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Studies on the genetic basis of heterosis and inbreeding depression for yield and yield attributing characters in rice (*Oryza sativa* L.)

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Abstract
Heterosis studies in rice were carried out on eighteen characters against two crosses (Cross I: Mashuri × Bhutmuri and Cross II: IR36 × Bhutmuri) at Instructional Farm, Jaguli, BCKV, West Bengal. Heterosis of F_1 hybrids over mid parent and better parent varied from character to characters in the two crosses. Significant positive heterosis was observed for number of tillers per plant and number of panicles per plant in both the crosses. Highest inbreeding depression was observed for number of secondary branches per panicle and lowest for straw weight in Cross I. While highest inbreeding depression was observed for tillers per plant and lowest for grain L/B ratio in Cross II. Secondary branches per panicle in Cross I and number of tillers per plant in Cross II recorded high level of heterosis and inbreeding depression. Number of panicles per plant in Cross I and harvest index in Cross II showed high level of heterosis and low level of inbreeding depression which indicated the presence of both additive and non-additive gene effects for these characters. Above studies suggested that for crop improvement it would be desirable to follow different selection methods / breeding methods according to the gene action that controls the yield and different yield attributing characters.

Keywords: Rice, heterosis, inbreeding depression, gene action

Introduction
Rice is the important cereal food crop and serves as the primary source of staple food for more than half of the global population. Because of higher population growth rate than crop productivity, there are food shortages in most of the area of India. Use of hybrid variety is an important stratergy to meet the demand of increasing population. Hybrid rice is an economically viable option to increase cultivars yield potential. Heterosis in yield contributing traits ultimately brought about yield improvement in F_1 hybrid rice (Vanaja and Babu, 2004) [8]. The superiority of F_1 hybrid over both its parents in terms of yield or some other characters is known as heterosis. Both positive and negative heterosis is useful in crop improvement, depending on the breeding objectives and nature of the traits. Heterosis is useful for deciding the direction of future breeding programme and to identify the superior cross combinations. Knowledge on heterosis together with inbreeding depression would be helpful for identification of poor crosses in early generations. In the present study two crosses were made in rice to study the manifestation of heterosis for yield and its components as well as to estimate the inbreeding depression.

Material and Method
The experimental materials consisted of three parental varieties, i.e., Mahsuri, Bhutmuri, IR36 .The experiment was carried out at the Instructional Farm, Bidhan Chandra Krishi Viswavidyalaya, Jaguli, Nadia, West Bengal during 2017-18. Crossing was also made between Mahsuri × Bhutmuri and IR 36 × Bhutmuri during kharif season to obtain the F_1 seeds of the said crosses. Three parents, F_1 seeds were sown during boro season to generate the F_2 seeds. Again three parents, F_1 and F_2 seeds were sown during Kharif season to generate the F_2& F_3 seeds respectively. The experiment was laid in RBD with four replications. The parental lines and $F_{1,}$ F_2 and F_3 were grown in 1, 2 and 3 rows each of 3m length at a spacing of 30 x 15 cm respectively. Observations were recorded for different characters such as days to 50% flowering, days to maturity, plant height, number of tillers per plant, number of panicles per plant, panicle length, number of primary branches per panicle, number of secondary branches per panicle, number of grains per panicle, number of filled grains per panicle, fertility

percentage (%), 1000 grain weight, grain length, grain breadth, grain L/B ratio, straw weight, harvest index(%) and grain yield per plant. The magnitude of heterosis was estimated in relation to mid parental (MP) and better parental (BP) values by the methods of Turner (1953) [7].

Estimation of heterosis

The treatment mean value for each character of F_1 population were used for the estimation of heterosis. The magnitude of heterosis was estimated in relation to mid parental (MP) and better parent (BP) values by the methods of Turner (1953) [7]. The significance was tested by using the formula given by Wyne *et al.*, (1970).

Heterosis over mid-parent (Ha%) = $\frac{\overline{F1}-\overline{MP}}{\overline{MP}} X100$

Heterobeltiosis (Hb %) = $\frac{\overline{F1}-\overline{BP}}{\overline{BP}} X\ 100$

Where, F_1 is the average performance of the F_1 hybrid; MP, the average performance of mid parent, BP, the average performance of better parent. Thus, heterosis is expressed as percent increase of the F_1 hybrids performance over MP and BP values.

Inbreeding Depression % = $\frac{\overline{F1}-\overline{F2}}{\overline{F1}}\ X\ 100$

Where, F_1 = Mean value of F_1 generation
F_2 = Mean value of F_2 generation

Significance of heterosis was tested by't' test as follows:

$^tMP = \frac{\overline{F1}-\overline{BP}}{\text{SE of heterosis over mid−parent}}$

$^tBP = \frac{\overline{F1}-\overline{MP}}{\text{SE of heterosis over better− parent}}$

Where,
SE of heterosis over mid-parent = $[3Me/2r]^{1/2}$
SE of heterosis over better parent = $[2Me/2r]^{1/2}$
Me= error mean square; r= replication)
All the statistical analysis was done by using IndoStat statistical software.

Result and Discussion

Three parents, and two F_1 crosses were studied during Kharif 2017. Different morphological characteristics were studied and enlisted in Table 1. Analysis of variance revealed significant difference among the parents, F_1 hybrids and F_2 generation against all characters studied (Table 2.1 and 2.2). Among the yield component in cross I, number of secondary branches per panicle exhibited highest significant difference. Among the yield component in cross II, number of grains per panicle exhibited highest significant difference and grain length/breadth (L/B) exhibited lowest significant difference in both cross I and II.

Heterosis, heterobeltiosis, standard heterosis and inbreeding depression for 18 characters in cross I and Cross II are given in Table 3.

In Cross I significant positive desirable relative heterosis (mid parent heterosis) was observed for number of tillers per plant (46.79), number of panicles per plant (35.78), number of primary branches per panicle (51.27), number of secondary branches per panicle (67.36), number of grains per panicle (15.23), number of filled grains per panicle (44.12), fertility percentage(%) (10.61), and harvest index (%) (12.06). Days to 50% flowering (7.21), days to maturity (4.83), and plant height (3.30) also showed the significant positive relative heterosis but not in desired direction but significant negative relative heterosis in desired direction was observed for straw weight (-11.60). Thorat *et al*. (2017) [5] reported significant positive heterosis for fertility percentage (%). Significant positive desirable heterobeltiosis was observed for number of tillers per plant (32.60), number of panicles per plant (18.67), number of primary branches per panicle (39.25), number of secondary braches per panicle (74.22), number of filled grains per panicle (16.56), fertility percentage (%) (8.99) and but significant negative heterobeltiosis in desired direction was observed for days to 50% flowering (-5.85), days to maturity (-4.85), grain length (-11.18), grain breadth (-17.83%) and straw weight (-19.08). Negative heterosis is desirable for days to 50% flowering because this will help the hybrid to mature earlier. Short duration varieties are of breeders interest for cultivation, therefore, heterosis in negative direction is desirable for days to maturity. Reddy *et al*. (2012) [4] reported significant negative heterosis over better parent for days to 50% flowering. While cross II exhibited high significant desirable positive heterosis over mid parent for number of tillers per plant (77.27), number of panicles per plant (65.38), number of grains per panicle (21.84), number of filled grains per panicle (29.01), harvest Index (%) (16.54) and grain yield per plant (24.45) but significant negative relative heterosis was observed for fertility percentage (%) (-6.09) and grain length (-8.06). Raju *et al.* (2005) reported high degree of heterosis for number of tillers per plant. Days to maturity (8.43) and plant height (12.43) also showed the significant positive relative heterosis but not in desired direction. However, Cross II showed high significant positive heterosis over better parent in desired direction for number of tillers per plant (87.85), number of panicle per plant (44.54) and harvest index (%) (13.99). Vanaja and Babu (2004) [8] reported significant and favorable heterosis in number of panicles per plant. They found that yield increase was largely due to significant and favorable heterosis. Significant negative heterobeltiosis in desired direction was observed for days to 50% flowering (-11.86), plant height (-4.47), number of grains per panicle (-9.61), number of filled grains per panicle (-10.27) fertility percentage (%) (-15.14), 1000 grain weight (-15.85), grain length (-8.49), grain breadth (18.90), grain length to breadth ratio (-17.34), and straw weight (-11.58). The present findings are akin to the findings of Gontcharova and Gontcharova (2003) who reported significant heterosis for plant height. Heterosis in positive as well as negative direction for grain Length has been reported by Reddy *et al*. (2012) [4]. Several workers have also reported wide range of variation in expression of heterosis for grain yield trait (Reddy 2004, Tiwari *et al*. (2011) and Thorat *et al*. (2017) [5, 6, 3]. Among the different characters studied highest inbreeding depression was observed for number of secondary branches per panicle (35.33%), in F_1 and F_2 and also for F_2 and F_3 (28.45%) generation of cross I.

Number of tillers per plant (42.65%) in F_1 and F_2 generation and filled grains per panicle (37.86%) in F_2 and F_3 generation of cross II shows the highest inbreeding depresssion. Lowest inbreeding depression was observed for straw weight (-14.9) in F_1 and F_2 generation and 1000 grain Weight (g)(-9.55) in F_2 and F_3 generation of cross I. Grain length /breadth (L/B) ratio (-9.07%) in F_1 and F_2 generation and F_2 and F_3 generation(-8.33) of cross II. Raju *et al.* (2005) studied heterosis and inbreeding depression in rice for yield components and kernel characteristics.

Table 1: Morphological features of F_1 and their parents

SL No.	Characters	Bhutmuri	Mahsuri	IR 36	Mahsuri x Bhutmuri (F_1)	IR 36 x Bhutmuri (F_1)
1	Basal leaf: sheath colour	Uniform purple	Light purple	Green	Light purple	Light purple
2	Leaf: intensity of green colour	Medium	Dark	Dark	Light	Medium
3	Leaf: pubescence of blade surface	Strong	Weak	Weak	Weak	Medium
4	Leaf: auricles	Present	Present	Present	Present	Present
5	Leaf: anthocyanin colouration of auricles	Light purple	Colourless	Light purple	Light purple	Light purple
6	Leaf: ligule	Present	Present	Present	Present	Present
7	Leaf: colour of ligule	White	Light purple	Light purple	White	Purple
8	Leaf: shape of ligule	Acute	Split	Split	Split	Split
9	Leaf: collar	Absent	Present	Present	Present	Present
10	Flag leaf: attitude of blade (early observation)	Semi-erect	Erect	Erect	Semi-erect	Erect
11	Stem: anthocyanin colouration of nodes	Present	Absent	Present	Present	Present
12	Panicle: length of main axis	Medium	Long	Medium	Medium	Medium
13	Panicle: awns	absent	absent	Present	absent	present
14	Panicle: attitude of branches	Semi-erect	Semi-erect to spreading	Semi-erect	Semi-erect to spreading	Semi-erect
15	Spikelet: density of pubescence of lemma	Weak	Medium	Medium	Medium	Medium

Table 2.1: Analysis of variance for different characters in Cross I (Mahsuri X Bhutmuri)

S. No.	Characters	Mean sum of square			SEd	CD
		Replication (d.f. 3)	Generation (d.f. 4)	Error (d.f. 12)		
1	Days to 50%Flowering	5.12	537.58***	12	2.39	5.20
2	Days to maturity	3.0	473.33***	4.13	1.44	3.13
3	Plant height(cm)	3.23	118.11***	4.84	1.56	3.39
4	No. of tillers per plant	0.15	74.89***	1.29	0.8	1.75
5	No. of panicles per plant	3.0	115.36***	1.66	0.91	1.99
6	Panicle length(cm)	2.15	29.13**	4.90	1.57	3.41
7	No. of primary branches per panicle	0.48	37.66***	1.09	0.74	1.61
8	No. of secondary braches per panicle	5.90	1301.27***	10.83	2.33	5.07
9	No. of grains per panicle	20.01	847.44***	66.30	5.76	12.55
10	No. of filled grains per panicle	18.75	910.18***	18.14	3.01	6.56
11	Fertility percentage (%)	5.32	48.56*	7.61	1.95	4.25
12	1000 grain weight (g)	1.79	22.07**	3.87	1.39	3.03
13	Grain length(mm)	0.05	0.89*	0.18	0.30	0.66
14	Grain breadth(mm)	0.08	0.67***	0.03	0.12	0.27
15	Grain length/breadth (L/B) ratio	0.13	0.40*	0.08	0.20	0.45
16	Straw weight (g)	2.06	62.06***	5.59	1.67	3.64
17	Harvest index (%)	23.18*	37.89***	2.96	1.22	2.65
18	Grain yield per plant (g)	19.73	141.15***	6.56	1.81	3.94

* significant at 5% level, ** significance at 1% level, ***significant at 0.01% level

Table 2.2: Analysis of variance for different characters in Cross II (IR 36X Bhutmuri)

S No.	Characters	Mean sum of square			SEd (±)	CD (5%)
		Replication (d.f. 3)	Generation (d.f. 4)	Error (d.f. 12)		
1	Days to 50%Flowering	25.73	305.30***	27.73	3.72	8.11
2	Days to maturity	28.18	415.88***	16.64	2.88	6.28
3	Plant height(cm)	3.61	1073.75***	8.39	2.05	4.46
4	No. of tillers per plant	1.25	488.16***	0.80	0.63	1.38
5	No. of panicles per plant	1.93	126.40***	4.62	1.52	3.31
6	Panicle length(cm)	6.68*	10.70**	1.56	0.88	1.92
7	No. of primary branches per panicle	1.99	9.21**	1.60	0.90	1.95
8	No. of secondary braches per panicle	6.41	51.73**	8.72	2.09	4.55
9	No. of grains per panicle	8.25	4936.73***	12.01	2.45	5.34
10	No. of filled grains per panicle	1.95	3921.83***	14.72	2.71	5.91
11	Fertility percentage (%)	2.36	121.66***	3.24	1.27	2.77
12	1000 grain weight (g)	7.30*	7.66*	1.67	0.91	1.99
13	Grain length(mm)	0.05	0.55***	0.05	0.15	0.33
14	Grain breadth(mm)	0.07	0.39*	0.06	0.18	0.39
15	Grain length/breadth (L/B) ratio	0.09	0.37*	0.31	0.39	0.81
16	Straw weight (g)	2.95	24.52***	1.94	0.98	2.14
17	Harvest index (%)	14.02	29.93*	9.06	2.13	4.64
18	Grain yield per plant (g)	8.31	41.61*	8.46	2.06	4.48

* significant at 5% level, **significance at 1% level, *** significant at 0.01% level

Table 3: Percent heterosis and inbreeding depression in Cross I (Mahsuri x Bhutmuri) and Cross II (IR 36 X Bhutmuri) for yield components in rice

S. No.	Characters	Cross I : MahsuriX Bhutmuri				Cross II: IR 36x Bhutmuri			
		Heterosis (Mid-Parent)	Heterosis (Better parent)	Inbreeding Dipression		Heterosis (Mid-Parent)	Heterosis (Better parent)	Inbreeding Depression	
				F_1 and F_2	F_2 and F_3			F_1 and F_2	F_2 and F_3
1	Days to 50% flowering	7.21**	-5.85**	3.11	1.7	0.59	-11.86**	2.92	3.01
2	Days to maturity	4.83**	-4.85**	2.96	-1.69	8.43**	-2.5	4.13	2.87
3	Plant height (cm)	3.30**	1.22	6.31	3.04	12.45**	-4.47*	0.19	8.79
4	Number of tillers/ Plant	46.79**	32.60**	24.58	6.05	77.27**	87.85**	42.65	11.19
5	Number of panicles/ plant	35.78**	18.67**	-13.27	4.61	65.38**	44.54**	20.23	3.39
6	Panicle length (cm)	-8.64	-15.19*	6.47	3.7	6.38	-1.48	1.5	8.13
7	Number of primary Branches/ panicle	51.27**	39.25**	7.38	23.18	-9.19	-12.22	16.2	7.85
8	Number of secondary braches/ panicle	67.36**	74.22**	35.33	-28.45	2.52	-2.87	8.52	13.99
9	Number of grains/ panicle	15.23*	-3.74	5.49	1.94	21.84**	-9.61**	6.15	33.04
10	Filled Grains/ Panicle	44.12**	16.56**	16.48	2.38	29.01**	-10.27**	12.38	37.86
11	Fertility %	10.61**	8.99*	1.23	-1.63	-6.09**	-15.14**	-5.09	3.6
12	1000 Grain Weight (g)	-6.97	-19.24**	5.76	-9.55	-8.53	-15.85**	-1.9	-3.27
13	Grain length (mm)	-6.07	-11.18**	1.99	0.67	-8.06**	-8.49**	0.34	0.68
14	Grain breadth (mm)	-6.19	-17.83**	12.26	6.43	-9.25	-18.90**	1.94	5.92
15	Grain length/ breadth(L/B) ratio	-4.08	-13.44	-12.72	-5.91	-6.91	-17.34*	-9.07	-8.33
16	Straw Weight(g)	-11.60**	-19.08**	-14.9	-5.69	-3.5	-11.58**	-4.9	-1.14
17	harvest Index (%)	12.04**	3.74	7.46	1.22	16.54**	13.99*	7.75	-1.26
18	Grain yield per plant(g)	11.76	-12.87*	-1.18	-2.28	24.45**	10.3	9.16	-3.55

***** Significant at 5% level, ** Significance at 1% level, *** Significant at 0.01% level

Conclusion

The present investigation highlighted the differential performance in two rice crosses for heterosis and inbreeding depression against different component characters. In cross I (Mahsuri× Bhutmuri) most of the yield attributing characters were recorded as positively significant heterosis over mid parent and better parents. To develop commercial hybrids it is important to have significantly better heterotic combinations in component characters ultimately enhance the grain yield which significantly enhance the yield performance. If high heterosis is followed by high inbreeding depression, indicates presence of non- additive gene action. Secondary branches per panicle in Cross I and number of tillers per plant in Cross II showed high level of heterosis coupled with inbreeding depression was revealed the importance of dominance gene effects for controlling the said varieties. Since dominance makes the large contribution to heterosis in Secondary branches per panicle and number of tillers per plant in rice, therefore, heterosis breeding and recombinant breeding are adequate to improve these traits. High heterosis is well-known to be a result of the effects of non-additive genes. Additive gene action was observed for number of panicles per plant in Cross I and harvest index (%) in Cross II as it was evident for a high level of heterosis along with low level of inbreeding depression. Therefore simple selection procedures i.e, pureline selection and mass selection method are sufficient to harness the additive gene action. The ideal trait will be one which shows positively significant heterosis with low percent of inbreeding depression. Under this situation, the importance should be given to those hybrids, which exhibited significant positive heterosis coupled with low inbreeding depression. That may results in transgressive segregation in F_2 generation.

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