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Research Article

Heterobeltiosis and Economic Heterosis for Grain Yield Related Traits of Boro Rice (*Oryza sativa* L.)

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Abstract

Rice is a staple food for more than half of the world's population and to increase the yield potential of rice would be a key factor for mitigating global demands of about 810 million tons of rice by 2025. To exploit the economic importance of heterosis, quantitative valuation was carried out in a randomized complete block design with three replications for 16 agronomic traits of 5x5 half diallel populations during boro season of 2017-2018. Diallel populations were generated by using five selected parents (P_1: BRRI dhan28, P_2: BRRI dhan74, P_3: BINA dhan10, P_4: IR59418-7B-21-3 and P_5: BRRI dhan67) where, P_1 was considered as standard check to estimate the economic heterosis. Analysis of variance revealed highly significant variability among the genotypes for most of the traits except grain length and length-breadth ratio. The results showed that none of the hybrid combination performed better for all the traits over the three types of heterosis. The highest relative heterosis was recorded in $P_3 \times P_4$ followed by $P_4 \times P_5$ for grain yield plant^{-1}, filled grains panicle^{-1}, effective tillers plant^{-1}. Majority of the cross combinations (>60%) revealed highly significant positive heterosis for grain yield plant^{-1} over mid parent. Heterobeltiosis for grain yield plant^{-1} was observed significant for 50% cross combinations and could be utilized in hybrid breeding. Whereas, more than 70% crosses exhibited undesirable negative standard heterosis for grain yield plant^{-1}. Only two cross combinations ($P_3 \times P_5$ and $P_3 \times P_4$) among ten revealed significant positive economic heterosis for grain yield plant^{-1} and those could be exploited in rice breeding.

Keywords: Rice; hybrid; check variety; standard heterosis; grain yield.

Introduction

Rice (*Oryza sativa* L.) is the most important food crop in the world. Rice occupies a fundamental place since it forms the staple food for about two thirds of the world's population, provides approximately 43 % calories necessity in addition to 20-25 % agriculture income (Kumar *et al.*, 2018). Rice cultivation occupies over an area of about 167.13 million hectares worldwide with a yearly rice production of about 782.00 million tons (Kumar *et al.*, 2020). Rice breeders are continuously trying to alter new genotypes with improved yield potential and to release them as stable high yielding varieties over the existing ones (Sundaram *et al.*, 2019). The breeding methodology like ploidy along with mutation breeding has ended due to poor results. Therefore, the breeders in all the rice growing countries in the world are habitually attempting to refine the pedigree and hybrid breeding method through the utilization of biometrical as well as genetical analyses. Previously, rice genetics have been found to useful to refine the breeding methodology in the rice improvement with these prospects, an exploration was then undertaken to estimate parents and desirable crosses which would give better off-springs for superior productivity with higher breeding value. Heterosis breeding is one of the utmost important genetic tools that able to facilitate yield augmentation from 30% to 400%, moreover, helps to enrich various desirable quantitative as well as qualitative characters in crops (Rahimi *et al.*, 2010).

Heterosis or hybrid vigor refers to the phenomenon of superior performance of a hybrid over its parent in terms of biomass production, development rate, grain yield, and stress tolerance. Utilization of heterosis has tremendously increased productivity of many crops, globally. The term heterosis was first coined by Shull (1914), denotes superiority of F_1 hybrids over both of its parents in terms of yield or any other character. Jones (1926), first reported heterosis in rice and observed a tremendous increase in culm number and grain yield in F_1 hybrids compared to their parents. Heterosis is usually expressed into three ways, depending on the criterion used to evaluate the performance of a hybrid (Gupta, 2000). These are mid-parent heterosis, better parent heterosis or called heterobeltiosis and standard heterosis. Heterosis breeding is a vital genetic tool that could assist in yield improvement from 30% to 400% as well as helps to augment many other desirable quantitative and qualitative traits in crops (Ghidan *et al.*, 2019; Gupta *et al.*, 2020). Both the positive as well as negative heterosis is useful in crop improvement program, usually depends on breeding objectives. Generally, positive heterosis is desirable for yield while negative heterosis in concern to early maturity followed by early flowering. Exploitation of heterosis is of utmost importance for increasing agricultural productivity and also one of the most successful examples in many crops including rice (Lv *et al.*, 2020; Ismaeel *et al.*, 2019; Singh *et al.*, 2019). Therefore, the objective of this study is to estimate three types of heterosis for yield related traits of boro rice.

Materials and Methods

Parental Materials

The experiment was comprised with five boro rice varieties which were collected from two research institutions viz. Bangladesh Rice Research Institute, Gazipur (BRRI) and Bangladesh Institute of Nuclear Agriculture, Mymensingh (BINA). The selected varieties were BRRI dhan28 (P_1), BRRI dhan74 (P_2), BINA dhan10 (P_3), IR59418-7B-21-3 (P_4) and BRRI dhan67 (P_5).

Development of Hybrids

The experimental hybrids were developed by using 5x5 half diallel mating design. Total of 10 direct hybrids viz. $P_1{\times}P_2$, $P_1{\times}P_3$, $P_1{\times}P_4$, $P_1{\times}P_5$, $P_2{\times}P_3$, $P_2{\times}P_4$, $P_2{\times}P_5$, $P_3{\times}P_4$, $P_3{\times}P_5$ and $P_4{\times}P_5$ were obtained through diallel mating among five selected parental genotypes in the boro season of 2017. Seeds of 10 F_1's along with their five parents were harvested and stored in the cold room of Department of Genetics and Plant Breeding, Bangabandhu Sheikh Mujibur Rahman Agricultural University (BSMRAU) for cultivating to the next boro season.

Evaluation of Experimental Materials

The F_1 populations along with their five parents were grown in the experimental field following randomized complete block design (RCBD) with three replications during boro season of 2018 following inputs and operations recommended by BRRI (2018). Data were collected from ten randomly selected plants for each replication for selected agronomic traits under study. The traits were days to panicle exertion (DPE), days to maturity (DMT), plant height (PHT), culm length (CLT), panicle length (PLT), number of tillers plant^{-1} (TPP), number of effective tillers plant^{-1} (ETP), non-effective tillers plant^{-1} (NTP), filled grains (FGP), unfilled grains (UGP), grain length (GLT), grain breadth (GBD), length-breadth ratio (LBR), straw weight (SDW), thousand grains weight (TGW) and grain yield plant^{-1} (YPP).

Statistical Analysis of Data

The preface statistical analysis of the data was carried out according to standard texts and the subjects (Snedecor and Cochran, 1967; Clark, 1973). The data were subjected to the statistical software TNAUSTAR (Nadarajan *et al.*, 2016) for the estimation of several important genetic parameters. Three types of heterosis (mid parent, better parent as well as standard heterosis) were computed by the software TNAUSTAR. In computing standard heterosis the parental genotype P_1 (BRRI dhan 28) was considered as standard check as it is a mega variety of rice in Bangladesh with better yield potential.

Results and Discussion

Analysis of Variance (ANOVA)

Analysis of variance was carried out for 16 agronomic characters of five parents with their 10 hybrids (Table 1). The results revealed highly significant variability among the genotypes for most of the agronomic characters. The analysis of variances displayed vast significant differences among the genotypes (parents and hybrids) for maximum number of traits which depicts wider range of variability for the genotypes (Table 1). Similar findings were also reported by Saha *et al.* (2019).

The analysis of variance displayed that mean sum of squares for the genotypes were significant at 1% level ($P \leq 0.01$) for most of the agronomic traits excluding grain breadth as well as length breadth ratio. The higher significance differences among the genotypes for most of the traits including yield indicated that they are suitable for further genetic studies.

Mean Performance of the Parents and Hybrids

The mean values of parental genotypes and their F_1's are presented in the Table 2 and their corresponding analysis of variance in Table 2. The mean values for yield along with its related traits indicated variations among the both parental as well as hybrid populations. Among the parents, P_3 was found better both for early panicle exertion (63.85 days) and days to maturity (142.66 days) whereas P_2 required longer period (78.4 days) for panicle exertion. Generally, plants with the lowest mean value for days to panicle exertion and days to maturity are desirable in rice breeding. The cross combination $P_2 \times P_3$ showed mean value of 68.35 days for days to panicle exertion and it was intermediate to both of parents (Table 2). In case of days to maturity, $P_1 \times P_3$ revealed the lowest mean value (139.08 days) among the F_1's. The parent P_2 had the shorter plant height (92.99cm) than other parental genotypes which is good as shorter height is desirable trait in rice. Among the crosses, $P_2 \times P_3$ and $P_2 \times P_4$ produced shorter plant of 98.1 and 98.21 cm, respectively (Table 2). The highest mean value for culm length was recorded in P_5 (75.05 cm) and shorter culm length in P_1 (64.00 cm). The highest culm length was produced by the crosses $P_1 \times P_5$ and $P_2 \times P_3$ (75 and 75.05 cm, respectively) and $P_2 \times P_4$ (68.2 cm) was found to produce shorter culm length than others (Table 2). In regard of panicle length, the hybrid $P_1 \times P_2$ and parental genotype P_1 had the highest and the lowest mean values (25.75 and 24.15cm, respectively) that indicated plants with the longest and the shortest culm length. Among the hybrid populations, $P_1 \times P_4$ and $P_4 \times P_5$ had similar culm length of 24.35 cm and 24.25 cm, respectively. For tiller number plant^{-1}, the recombinants of $P_1 \times P_2$ and $P_1 \times P_5$ both had the highest mean value of 22.00 while parental genotype P_5 had the lowest tiller number plant^{-1} which was 15.6 (Table 2).

Higher mean value for effective tillers plant^{-1} is one of the most important agronomic traits for selection of elite genotypes in rice breeding. The hybrids $P_1 \times P_3$, $P_4 \times P_5$, $P_3 \times P_4$, and $P_1 \times P_5$ produced more number of tillers plant^{-1} of 19.8, 19.5, 19.3, and 19.25, respectively (Table 2). Among the parental lines, P_1 and P_3 possessed higher tiller number (17.0 and 17.1) compared to other three parents (Table 2). Although the highest mean value is desirable for effective tillers per plant but on the contrary, the lowest value is expected for non-effective tillers plant^{-1} for increasing yield. Plants with minimum non-effective tillers have been found in $P_2 \times P_4$ (0.7). The hybrids $P_2 \times P_5$, $P_3 \times P_4$ and $P_4 \times P_5$ had the lower value of 1.04, 1.13 and 1.17, respectively for non-effective tiller plant^{-1} (Table 2). On the other hand, the hybrid $P_1 \times P_3$ produced the highest number of non-effective tillers plant^{-1} and the value was 3.82.

For filled grains panicle^{-1}, the cross combinations $P_2 \times P_4$ and $P_3 \times P_5$ produced the maximum number of filled grains of 120.6 and 120.0, respectively and that would be a good value for increasing the yield (Table 1). In case of parental genotypes, P_3 produced the highest number of filled grain panicle^{-1} while P_4 produced the lowest number of filled grains panicle^{-1} (Table 2). Parental genotype P_4 produced minimum number of unfilled grains panicle^{-1} (21.45), while maximum by $P_1 \times P_2$ (27.85).

As regards of grain length maximum mean value has been recorded for the hybrid $P_1 \times P_2$ (9.1cm) and minimum values were found for both the hybrids $P_1 \times P_3$ and the parent P_5 (6.83). Furthermore, it has been noticed that, all parental genotypes and their hybrids had closer mean values for both the grain length and breadth (Table 2). In case of grain breath, plants of $P_1 \times P_2$ and the parent P_2 exhibited the lowest (2.29) and the highest (2.55) mean values, respectively. For grain length-breadth ratio, the mean values that have been recorded for five parents along with their respective 10 hybrids have almost similar and there were little differences among them for L-B ratio. The highest straw dry weight was recorded in hybrid $P_2 \times P_4$ (35.93g) and the lowest (23.58g) in the parental genotype P_1 (Table 2). Maximum thousand grain weight (33.05g) and yield plant^{-1} (43.64g) was recorded in the hybrids $P_1 \times P_4$ and $P_3 \times P_5$ while minimum thousand grain weight (21.97g) in the hybrid $P_3 \times P_4$ and yield plant^{-1} (24.58g) in the hybrid $P_1 \times P_3$.

Lower value of coefficient of variance (CV) is the indicator of constancy of data which can be used to validate the individual data whether it is acceptable or unacceptable. The lower value of CV for days to panicle exertion (3.59%), days to maturity (3.10%), plant height (3.30%), culm length (3.29%), filled grain (4.15%), grain length (1.36%), grain breadth (2.29%), and length breadth ratio (2.7%) suggested that the estimates were consistence and more accurate. Higher CV value implies less consistency of data as well as the estimates with less accuracy.

Table 1. Simple analysis of variance (ANOVA) for 16 agronomic characters of 5×5 diallel populations of rice

Sources of Variation	df	DPE	DMT	PHT	CLT	PLT	TPP	ETP	NTP	FGP	UGP	GLT	GBD	LBR	SDW	TGW	YPP
Replication	2	4.29	47.66	1.14	41.11	1.01	9.85	8.26	1.53	20.73	0.90	0.005	0.00	0.01	22.29	7.74	85.38
Genotypes	28	44.60**	114.70**	25.99**	22.44**	0.88ns	7.31**	3.20**	2.63**	63.60**	5.99**	1.36**	0.03ns	0.28ns	23.47**	15.55**	75.56**
Error	29	12.91	22.10	11.19	5.03	0.67	4.24	3.03	1.11	21.38	6.40	0.01	0.005	0.01	7.69	7.34	15.56

*, ** represent significant at 5% and 1% level, respectively; df= degree of freedom; ns= non-significant

DPE- Days to panicle exertion, DMT- Days to maturity, PHT- Plant height (cm), CLT-Culm length (cm), PLT- Panicle length (cm), TPP- Tillers per plant (no.), ETP- Effective tillers per plant, NET- Non-effective tiller per plant, FGP- Filled grain, UGP- Unfilled grain, GLT- Length of grain (mm), GBD- Breadth of grain (mm), LBR- Grain length breadth ratio, SDW- Straw dry weight (g), TGW- 1000-grain weight (g), YPP- Yield per plant (g).

Table 2. Mean values of 16 agronomic characters including grain yield per plant of 5×5 diallel populations of rice

Genotypes	DPE	DMT	PHT	CLT	PLT	TPP	ETP	NTP	FGP	UGP	GLT	GBD	LBR	SDW	TGW	YPP
P1×P2	73.81	152.63	102.65	73.30	25.35	22.00	18.05	3.50	112.20	27.85	9.10	2.29	3.97	31.96	23.48	28.57
P1× P3	68.95	139.08	102.20	72.50	25.60	21.50	19.80	3.82	114.85	25.60	6.83	2.43	2.81	27.05	29.70	24.58
P1×P4	78.64	159.05	103.85	69.70	24.35	21.50	17.45	3.28	117.50	24.95	7.01	2.41	2.91	28.81	33.05	37.85
P1×P5	74.82	153.52	103.20	75.50	25.75	22.00	19.25	3.67	111.45	26.20	8.58	2.33	3.68	30.15	27.86	26.20
P2×P3	68.35	140.93	98.10	75.05	25.10	21.50	18.70	3.21	108.05	22.30	8.96	2.45	3.65	27.43	25.42	39.02
P2×P4	76.46	153.61	98.21	68.20	25.20	17.50	19.08	0.70	120.60	23.75	9.06	2.47	3.68	35.93	23.94	26.83
P2×P5	78.90	159.17	99.00	73.85	24.80	18.50	18.94	1.04	102.10	25.90	8.64	2.38	3.62	28.55	25.48	37.92
P3×P4	69.11	156.95	102.30	73.35	24.40	19.10	19.30	1.13	108.05	23.85	8.21	2.54	3.23	31.66	21.97	41.96
P3×P5	70.00	141.22	98.25	71.75	25.20	18.50	17.95	0.81	120.60	22.90	8.56	2.51	3.41	30.16	22.42	43.64
P4×P5	78.23	157.61	100.55	73.70	24.25	19.19	19.50	1.17	113.10	23.30	8.21	2.41	3.41	30.10	25.06	40.22
P1	68.96	145.77	103.38	64.00	24.15	19.50	17.00	3.22	107.80	25.25	9.00	2.38	3.78	23.58	26.73	39.68
P2	78.40	161.46	92.99	66.70	23.45	19.00	16.55	3.17	108.60	23.25	9.01	2.55	3.53	25.71	25.87	32.83
P3	63.85	142.66	101.00	70.45	24.60	20.50	17.15	3.05	108.60	26.10	8.56	2.70	3.18	23.86	26.08	37.60
P4	75.99	152.49	107.96	73.70	25.55	17.50	16.15	2.27	102.10	21.45	9.05	2.78	3.26	25.49	26.34	30.72
P5	71.47	156.76	105.15	75.00	25.50	15.60	16.10	2.67	111.80	23.65	6.83	2.53	2.70	24.83	25.58	35.66
Max.	78.90	161.46	107.96	75.05	25.75	22.00	19.80	3.82	117.50	27.85	9.10	2.78	3.97	35.93	33.05	43.64
Min.	63.85	139.08	92.99	64.00	24.15	15.60	16.10	0.70	102.60	22.23	6.83	2.29	2.70	23.58	21.97	24.58
CV(%)	3.59	3.10	3.30	3.12	3.29	10.52	9.64	43.06	4.15	10.35	1.36	2.77	2.93	9.78	10.44	11.30
LSD	2.54	4.70	3.34	2.24	2.44	2.05	1.74	1.05	4.62	2.52	0.11	0.06	0.09	2.77	2.70	3.94

DPE- Days to panicle exertion, DMT- Days to maturity, PHT- Plant height (cm), CLT-Culm length (cm), PLT- Panicle length (cm), TPP- Tillers per plant (no.), ETP- Effective tillers per plant, NET- Non-effective tiller per plant, FGP- Filled grain, UGP- Unfilled grain, GLT- Length of grain (mm), GBD- Breadth of grain (mm), LBR- Grain length breadth ratio, SDW- Straw dry weight (g), TGW- 1000-grain weight (g), YPP- Yield per plant (g).

Evaluation of Heterosis

Heterosis has been computed as regards of percent increase or decrease of values in the first filial generation (F_1) over mid parent, better parent (heterobeltiosis) and standard check. The results are presented in Table 3, 4 and 5.

Mid Parent Heterosis (Relative Heterosis):

The estimates of heterosis over mid parent for 10 cross combinations in 16 agronomic traits are presented in Table 3. In the present study, none of the cross combination revealed significant desirable heterosis over mid parent for all characters. Generally, negative heterosis is desirable for days to flowering, days to maturity as they will produce flower earlier and also will mature earlier as compared to parents. Similarly, for plant height, breeder prefers shorter and dwarf statured plant in rice breeding, thus negative significant values are preferable for heterosis.

The hybrid $P_2 \times P_3$ exhibited highly significant negative heterosis value over mid parent for days to panicle exertion and days to maturity. The cross combinations $P_2 \times P_4$ and $P_3 \times P_5$ showed significant negative heterosis for both the trait of days to maturity and plant height. Kumar *et al.* (2020) also found similar results in case of days to flowering and days to maturity. For plant height, highly significant negative heterosis was recorded in the cross combinations of $P_4 \times P_5$ and $P_3 \times P_5$ (Table 3). The hybrids $P_1 \times P_2$, $P_1 \times P_3$, $P_2 \times P_3$ and $P_2 \times P_4$ had highly significant positive heterosis over mid parents for panicle length, effective tillers plant^{-1} and filled grains panicle^{-1} and grain yield plant^{-1} except $P_1 \times P_2$, which has negative heterosis for grain yield plant^{-1}. In case of effective tillers plant^{-1} and straw dry weight, all cross combinations had highly significant and positive heterosis over mid parent and none of the hybrids showed negative values for these traits. The hybrids of $P_3 \times P_5$ would produce rice with longer grain with shorter breadth as this hybrid produced the highest significant and positive heterosis for grain length but negative heterosis for grain breadth. The maximum mid parent heterosis was found in $P_1 \times P_4$ for thousand grain weight. As yield is the ultimate goal of rice breeding, highly significant positive heterosis estimates are desirable for increasing grain yield plant^{-1} and the hybrid $P_2 \times P_4$ had the highest heterosis value (Table 3).

It was noticed that none of the cross combination showed desirable heterosis over mid parent regarding all the traits. More than 65% hybrid combinations showed significant positive and desirable heterosis for grain yield plant^{-1}, indicating that it would be effective to choose these hybrids for these traits to increase the yield. It was also observed that, parents of all the hybrids performed both as good and poor combiners in different aspect, indicating the presence of dominance gene action. Thus, these hybrids can be recommended for heterosis breeding.

Better Parent Heterosis (Heterobeltiosis):

The estimates of heterosis over better parent for 10 cross combinations in 16 agronomic traits are presented in Table 4.

The cross combinations $P_1 \times P_2$, $P_2 \times P_3$ and $P_3 \times P_5$ exhibited significant negative heterosis over better parent for days to panicle exertion and days to maturity. While, the hybrids of $P_1 \times P_3$ and $P_2 \times P_3$ had significant negative heterosis over better parent for plant height indicating shorter plant height and significant positive heterosis for panicle length (Table 4).

Regarding the number of tiller plant^{-1} and effective tillers, cross combinations of $P_1 \times P_2$, $P_1 \times P_3$, $P_1 \times P_4$, $P_1 \times P_5$, $P_2 \times P_3$ and $P_4 \times P_5$ gave significant positive heterosis over the better parent and could be utilized in the exploitation of heterosis for these traits. Moreover, the estimates for effective tillers plant^{-1} revealed that all the hybrid combinations exhibited significant positive heterosis over the better parent.

Highly significant positive heterobeltiosis was observed in the crosses $P_1 \times P_4$, $P_3 \times P_5$ and $P_1 \times P_3$ for filled grains panicle^{-1} (Table 4). On the other hand, the crosses $P_1 \times P_2$, $P_2 \times P_5$ and $P_1 \times P_5$ had highly significant positive value for unfilled grains panicle^{-1} implying more number of empty grains in the hybrid population. More filled grains panicle^{-1} is desirable in rice breeding for increasing the grain yield plant^{-1}. Now days, longer but fine-grained rice is more preferable, thus positive heterosis would be a good indicator for grain length and negative heterosis for grain breadth. But it was observed that, most of the cross combinations produced significant negative heterosis estimates for grain length and breadth over better parent.

Considering thousand grain weight, cross combinations $P_1 \times P_4$ and $P_1 \times P_3$ had highly significant positive heterosis over better parent (Table 4). These crosses would not be efficient for utilization in breeding program where yield is the major concern as they have not exhibited positive heterosis for grain yield plant^{-1}. They showed highly significant negative heterosis over better parent for grain yield plant^{-1}. In case of straw dry weight, none of the crosses had negative heterosis over better parent.

Among the 10 cross combinations, $P_3 \times P_5$, $P_4 \times P_5$ and $P_3 \times P_4$ had highly significant positive heterosis for grain yield plant^{-1} over better parent. Five hybrids manifested significant positive heterosis for grain yield over better parent, would perform better in the hybrid breeding program for increasing grain yield. The magnitude of heterosis over better parent greatly varied from trait to trait as well as parent to parent. Similar findings were reported by Abo-Yousef *et al.* (2020).

Table 3: Estimation of heterosis of F_1 hybrids over mid parent (relative heterosis) for 16 agronomic characters in boro rice

Genotypes	DPE	DMT	PHT	CLT	PLT	TPP	ETP	NTP	FGP	UGP	GLT	GBD	LBR	SDW	TGW	YPP
P1×P2	0.18ns	-0.64ns	4.55**	12.17**	6.51**	14.29**	7.6**	9.64**	3.7**	14.85**	1**	-7.29**	8.76**	29.68**	-10.73**	-21.22**
P1× P3	3.83**	-3.56**	0.01ns	7.85**	5.03**	7.5**	15.96**	21.7**	6.15**	-0.29ns	-22.24**	-4.13**	-19.18**	14.04**	12.48**	-36.38**
P1×P4	8.5**	6.65**	-1.72*	1.23*	-2.01**	16.22**	5.28**	19.23**	11.96**	6.85**	-22.33**	-6.87**	-17.17**	17.42**	24.56**	7.53**
P1×P5	6.55**	1.49*	-1.02*	8.63**	3.73**	25.36****	16.31**	24.84**	1.5*	7.16**	8.43**	-5.19**	13.76**	24.56**	6.53**	-30.45**
P2×P3	-3.9**	-7.32**	1.14*	9.44**	4.47**	8.86**	10.98**	3.16**	-0.51ns	-9.63**	2.03**	-6.48**	8.96**	10.67**	-2.14*	10.79**
P2×P4	-0.96ns	-2.14**	-2.36**	-2.85**	2.86**	-4.11**	16.67**	-74.3**	14.48**	6.26**	0.33ns	-7.59**	8.34**	40.35**	-8.29**	-15.55**
P2×P5	5.29**	0.04ns	-0.07ns	4.23**	1.33*	6.94**	16.05**	-64.37**	-7.35**	10.45**	9.03**	-6.19**	16.31**	12.98**	-0.94ns	10.72**
P3×P4	-1.16*	6.35**	-2.09**	1.77*	-2.69**	0.53ns	15.92**	-57.56**	2.56*	0.32ns	-6.78**	-7.21**	0.41ns	28.31**	-16.19**	22.81**
P3×P5	3.45**	-5.67**	-4.68**	-1.34*	0.6ns	2.49**	7.97**	-71.67**	9.44**	-7.94**	11.27**	-3.92**	16.16**	23.89**	-13.2**	19.13**
P4×P5	6.09**	1.93*	-5.63**	-0.87ns	-5**	15.98**	20.93**	-52.43**	5.75**	3.33**	3.39**	-9.23**	14.3**	19.63**	-3.48**	21.17**

*, ** represent significant at 5% and 1% level, respectively; df= degree of freedom; ns= non-significant

DPE- Days to panicle exertion, DMT- Days to maturity, PHT- Plant height (cm), CLT-Culm length (cm), PLT- Panicle length (cm), TPP- Tillers per plant (no.), ETP- Effective tillers per plant, NET- Non-effective tiller per plant, FGP- Filled grain, UGP- Unfilled grain, GLT- Length of grain (mm), GBD- Breadth of grain (mm), LBR- Grain length breadth ratio, SDW- Straw dry weight (g), TGW- 1000-grain weight (g), YPP- Yield per plant (g).

Table 4: Estimation of heterosis of F_1 hybrids over better parent (Heterobeltiosis) for 16 agronomic characters in boro rice

Genotypes	DPE	DMT	PHT	CLT	PLT	TPP	ETP	NTP	FGP	UGP	GLT	GBD	LBR	SDW	TGW	YPP
P1×P2	-5.85**	-5.47**	-0.71ns	9.9**	4.97**	12.82**	6.18**	8.81**	3.31*	10.3**	0.92ns	-10.37*8	5.2**	24.31**	-12.17**	-28.01**
P1× P3	-0.01ns	-4.59**	-1.14*	2.91*	4.07**	4.88**	15.45**	18.51**	5.76**	-1.92**	-24.13**	-9.65**	-25.6**	13.37**	11.12**	-38.04**
P1×P4	3.48**	4.3**	-3.8**	-5.43**	-4.7**	10.26**	2.65*	1.72*	9**	-1.19*	-22.57*8	-13.49**	-22.8**	13.02**	23.65**	-4.61*
P1×P5	4.68**	-2.06*	-1.85*	0.67ns	0.98ns	12.82**	13.24**	14.12**	-0.31ns	3.76**	-4.66**	-7.91**	-2.48**	21.43**	4.23*	-33.97**
P2×P3	-12.81**	-12.71**	-2.87*	6.53**	2.03*	4.88**	9.04**	1.21*	-0.51ns	-14.56**	-0.54ns	-8.91**	3.51**	6.69**	-2.55ns	3.76*
P2×P4	-2.48*	-4.86**	-9.13**	-7.46**	-1.37*	-7.89**	15.26**	-77.94**	11.05**	2.15**	0.1ns	-11.33**	4.24**	39.75**	-9.11**	-18.27**
P2×P5	0.64ns	-1.42*	-5.85**	-1.53*	-2.75*	-2.63*	14.47**	-67.2**	-8.68**	9.51**	-4.19**	-6.65**	2.62**	11.05**	-1.5ns	6.34*
P3×P4	-9.06**	2.92*	-5.24**	-0.47ns	-4.5**	-6.83*	12.54**	-62.96**	-0.51ns	-8.62**	-9.32**	-8.63**	-0.9ns	24.21**	-16.6**	11.57**
P3×P5	-2.06*	-9.91**	-6.56**	-4.33**	-1.18*	-9.76*	4.66**	-73.45**	7.87**	-12.26**	0.01ns	-6.86**	7.41**	21.47**	-14.04**	16.05**
P4×P5	2.93*	0.55ns	-6.86**	-1.73*	-5.09**	9.69**	20.74**	-55.93**	1.16*	-1.48*	-9.32**	-13.31**	4.43**	18.09**	-4.88*	12.77**

*, ** represent significant at 5% and 1% level, respectively; df= degree of freedom; ns= non-significant

DPE- Days to panicle exertion, DMT- Days to maturity, PHT- Plant height (cm), CLT-Culm length (cm), PLT- Panicle length (cm), TPP- Tillers per plant (no.), ETP- Effective tillers per plant, NET- Non-effective tiller per plant, FGP- Filled grain, UGP- Unfilled grain, GLT- Length of grain (mm), GBD- Breadth of grain (mm), LBR- Grain length breadth ratio, SDW- Straw dry weight (g), TGW- 1000-grain weight (g), YPP- Yield per plant (g).

Table 5: Estimation of heterosis of F_1 hybrids over standard parent (Economic/Standard Heterosis) for 16 agronomic characters in boro rice

Genotypes	DPE	DMT	PHT	CLT	PLT	TPP	ETP	NTP	FGP	UGP	GLT	GBD	LBR	SDW	TGW	YPP
P1×P2	7.03**	4.7*	-0.71ns	14.53**	4.97**	12.82**	6.18**	8.81**	4.08**	10.3**	1.09*	-3.98**	5.2**	35.54**	-12.17**	-28.01**
P1× P3	-0.01ns	-4.59*	-1.14*	13.28**	6**	10.26**	16.47**	18.51**	6.54**	1.39*	-24.13**	2.1**	-25.6**	14.72**	11.12**	-38.04**
P1×P4	14.03**	9.11**	0.45ns	8.91**	0.83ns	10.26**	2.65ns	1.72*	9**	-1.19*	-22.09**	0.84ns	-22.8**	22.18**	23.65**	-4.61ns
P1×P5	8.49**	5.31**	-0.17ns	17.97**	6.63**	12.82**	13.24**	14.12**	3.39**	3.76**	-4.66**	-2.31**	-2.48**	27.86**	4.23**	-33.97**
P2×P3	-0.88ns	-3.32*	-5.11**	17.27**	3.93**	10.26**	10**	-0.33ns	0.23ns	-11.68**	-0.37ns	2.94**	-3.26**	16.33**	-4.91**	-1.66ns
P2×P4	10.87**	5.38**	-5.11**	6.56**	4.35**	-10.43**	12.21**	-78.27**	11.87**	-5.94**	0.72ns	3.35**	-2.58**	52.37**	-10.44**	-32.37**
P2×P5	14.41*8	9.19**	-4.24**	15.39**	2.69*	-5.13**	11.44**	-67.7**	-5.29**	2.57**	-4.03**	0.12ns	-4.09**	21.08**	-4.68**	-4.44ns
P3×P4	0.22ns	7.66**	-1.04*	14.61**	1.04*	-2.05*	13.53**	-64.9**	0.23ns	-5.54**	-8.76**	6.5**	-14.4**	34.27**	-17.82*8	5.73*
P3×P5	1.51*	-3.12*	-4.96**	12.11**	4.35**	-5.13*	5.59**	-74.84**	11.87**	-9.31**	-4.87**	5.24**	-9.64**	27.91**	-16.13**	9.98**
P4×P5	13.44**	8.12**	-2.74*	15.16**	0.41ns	1.56ns	14.71**	-63.5**	4.92**	-7.72**	-8.76**	1.05*	-9.79**	27.65**	-6.27**	1.35ns

*, ** represent significant at 5% and 1% level, respectively; df= degree of freedom; ns= non-significant

DPE- Days to panicle exertion, DMT- Days to maturity, PHT- Plant height (cm), CLT-Culm length (cm), PLT- Panicle length (cm), TPP- Tillers per plant (no.), ETP- Effective tillers per plant, NET- Non-effective tiller per plant, FGP- Filled grain, UGP- Unfilled grain, GLT- Length of grain (mm), GBD- Breadth of grain (mm), LBR- Grain length breadth ratio, SDW- Straw dry weight (g), TGW- 1000-grain weight (g), YPP- Yield per plant (g).

Heterosis over Standard Parent (Economic Heterosis):

Data on estimates of heterosis over standard parent implies superiority or inferiority in the performance of hybrids in comparison to standard parent concerning specific trait. The estimates of heterosis over standard parent has been presented in Table 5. A wide range of variation was observed in the estimates of standard heterosis both in positive and negative direction for grain yield plant^{-1}. None of the hybrid showed significant negative heterosis over standard parent for days to panicle exertion, rather most of the cross combinations exhibited highly significant positive heterosis for days to panicle exertion implies late flowering in the hybrid combinations. The hybrids combinations $P_1{\times}P_2$ and $P_2{\times}P_3$ together with $P_3{\times}P_5$ revealed early maturity and shorter statured plant the standard heterosis value was significant and negative for days to maturity and plant height. It was notified that, none of the hybrids had negative heterosis for both culm length and panicle length over standard parent, rather most of the cross combinations possessed highly significant positive heterosis except $P_1{\times}P_4$ and $P_4{\times}P_5$ which showed non-significant and positive heterosis for panicle length. Highly significant positive heterosis was recorded in the hybrid combinations $P_1{\times}P_2$, $P_1{\times}P_3$, $P_1{\times}P_4$, $P_1{\times}P_5$ and $P_2{\times}P_3$ for tillers plant^{-1} and most of hybrid combinations exhibited significant positive estimates for effective tillers plant^{-1} over the standard parent. Significant negative heterosis are desirable in regards to non-effective tillers plant^{-1}.

Six hybrid combinations were found to have negative heterosis for non-effective tillers plant^{-1}, among which the hybrid $P_2{\times}P_5$ have the highest estimates over standard parent for non-effective tillers plant^{-1}. Maximum and significant positive heterosis was found in the hybrid combinations $P_2{\times}P_4$ and $P_3{\times}P_5$ for filled grains panicle^{-1} while $P_2{\times}P_3$ had significant negative heterosis for unfilled grains panicle^{-1} over standard parent. All cross combinations had significant positive heterosis for straw dry weight among which $P_2{\times}P_4$ had the maximum standard heterosis.

Majority of cross combinations performed better for shorter and finer grain as produced highly significant negative standard (economic) heterosis for both grain length and length breadth ration over the standard parent except $P_1{\times}P_2$. It was found that, most of the hybrids did not have desirable significant positive heterosis for thousand grain weight and grain yield plant^{-1} except fewer hybrids. Only two hybrid combinations $P_3{\times}P_5$ and $P_3{\times}P_4$ showed significant positive economic heterosis for grain yield over standard parent which is desirable.

Conclusion

The analysis of variance (ANOVA) exhibited highly significant variations among the genotypes for all the characters except grain breadth and length breadth ratio. The hybrid combination $P_3 \times P_5$ exhibited as the best performer for filled grain and grain yield plant^{-1}. While the parental genotype P_3 exhibited desired mean value for panicle exertion and days to maturity. The parental combination $P_2 \times P_3$ exhibited desirable positive heterosis over the both mid and better parent for days to maturity followed by days to flowering, panicle length, number of effective tillers panicle^{-1}, grain length and grain yield plant^{-1}. On the other hand, cross combination $P_1 \times P_4$ revealed as good performer for plant height, number of effective tillers plant^{-1} and filled grains panicle^{-1}, thousand grain weight and grain yield over mid parent. In regards to standard heterosis, the cross combination $P_3 \times P_5$ would be a good combination for early flowering with early maturity, shorter plant stature, higher number of effective tillers plant^{-1}, filled grains panicle^{-1} and maximum grain yield plant^{-1} revealed its candidature for selecting as superior genotypes over standard variety.

Authors' Contribution

A.K.M. Aminul Islam designed the research plan; Shuma Rani Ray performed experimental works & collected the required data. Shuma Rani Ray & A.K.M. Aminul Islam analysed the data; Shuma Rani Ray prepared the manuscript. A.K.M. Aminul Islam, M.G. Rasul, M.M. Hasan Saikat & J.U. Ahmed critically revised and finalized the manuscript. Final form of manuscript was approved by all authors.

Conflict of Interest

The authors declare that there is no conflict of interest with present publication.

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