IR-8 x Basmati-2000	8.45	14.80*
26.	Basmati-2000 x DR-92	1.36	1.56	54.	IR-8 x DR-83	-0.25	5.45
27.	Basmati-2000 x Shua-92	5.16	6.24	55.	IR-8 x DR-92	-1.29	4.29
28.	Basmati-2000 x IR-8	-0.12	5.74	56.	IR-8 x Shua-92	0.62	5.38

Table 8: Mid parent heterosis (MPH%) and high parent heterosis (HPH%) for 100-grain weight of 56 F_1 rice hybrids at Peshawar during 2019.

S.NO.	F_1 Rice Hybrids	Grain yield plant^{-1}		S.NO.	F_1 Rice Hybrids	Grain yield plant^{-1}	
		MPH%	HPH%			MPH%	HPH%
1.	DR-82 x Shaheen-Basmati	43.81**	22.43**	29.	DR-83 x DR-82	43.81**	22.43**
2.	DR-82 x KS-282	34.04**	11.49	30.	DR-83 x Shaheen-Basmati	34.04**	11.49
3.	DR-82 x Basmati-2000	19.62**	26.89**	31.	DR-83 x KS-282	19.62**	26.89**
4.	DR-82 x DR-83	27.16**	19.59**	32.	DR-83 x Basmati-2000	27.16**	19.59**
5.	DR-82 x DR-92	24.78**	16.35**	33.	DR-83 x DR-92	24.78**	16.35**
6.	DR-82 x Shua-92	30.25**	14.32*	34.	DR-83 x Shua-92	30.25**	14.32*
7.	DR-82 x IR-8	22.78**	11.08*	35.	DR-83 x IR-8	22.78**	11.08*
8.	Shaheen-Basmati x DR-82	35.24**	15.14**	36.	DR-92 x DR-82	35.24**	15.14**
9.	Shaheen-Basmati x KS-282	70.13**	75.15**	37.	DR-92 x Shaheen-Basmati	70.13**	75.15**
10.	Shaheen-Basmati x Basmati-2000	100.21**	12.77*	38.	DR-92 x KS-282	100.21**	12.77*
11.	Shaheen-Basmati x DR-83	36.69**	22.85**	39.	DR-92 x Basmati-2000	36.69**	22.85**
12.	Shaheen-Basmati x DR-92	33.28**	48.65**	40.	DR-92 x DR-83	33.28**	48.65**
13.	Shaheen-Basmati x Shua-92	148.56**	157.88**	41.	DR-92 x Shua-92	148.56**	157.88**
14.	Shaheen-Basmati x IR-8	32.44**	42.50**	42.	DR-92xIR-8	32.44**	42.50**
15.	KS-282 x DR-82	71.57**	115.07**	43.	Shua-92 x DR-82	71.57**	115.07**
16.	KS-282 x Shaheen-Basmati	93.47**	99.19**	44.	Shua-92 x Shaheen-Basmati	93.47**	99.19**
17.	KS-282 x Basmati-2000	63.97**	120.57**	45.	Shua-92 x KS-282	63.97**	120.57**

18.	KS-282 x DR-83	122.05**	94.63**	46.	Shua-92 x Basmati-2000	122.05**	94.63**
19.	KS-282 x DR-92	42.88**	64.56**	47.	Shua-92 x DR-83	42.88**	64.56**
20,	KS-282 x Shua-92	32.57**	41.75**	48,	Shua-92 x DR-92	32.57**	41.75**
21.	KS-282 x IR-8	49.72**	66.19**	49.	Shua-92 x IR-8	49.72**	66.19**
22.	Basmati-2000 x DR-82	28.41**	36.22**	50.	IR-8 x DR-82	28.41**	36.22**
23.	Basmati-2000 x Shaheen-Basmati	28.89**	17.57**	51.	IR-8 x Shaheen-Basmati	28.89**	17.57**
24	Basmati-2000 x KS-282	33.54**	47.11**	52	IR-8 x KS-282	33.54**	47.11**
25.	Basmati-2000 x DR-83	43.05**	46.84**	53.	IR-8 x Basmati-2000	43.05**	46.84**
26.	Basmati-2000 x DR-92	29.80**	14.94*	54.	IR-8 x DR-83	29.80**	14.94*
27.	Basmati-2000 x Shua-92	25.85**	5.30	55.	IR-8 x DR-92	25.85**	5.30
28.	Basmati-2000 x IR-8	20.92**	2.43	56.	IR-8 x Shua-92	20.92**	2.43

Table 9: Mid parent heterosis (MPH%) and high parent heterosis (HPH%) for grain yield plant^{-1} of 56 F_1 rice hybrids at Peshawar during 2019.

Conclusion

The higher yield is obtained by F_1 rice hybrids in the present study is a result of higher values for panicle length, primary branches panicle^{-1}, secondary branches panicle^{-1}, grains panicle^{-1} and 100-grain weight. Among F_1 cross combinations, Shaheen-Basmati × Shua-92 displayed maximum panicle length (33.7 cm), primary branches panicle^{-1} (12), secondary branches panicle^{-1} (35), grains panicle^{-1} (95), 100-grain weight (4.0 g) and grain yield plant^{-1} (44.7 g). F_1 cross combination, DR-82 × Shaheen-Basmati revealed the highest better-parent heterosis for panicle length (16.38%) and 100-grain weight (32.50%) while F_1 hybrid, Shaheen-Basmati × Shua-92 showed maximum better-parent heterosis for primary branches panicle^{-1} (24.44%) and secondary branches panicle^{-1} (21.35%). Maximum better-parent heterosis for grains panicle^{-1} (67.31%) was manifested by F_1 cross combination, DR-92 × Shaheen-Basmati whereas highest better-parent heterosis for grain yield plant^{-1} (157.88%) was displayed by F_1 rice hybrid, Shaheen-Basmati × Shua-92. F_1 cross combinations, Shaheen-Basmati × Shua-92, Shaheen-Basmati × Basmati-2000, DR-82 × Shaheen-Basmati and DR-92 × Shaheen-Basmati are recommended for multi-locational trials for use in hybrid rice breeding programs. Moreover, these F_1 cross combinations could be advanced in segregating generations for development of rice cultivars.

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