Heterosis and potence ratio for earliness and yield of Rice (*Oryza sativa* L.)

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Abstract

An experiment of six-parent half diallel analysis on rice (*Oryza sativa* L.) was conducted to evaluate the heterosis and potence ratio for seven characters including days to maturity and yield. Analysis of variance indicated highly significant differences for all the characters suggested the presence of genetic variability among the studied germplasms. Out of fifteen crosses, four crosses for tillers plant^{-1}, seven crosses for primary branches panicle^{-1}, eight combinations for secondary branches panicle^{-1}, twelve crosses for panicle weight (g), six crosses for days to maturity, ten crosses for yield and three crosses for harvest index (%) were recorded with desired heterosis. In potence ratio analysis complete, partial, over dominance were observed in the cross combinations where few combinations were also found with no dominance. An Aus×Aus cross, BR24×BR26 expressed desirable heterosis for panicle weight and secondary branch panicle^{-1}. The combination BR21×BRRI dhan29 showed desirable heterosis for days to maturity, grain yield plant^{-1} and harvest index; BR21× BRRI dhan36 for and grain yield plant^{-1}; BR24×BRRI dhan29, BR26×BRRI dhan29 and BR21×BRRI dhan28 for days to maturity.; BR24×BRRI dhan36 and BR26×BRRI dhan36 for secondary branch panicle^{-1}, and grain yield plant^{-1}; BR26×BRRI dhan29 for panicle weight. For grain yield plant^{-1} the cross BR26×BRRI dhan36 was the best one followed by BR26× BRRI dhan29, BR21×BRRI dhan36, BR24×BRRI dhan36, and BR21×BRRI dhan29. Boro×Boro crosses, BRRI dhan28×BRRI dhan29 and BRRI dhan29×BRRI dhan36 were favorably heterotic for days to maturity and panicle weight; BRRI dhan28×BRRI dhan36 was positively heterotic for secondary branch panicle^{-1}, panicle weight and grain yield plant^{-1}. Combinations of BR26, BRRI dhan29 and BRRI dhan36 with other parents were better for overall performance.

Key words: Rice, Heterosis, Potence ratio, Diallel

Introduction

Rice (*Oryza sativa* L.) belonging to the family Poaceae; is the staple food in areas of high population density and fast population growth. More than half of the world's population depends on rice for calories and protein, especially in developing countries. The world's population particularly in that of the rice consuming countries is increasing at a faster rate. So demand for rice is also increasing. In the year 2016-17 worlds' milled rice production was about 499.2 million tonnes (FAO, 2017).

Rice is the leading crop in our agro based country, Bangladesh where it is grown as Boro, Aus, and Aman crops in three overlapping seasons with large number of varieties that suit various agro-ecological and climatic niches. Thus the varietal requirements for each type varied on respect of plant type, growth duration, and biotic and abiotic stress factors (Das, 2005). Rice occupies 74.85% of total cultivated area where Boro covered 41.94% of rice growing area of Bangladesh during 2015-2016. It was cultivated in 4.773 million hectare (ha) of land and its record production was 18.938 million metric ton which was 54.56% of total rice production during 2015-2016 (BBS, 2016). But high yielding Boro rice varieties require a very long period of 140-165 days to be matured On the other hand, Aus varieties require comparatively shorter (80-120 days) duration (Alam 1982). Longer duration of Boro rice allows them to face more adverse conditions of high temperature, high humidity, frequent precipitation and other uncertain environmental conditions as a result of climate change, particularly at the early period of summer. Again, in most of the cases the Aman-Boro rice cropping pattern does not allow to grow a third crop in between them thus restricting only two crops in a year. In order to allow a third rabi crop between Boro and Aman rice crop and harvest Boro rice within a range of 130-140 days we need to develop short duration materials. There is an opportunity to combine the traits, earliness of Aus ecotype and high yield potential of Boro ecotype through hybridization.

Crop improvement in rice depends on the magnitude of genetic variability and the extent to which the desirable genes are heritable. Again, one of the main problems of plant breeders for improving varieties with desired traits is to select good parents and crosses. Estimation of heterosis through Diallel analysis is thus one of the most powerful tools for selecting of desirable parents and crosses which help discern the goal and direction in a breeding program. Therefore, the study was undertaken to estimate the extent and magnitude of heterosis, degree of dominance through potence ratio analysis and to select early materials with high yield potential to utilize them directly in varietal improvement program.

Materials and methods

The experiment was conducted at the experimental farm of Sher-e-Bangla Agricultural University, Dhaka-1207. Six different BRRI released rice varieties of two ecotypes, Aus and Boro were selected and collected from Bangladesh Rice Research Institute, Gazipur. Three Aus varieties were namely BR21 (P1), BR24 (P2) and BR26 (P3) and three Boro varieties were BRRI dhan28 (P4), BRRI dhan29 (P5) and BRRI dhan36 (P6). Collected rice varieties of two ecotypes were hybridized in all possible combinations following half diallel fashion. Fifteen hybrids were divided into three groups such as Aus×Aus (group 1), Aus×Boro (group 2) and Boro×Boro (group 3). Fifteen hybrids along with their parents were evaluated against seven traits including earliness (days to maturity) and yield. The experiment was conducted following Randomized Complete Block Design (RCBD) with three replications. Each entry was grown in an individual plot of 2.5m × 2m with a spacing of 25cm×20cm with single seedling per hill. Data were recorded on tiller plant^{-1}, panicle weight (g), primary branches panicle^{-1}, secondary branches panicle^{-1}, days to maturity, yield plant^{-1} (g) and harvest index (%) for all the parental lines and cross combinations on ten randomly selected plants in each replication.

Average grain yield (g) from 10 plants was recorded at 14% moisture content.

$$\text{Grain yield at 14\% MC} = \frac{W\,(100 - M)}{(100 - 14)}$$

Where, W = Weight of sun dried grain, M = percent moisture of sun dried grain

Harvest index (HI) was calculated using following formula

$$\text{HI}\,(\%) = \frac{\text{Economic yield}}{\text{Biological yield}} \times 100$$

Where, Economic yield = Grain yield; Biological yield = Grain yield + Straw yield

Data derived from plant mean of parents and crosses were subjected to analysis of variance according to a RCB design and Duncan's multiple range test (DMRT) was used to compare means (Gomez and Gomez, 1984) using a statistical computer package MSTAT-C. The significance in increase or decrease in crosses over their corresponding mid parent and better parent were tested by comparing their means with the help of appropriate standard error values in percentage. The amount of heterosis in the F_1s was analyzed using the procedure illustrated by Mather and Jinks (1971) as follows:

$$\text{Heterosis over mid parent \%} = \frac{\overline{F_1} - \overline{MP}}{\overline{MP}} \times 100$$

Where, $\overline{F_1}$ = Mean of F_1 individuals; $\overline{MP}$ = Mean value of the two parents for that hybrid (P1+ P2)/2.

$$\text{Heterosis over better parent \%} = \frac{\overline{F_1} - \overline{BP}}{\overline{BP}} \times 100$$

Where, $\overline{F_1}$ = Mean of F_1 individuals; $\overline{BP}$ = Mean of the better parent values.

The significance of heterosis were tested by the't' test ± t = effect/variance of effect, where the variance of an effect is a linear function of the variance of its mean.

Potence ratio was calculated according to Smith (1952) to deter-mine the degree of dominance as follows:

$$P = \frac{\overline{F_1} - \overline{MP}}{0.5(\overline{P_2} - \overline{P_1})}$$

Where, P= relative potence of gene set, F_1= first generation mean, P_1= the mean of lower parent, P_2=the mean of higher parent, MP= mid-parents value = $(P_1+ P_2)/2$

Complete dominance was indicated when P = +1; while partial dominance is indicated when "P" is between (−1 and +1), except the value zero, which indicates absence of dominance. Over-dominance was considered when potence ratio exceeds ±1. The positive and negative signs indicate the direction of dominance of either parent.

Results and discussion

The analysis of variance carried out for seven characters are presented in Table 1. Highly significant difference among genotypes was observed for all of the traits under the study. Treatment mean sum of squares (mean of genotypes) were further partitioned into parents, crosses (hybrids) and parent vs. crosses, which revealed highly significant variance for all the characters except number of tillers plant^{-1} (Table 1) and harvest index in case of crosses and parent vs. crosses respectively. Sah *et al*. (2002) found significant variation among parents and crosses. Bashar (2002) reported that parents and crosses showed highly significant variances for all the characters analyzed except tillers plant^{-1} in case of parent.

Mean performance

Mean performance of six parents and fifteen cross combinations were presented in Table 2. Statistical differences were found in mean values for all the traits under consideration.

The highest no. of tiller plant^{-1} (29.33) was found in P5× P6 and the lowest (16.33) was observed in P2. For primary branches panicle^{-1} the highest no. (10.33) was occupied by P1×P5 and P3× P5 where the lowest no. (7.00) was in parents P3, P4 and cross P1×P4. The cross P2×P5 was recorded with the highest no. of secondary branches panicle^{-1} (45.33) and the cross P1×P3 was accompanied by the lowest no. of secondary branches panicle^{-1} (21.00). The cross P3×P5 provided the heaviest panicle (23.68g) where the parent P2 presented the lightest panicle (17.84g). Parent P5 required the largest duration to maturity (157.67days) whereas the parent P2 matured within the shortest duration (119.33days). More statistical differences were observed in case of yield plant^{-1} where cross P3×P5 occupied the highest value (40.73g) and the parent P1 expressed the lowest yield plant^{-1} (12.06g). Parent P6 showed the highest percentage of harvest index (56.43%) and the parent P1 revealed the lowest harvest index (32.79%).

<u>*Heterosis*</u>

Heterosis is the average performance of F_1S, as percent increases or decreases over mid parent (MPH), the better parent (BPH), standard checks (SH). Seven characters of rice (*Oryza sativa* L.) including earliness (days to maturity) and yield were studied in six parental genotypes and their fifteen cross combinations obtained from a half diallel mating design of crossing. The nature and magnitude of heterosis for different characters of the cross combinations over their respective mid and better parent were shown in Table 3 and the character wise results were described below.

For no. of tiller plant^{-1} all of fifteen cross combinations exhibited positive heterosis over mid parent ranging from 0.65% to 34.92% (Table 3) where only five of them showed significant values.

Table 1. Analysis of variance (ANOVA) in rice

Source of Variation	No. of Tillers plant^{-1}	Primary branches panicle^{-1}	Secondary branches panicle^{-1}	Panicle weight (g)	Days to maturity	Grain yield plant^{-1} (g)	Harvest index (%)
Replication	26.59	1.33	17.83	2.83	56.78	7.63	3.43
Genotypes	28.48*	3.57**	207.15**	21.27**	303.26**	213.32**	116.92**
Cross (C)	12.53	2.81**	200.57**	20.55**	176.90**	209.52**	99.80**
Parent (P)	43.42**	4.63**	181.16**	12.97**	633.87**	130.76**	174.54**
P vs C	177.07**	8.93**	429.21**	72.73**	419.36**	679.23**	68.38
Error	12.30	0.43**	11.59	0.97	12.74	5.05	11.17

'*' P<0.05, '**' P<0.01 '*' Significant at 5%level; '**Significant at 1% level

Table 2. Mean performance of parents and cross combinations

Group of parents or crosses		Genotypes	No. of tillers plant-1	Primary branches panicle-1	Secondary branches panicle-1	Panicle weight (g)	Days to maturity	Grain yield plant-1 (g)	Harvest index (%)
Parents	Aus	P1	26.00 abc	8.00 def	23.00 f	14.37 k	120.00 l	12.06 f	32.79 k
		P2	16.33 d	7.67 ef	23.67 f	17.84 j	119.33 l	13.11 f	44.65 fghi
		P3	19.33 cd	7.00 f	21.67 f	18.48 hij	126.00 k	15.73 ef	41.56 hi
	Boro	P4	24.00 abc	7.00 f	23.00 f	18.71 ghij	136.33 efgh	19.59 de	42.59 ghi
		P5	22.00 bcd	10.00 ab	42.00 a	20.29 defgh	157.67 a	30.26 b	45.55 efghi
		P6	25.67 abc	9.33 abc	24.00 ef	19.65 efghij	138.67 efgh	19.23 de	56.43 a
Crosses	Aus×Aus	P1×P2	25.33 abc	7.67 ef	26.33 def	19.81 efghi	127.33 jk	12.93 f	34.38 jk
		P1×P3	26.67 ab	8.67 cde	21.00 f	12.81 k	127.33 jk	12.59 f	39.54 ij
		P2×P3	23.67 abc	8.67 cde	31.00 cd	21.44 cde	132.67 hij	17.12 e	45.93 defghi
	Aus×Boro	P1×P4	26.67 ab	7.00 f	23.00 f	18.07 ij	129.33 ijk	18.66 de	42.30 ghi
		P1×P5	28.00 ab	10.33 a	36.00 bc	21.46 cde	135.67 fghi	34.34 b	52.62 abc
		P1×P6	26.00 abc	9.33 abc	26.33 def	20.20 defgh	138.33 efgh	23.96 c	51.23 abcde
		P2×P4	23.00 abc	7.67 ef	25.00 def	20.42 defg	134.67 ghi	21.79 cd	44.02 fghi
		P2×P5	24.00 abc	10.00 ab	45.33 a	21.88 bcd	145.33 bcd	33.88 b	40.13 hij
		P2×P6	28.33 ab	9.00 bcd	31.33 cd	21.04 cdef	136.67efgh	23.68 c	42.52 ghi
		P3×P4	23.67 abc	9.00 bcd	25.00 def	19.40 fghij	140.67 defg	22.65 cd	46.33 cdefgh
		P3×P5	27.67 ab	10.33 a	45.00 a	23.68 a	147.67 bc	40.73 a	49.96 bcdef
		P3×P6	27.67 ab	9.33 abc	30.33 cde	21.02 cdef	142.00 cdef	30.84 b	51.98 abcd
	Boro×Boro	P4×P5	23.33 abc	9.33 abc	43.00 a	22.48 abc	150.33 b	32.18 b	48.44 cdefg
		P4×P6	25.67 abc	9.00 bcd	30.33 cde	21.79 bcd	143.00 cde	25.70 c	48.63 cdefg
		P5×P6	29.33 a	9.67 abc	41.00 ab	23.54 ab	149.67 b	32.93 b	55.49 ab

Note: P1 = BR21, P2 = BR24, P3= BR26, P4 =BRRI dhan28, P5=BRRI dhan29 and P6 =BRRI dhan36

Table 3. Extent of heterosis (%) over mid-parent (MPH) and better parent (BPH) in 15 cross combinations of rice

Group of crosses	Cross com-binations	Tillers plant-1		Primary branches panicle-1		Secondary branches panicle-1		Panicle weight (g)		Days to maturity		Yield plant-1 (g)		Harvest index (%)	
		MPH	BPH	MPH	BPH	MPH	BPH	MPH	BPH	MPH	BPH	MPH	BPH	MPH	BPH
Group-1 Aus × Aus	P1×P2	19.69	-2.56	-2.13	-4.17	12.86	11.11	23.01**	11.02*	6.41**	6.11*	2.73	-1.37	-11.2*	-23.0**
	P1×P3	17.65	2.56	15.56*	8.33	-5.97	-8.70	-22.01**	-30.69**	3.52	1.06	-9.39	-19.94	6.37	-4.85
	P2×P3	32.71*	22.41	18.18**	13.04	36.76**	30.99*	18.02**	15.98**	8.15**	5.29*	18.74	8.86	6.55	2.85
Group-2 Aus × Boro	P1×P4	6.67	2.56	-6.67	-12.50	0.00	0.00	9.24*	-3.44	0.91	-5.13*	17.89	-4.75	12.24	-0.68
	P1×P5	16.67	7.69	14.81**	3.33	10.77	-14.29*	23.84**	5.77	-2.28	-13.95**	62.27**	13.48*	34.3**	15.52*
	P1×P6	0.65	0.00	7.69	0.00	12.06	9.72	18.73**	2.76	6.96**	-0.24	53.12**	24.58*	14.85**	-9.21
	P2×P4	14.05	-4.17	4.55	0.00	7.14	5.63	11.75**	9.16*	5.35**	-1.22	33.31**	11.27	0.92	-1.41
	P2×P5	25.22	9.09	13.21*	0.00	38.07**	7.94	14.78**	7.87	4.93**	-7.82**	56.25**	11.98	-11.02*	-10.13
	P2×P6	34.92**	10.39	5.88	-3.57	31.47**	30.56*	12.24**	7.07	5.94**	-1.44	46.41**	23.10*	-15.87**	-4.78
	P3×P4	9.23	-1.39	28.57**	28.57**	11.94	8.70	4.30	3.67	7.24**	3.18	28.26**	15.62	10.10	8.77
	P3×P5	33.87**	25.76	21.6**	3.33	41.36**	7.14	22.17**	16.74**	4.11*	-6.34**	77.14**	34.60**	14.72**	9.70
	P3×P6	22.96*	7.79	14.29*	0.00	32.85**	26.39*	10.24**	6.95	7.30**	2.40	76.43**	60.35**	6.10	-7.88
Group-3 Boro × Boro	P4×P5	1.45	-2.78	9.80	-6.67	32.31**	2.38	15.31**	10.83**	2.27	-4.65*	29.12**	6.36	9.92	6.36
	P4×P6	3.36	0.00	10.20	-3.57	29.08**	26.39*	13.58**	10.85*	4.00*	3.13	32.39**	31.19**	-1.77	-13.82**
	P5×P6	23.08*	14.29	0.00	-3.33	24.24**	-2.38	17.86**	16.02**	1.01	-5.07**	33.09**	8.85	8.83	-1.67

Note: '*' P<0.05, '**' P<0.01; P1 = BR21, P2 = BR24, P3= BR26, P4 =BRRI dhan28, P5=BRRI dhan29 and P6 =BRRI dhan36

Table 4. Potence ratio in 15 cross combinations of rice

Group of crosses	Cross com-binations	Tillers plant-1	Primary branches panicle-1	Secondary branches panicle-1	Panicle weight (g)	Days to maturity	Yield plant-1 (g)	Harvest index (%)
Group-1 Aus×Aus	P1×P2	0.86	-1.00	9.00	2.13	23.00	0.66	-0.73
	P1×P3	1.20	2.33	-2.00	-1.76	1.44	-0.71	0.54
	P2×P3	1.67	-1.00	0.00	0.70	0.14	0.75	0.94
Group-2 Aus×Boro	P1×P4	2.00	1.33	0.37	1.40	-0.17	1.45	2.11
	P1×P5	1.00	1.00	5.67	1.21	0.96	2.32	0.56
	P1×P6	3.89	4.00	8.33	10.23	3.00	2.06	1.82
	P2×P4	0.74	1.00	5.00	4.95	0.80	1.68	0.39
	P2×P5	1.71	1.00	1.36	2.31	0.36	1.42	-11.13
	P2×P6	1.57	0.60	45.00	2.54	0.79	2.45	-1.36
	P3×P4	0.86	0.00	4.00	7.06	1.84	2.59	8.20
	P3×P5	5.25	1.22	1.30	4.77	0.37	2.44	3.21
	P3×P6	1.63	1.00	6.43	3.34	1.53	7.62	0.40
Group-3 Boro×Boro	P4×P5	0.33	0.56	1.11	3.79	0.31	1.36	2.96
	P4×P6	1.00	0.71	13.67	5.52	4.71	35.58	-0.13
	P5×P6	3.00	0.00	0.89	11.26	0.16	1.49	0.83

Note: P1 = BR21, P2 = BR24, P3= BR26, P4 =BRRI dhan28, P5=BRRI dhan29 and P6 =BRRI dhan36

The significantly positive heterotic combinations are one from Aus×Aus;- P2×P3 (32.71), three from Aus×Boro;- P2×P6 (34.92%), P3×P5 (33.87%), P3×P6 (22.96%) and one from Boro×Boro cross combinations;- P5×P6 (23.08%). In case of heterobeltiosis the range was from -4.17% to 25.76%. Nine crosses were observed with positive, four with negative heterosis; but none of them showed significant values. The parents P3, P5 and P6 may be utilized for increasing number of tillers plant^{-1}; as those were more common in combinations with positive heterosis (Table 3) over both mid and better parents.

In terms of mid-parent heterosis for primary branches panicle^{-1} the range was from -6.67% to 28.57% where seven crosses were significantly positive heterotic (Table 3); two from Aus×Aus crosses;- P1×P3 (15.56%) and P2×P3 (18.18%) and five from Aus×Boro crosses;- P1×P5 in (14.81%), P2×P5 (13.21%), P3×P4 (28.57%), P3×P5 (21.57%) and P3×P6 (14.29%). Regarding heterobeltiosis, four combinations were found positive and only one of them was significant (Table 3) where range was from -12.50% to 28.57%. The highest and the only significant positive heterotic cross was an Aus×Boro combination namely, P3×P4 (28.57%). Therefore, P3×P4 was the best combination and P3 was more common in positive heterotic crosses considering both mid parent heterosis and heterobeltiosis.

For secondary branches panicle^{-1} the range of mid parent heterotsis was from -5.97% to 41.36 % (Table 3). Eight combinations showed significant positive heterosis and the negative heterotic cross was with insignificant value. The highest significant positive heterosis was observed in an Aus×Boro combination, P3×P5 (41.36%) followed by three other Aus×Boro crosses, P2×P5 (38.07%), P3×P6 (32.85%) and P2×P6 (31.47%). One Aus×Aus cross, P2×P3 (36.76%) and all of three Boro×Boro combinations, P4×P5 (32.31%), P4×P6 (29.08%) and P5×P6 (24.24) were also recorded with highly significant positive heterosis. The better parent heterosis for secondary branches panicle^{-1}, the range was from -14.29% to 30.99%. Four combinations were significantly positive heterotic (Table 3). The highest significant positive (30.99%) heterotic combination was P2×P3 (Aus×Aus). Two Aus×Boro combinations P2×P6 (30.56%) and P3×P6 (26.39%) revealed significant positive heterobeltiosis. Only one cross P1×P5 (Aus×Boro) manifested significant negative heterotic value (-14.29%) pointed out that it was the poorest combination for this trait. The Boro×Boro cross, P4×P6 also expressed significant positive (26.39%) heterosis. In the context of both type of heterosis P2×P3, P2×P6 and P3×P6 combinations performed better than the others and the parents P2, P3, P5 and P6 are common in significant favorable heterosis.

The range of mid parent heterosis for panicle weight was from -22.01% to 23.84% (Table 3) where thirteen combinations exhibited significant and positive heterosis over mid parent and one cross possessed significant negative heterosis. The highest significant positive mid parent heterosis (23.84%) was found in P1×P5 followed by the Aus×Aus cross;- P1×P2 (23.01%). Hence, almost all combinations produced heavier panicle indicating more grain weight than their parents. Significant heterobeltiosis was expressed by seven combinations out of thirteen positively heterotic crosses for panicle weight. The range of heterobeltiosis was from -30.69% to 16.74% (Table 3), where the highest significant heterotic value (16.74%) was presented by Aus×Boro cross;- P3×P5 followed by Boro×Boro cross;- P5×P6 (16.02%) and Aus×Aus combination;- P2×P3 (15.98%). Ali and Khan (1995) found significant positive heterobeltiosis for panicle weight. Hence for panicle weight P2, P3 and P5 are more common in crosses with favorable mid and better parent heterosis.

For the trait, days to maturity negative heterosis is favorable to produce early genotypes. The range of heterosis over mid parent was from -2.28% to 8.15% and only one combination namely, P1×P5 (Aus×Boro) found to have negative heterosis (-2.28%) but was non-significant. Fourteen combinations showed positive heterosis where ten combinations showed significant value (Table 3). Therefore, all cross combinations except P1×P5 needed longer duration to be matured than their corresponding mid parents. The range of heterobeltiosis was from -13.95% to 6.11% (Table 3). Almost two-third (nine) crosses were observed with negative heterosis over better parent where six of them possessed significant values. Four crosses of Aus×Boro group;- P1×P4 (-5.13%), P1×P5 (-13.95%), P2×P5 (-7.82%) and P3×P5 (-6.34%) and two Boro×Boro combinations, P4×P5 (-4.65%) and P5×P6 (-5.07%) provided desirable significant negative heterobeltiosis. P1 and P5 were more common in the crosses with preferable heterosis. The cross combinations with significant negative heterosis were earlier than their respective better parents. Accordingly, most of the Aus×Boro combinations obtained genes responsible for early maturity from their Aus parents and they were encouragingly early maturing than their respective better parents while the better parents were actually of Boro ecotype and with longer duration that was shown as mean performance in Table 2. Malini *et al*. (2006) and Pandey *et al*. (1995) found significant negative heterosis for days to maturity in many of hybrids in their study.

Considering mid parent heterosis and heterobeltiosis excellent heterotic combinations were observed for grain yield plant^{-1}. The range of mid parent heterosis was from -9.39% to 77.14% (Table 3). All the combinations exhibited positive heterosis over mid parent except the Aus×Aus cross;- P1×P3. Eleven crosses were found with significant positive heterosis over mid parent. All cross combinations of Aus×Boro group except P1×P4 and all Boro×Boro combinations confirmed highly significant positive heterosis over mid parent. The highest and highly significant positive mid parent heterosis was found in the Aus×Boro cross, P3×P5 (77.14%). Other Aus×Boro cross combinations nearer to the highest were P1×P5 (62.27%), P1×P6 (53.12%), P2×P4 (33.31%), P2×P5 (56.25%), P2×P6 (46.41%), and P3×P6 (76.43%). Therefore, most of the (seven out of nine) Aus×Boro combinations performed as per expectation. Kumar *et al*. (2005) found 70% hybrids with positive mid parent heterosis in their study. The heterosis over better parent varied from -19.94% to 60.35% (Table 3). Twelve cross combinations manifested positive heterobeltiosis and six of them was significantly positive heterotic. All Aus×Boro combinations except P1×P4 exhibited positive heterosis. The highest significant positive value was observed in the Aus×Boro cross;- P3×P6 followed by other Aus×Boro crosses;- P1×P5 (13.48%), P1×P6 (24.58%), P2×P6 (23.10%) and P3×P5 (34.60%). One Boro×Boro combination, P4×P6 possessed high degree of positive (31.19%) heterobeltiosis. Ali and Khan (1995) found significant positive heterobeltiosis in most of the crosses for grain yield/plant. Kumar *et al*. (2005) found 60% hybrids with positive heterosis over better parent. Bansal *et al*. (2000), Iftekharuddaula *et al*. (2004), Patil *et al*. (2011), Raju *et al*. 2005 and Satish and Ramaiah (2003) observed significant positive heterosis for grain yield in most of the hybrids under their study. Consequently, in terms of heterosis over mid parent and better parent performance of most of the Aus×Boro combinations were good performing and P3×P5 and P3×P6 were the best. It was impressive that the combinations of common Boro parents, P5 and P6 provided outstanding performance in case of grain yield plant^{-1}.

The range of heterosis over mid parent was from -15.87% to 34.33% in case of harvest index. Eleven hybrids expressed positive and three of them were noticed with significant values (Table 3). One Aus×Aus combination, P1×P2 expressed significant negative heterosis (-11.20%) which was undesirable. The highest positive significant heterosis (34.33%) was found in the Aus×Boro cross, P1×P5 followed by P1×P6 (14.85%) and P3×P5 (14.72%). Heterobeltiosis ranged from -23.00% to 15.52%. Only five crosses were noticed with positive value and only one of them, P1×P5 (Aus×Boro) was significantly heterotic (15.52%). Singh and Zaman (1998) observed significant positive heterobeltiosis for harvest index. Verma *et al*. (2002a) found three hybrids out of twenty one with significant positive heterosis. The positive heterosis was also reported by Virmani *et al*. (1981) and Peng and Virmani (1991). The significant and negative heterosis over better parent for harvest index was reported by Nijaguna and Mahadevappa (1982). Thus, P1×P5 and P3×P5 were good combinations in terms of harvest index where P5 is more common in good combinations with desirable heterosis considering mid parent and better parent heterosis.

It was importantly noticed that the Aus×Boro crosses, P1×P5, P1×P6, P3×P5 and P3×P6 with highly significant heterosis over both mid parent and better parent for grain yield plant^{-1} were also positively heterotic and significant in most cases for other yield contributing traits such as panicle weight, primary branches panicle^{-1} and secondary branches panicle^{-1}. P1×P5 and P3×P5 expressed preferable significant negative heterobeltiosis in case of days to maturity and positive heterosis for harvest index. One Boro×Boro combination, P4×P6 also showed significant positive heterosis for yield as well as panicle weight and secondary branches panicle^{-1} but was undesired positively heterotic for days to maturity indicating longer duration. Kumer *et al*. (2010) found positively heterotic hybrids which were also heterotic for harvest index. Satish and Ramaiah (2003) noticed that heterosis for yield was due to favorable heterosis in tiller plant^{-1}. Vanaja and Babu (2004) reported that positive heterosis for grain yield plant^{-1}. Lokaprokash *et al*. (1992) recorded favorable heterosis for grain yield plant^{-1} resulted for favorable heterosis for number of productive tillers, panicle weight and harvest index.

Potence ratio

The potence ratios exhibited in 15 F_1 crosses are presented in Table 4. For no. of tiller plant^{-1} potence ratio ranges from 0.33 (P4× P5) to 5.25 (P3× P5). Two crosses showed complete dominance (±1), four crosses exhibited partial dominance (-1 to +1) and nine crosses expressed over dominance (>±1) inheritance. In case of primary branches panicle^{-1} six cross combinations were found with complete dominance (±1), three crosses were recorded with partial dominance (-1 to +1), four combinations indicated over dominance (>±1), and two were found with no dominance (0) where the range of potence ratio was from -1.00 (P1× P2, P2× P3) to 4.00 (P1× P6). Potence ratio ranged from -2.00 (P1× P3) to 45.00 (P2× P6) for secondary branches panicle^{-1} where complete dominance (±1) was not found in the studied crosses, two crosses showed partial dominance (-1 to +1), twelve cross combinations expressed over dominance (>±1), and in one cross dominance was absent (0). In favor of panicle weight (g) the lowest potence ratio was -1.76 (P1× P3) and the highest potence ratio was 11.26 (P5× P6). For this trait there was lack of complete dominance (±1), over dominance (>±1) was indicated by fourteen cross combinations and partial dominance (-1 to +1) was observed in one cross. Potence ratio varied from -0.17 (P1× P4) to 23.00 (P1× P2) for days to maturity where nine crosses demonstrated partial dominance (-1 to +1) and six crosses exhibited over dominance (>±1) inheritance. For yield plant^{-1} the lowest potence ratio (-0.71) was found in P1× P3 and the highest potence ratio (35.58) was observed in P4× P6. Three crosses were found with partial dominance (-1 to +1), over dominance (>±1) was observed in twelve cross combinations. Similarly Abdel-Hafez *et. al.* (2016) also reported over dominance in the crosses for yield in their study. From -11.13 (P2× P5) to 8.20 (P3× P4) was the range of potence ratio for harvest index where seven crosses were over dominant (>±1) and eight combinations were accompanied with partial dominance (-1 to +1).

Conclusion

The magnitude of heterosis over mid parent and better parent and potence ratio were estimated in a six-parents half diallel analysis. The crosses were evaluated on the basis of desirable heterotic values. All Aus varieties studied were suitable for days to maturity. BRRI dhan29 and BRRI dhan36 of Boro varieties were excellent for most of the important yield related characters. These parents could be effectively used in future for developing rice varieties. Considering the studied characters Aus×Boro group performed better among three groups of crosses. Significant and preferable heterosis were observed in the Aus×Boro cross combinations BR21×BRRI dhan29, BR21×BRRI dhan36, BR24×BRRI dhan29, BR26×BRRI dhan29 and BR26×BRRI dhan36 for days to maturity and other yield and yield contributing traits. Therefore, these combinations may be recommended for further evaluations with standard check varieties to select desirable segregants with higher yield potential, earliness and other important characters.

References

Abdel-Hafez AG, AbdAllah AA, El Degwy IS and Ghazy MI. 2016. Inheritance of high temperature tolerance and some related traits in rice. *J. Agric. Res.* Kafr El-Sheikh Univ. **42**(4): 623-629.

Alam A. 1982. Bangladesh Rice. Urmee and Abu Bakar Publishers. 18, Green Road, Dhaka-15. p.90.

Ali SS and Khan MG. 1995. Studies for heterosis and combining ability in rice. *Pak. J. Sci. Ind. Res.* **38**(5/6): 200-204.

Bansal UK, Saini RG and Rani NS. 2000. Heterosis and combining ability for yield, its components, and quality traits in some scented rices (*Oryza sativa* L.). *J. Trop. Agr.* **77**(3): 180-187.

Bashar MK. 2002. Genetic and morphophysiological bases of heterosis in rice (*Oryza sativa* L.). An unpublished Ph.D. thesis in Genetics and Plant Breeding. BSMRAU, Salna, Gazipur.

BBS (Bangladesh Bureau of Statistics). 2016. Statistical Yearbook of Bangladesh. SID. Min. Planning, Government of the People's Republic of Bangladesh. Dhaka, Bangladesh. pp.34-39.

Das T. 2005. Rices in Bangladesh, Sadhin Graphics, Mymensingh. p.34-35

FAO. 2017. Rice market Monitor. **20** (1):1.

Gomez KA and Gomez AA. 1984. Statistical procedures for agricultural research. 2nd ed. John Wiley and Sons, New York. pp.207-215.

Iftekharuddaula KM, Salam MA, Newaz MA and Haque ME. 2004. *Per se* performance, specific combining ability, heterosis and interrelationships among them for yield and yield components in rice (*Oryza sativa* L.). *Bull. Inst. Trop. Agr. Kyushu Univ*. **27**: 1-10.

Kumar S, Sao A, Sharma D and Mishra RK. 2005. Heterosis studies in scented rice hybrids involving WA CMS lines. *J. Maharashtra Agric. Univ*. **30**(3): 344-345.

Kumar S, Singh HB, Sharma JK and Sood S. 2010. Heterosis for morpho-physiological and qualitative traits in rice. *ORYZA*. **47**(1):6.

Lokaprakash R, Shivashankar G, Mahadevappa M, Gowda BTS and Kulkarni RS. 1992. Heterosis in rice. *ORYZA*. **29**: 293-297.

Malini N, Sundaram T, Ramakrishnan SH and Saravanan S. 2006. Prediction of Hybrid Vigour for Yield Attributes among Synthesized Hybrids in Rice (*Oryza sativa* L.). *Res. J. Agr. Biol. Sci*. **2**(4): 166-170.

Mather K and Jinks JL. 1971. Biometrical Genetics, 2nd ed. Chapman and Hall Ltd. London, UK.

Nijaguna G and Mahadevappa M. 1982. Heterosis in interverietal hybrids of rice. *ORYZA*. **20**: 159-161.

Pandey MP, Singh JP and Singh H. 1995. Heterosis breeding for grain yield and other agronomic characters in rice (*Oryza sativa* L.). *Indian-J. Genet. Plant Breed*. **44**(4): 438-445.

Patil PP, Vashi RD, Shinde DA and Lodam VA. 2011. Nature and Magnitude of Heterosis for Grain Yield and Yield Attributing Traits in Rice (*Oryza sativa* L.). *Plant Archives*. **11**(1): 423-427.

Peng JY and Virmani SS. 1991. Heterosis in some international crosses of rice. *ORYZA*. **28**: 31-36.

Raju CHS, Rao MVB, Sudarshanam A and Reddy GLK. 2005. Heterosis and inbreeding depression for yield and kernel characters in rice. *ORYZA*. **42**(1): 14-19.

Satish Y and Ramaiah KVS. 2003. Heterosis for yield and grain quality characters in rice (*Oryza sativa* L.). *Ann. Bot.* **19**(1): 7-11.

Singh, A.K. and Zaman, F.U. (1998). Physiological basis of heterosis in rice. *IRRN*. **23**(2):32.

Smith, H.H. (1952). Fixing Transgressive Vigour in Nicotiana Rustica. In: Heterosis. Iowa State College Press, Ames, IA, USA.

Vanaja, T. and Babu, L.C. (2004). Heterosis for yield and yield components in rice (*Oryza sativa* L.). *J. Trop. Agric.* **42**(1/2): 43-44.

Verma, O.P., Santoshi, U.S. and Srivastava, H.K. (2002a). Heterosis and inbreeding depression for yield and certain physiological traits in hybrids involving diverse ecotypes of rice (*Oryza sativa* L.). *J. Genet. Breed.* **56**(3): 267-278.

Virmani SS, Chaudhury RC and Khush GS. 1981. Current outlook on hybrid rice. *ORYZA*. **18**:67-84.