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Studies on the genetic basis of heterosis and inbreeding depression through generation mean analysis for yield and its attributing traits in rice (*Oryza sativa* L.)

Chirag Solanki, Pramod Mistry, Rumit Patel and Kalpesh Raval

Abstract
The present investigation was started from *kharif*-2019 at Main Rice Research Centre, NAU, Navsari to study the genetic parameters *viz.*, gene action, heterosis, inbreeding depression, heritability and genetic advance of three crosses through generation mean analysis each having P_1, P_2, F_1, F_2, BC_1 and BC_2 generations evaluated in a Compact Family Block Design with three replications. Highly significant and positive relative heterosis, heterobeltiosis and inbreeding depression were recorded in all the crosses for most of the traits. For grain yield per plant, the best heterotic cross was cross I (Indrayani × NVSR-403) who showed highly significant heterosis in the desired direction for days to 50% flowering, days to maturity, plant height, 1000 grain weight, grain yield per plant and protein content. So, heterosis breeding in cross I would be a more practical approach for higher grain yield.

Keywords: Generation mean analysis, compact family block design, heterosis, inbreeding depression

Introduction

Rice (*Oryza sativa* L.) is a princess among the cereals and the most important cereal and food crop, second only to wheat in terms of annual production for human consumption globally. Asia is considered the 'rice bowl' of the world, producing and consuming more than 90% of world rice. India ranks first position in the area and second position in production.

Hybrid varieties are an essential strategy for fulfilling the demands of an ever-increasing population. Hybrid rice is a cost-effective way to boost the production potential of cultivars. In F_1 hybrid rice, heterosis in yield contributing characteristics led to yield enhancement (Vanaja and Babu, 2004) [12]. In terms of yield and other qualities, the heterosis reflects the F_1 hybrid's superiority or inferiority over its parents. Inbreeding depression, on the other hand, refers to the loss or decline in vigour, fertility, and yield caused by inbreeding. Both positive and negative heterosis are advantageous in crop growth, depending on the breeding aims and nature of the traits. The magnitude of heterosis aids in the identification of suitable cross combinations for use in a conventional breeding program to provide a wide range of diversity in segregating generations. Knowledge of heterosis and the level of inbreeding depression in following generations is critical for getting the most out of heterosis by using the right breeding methods.

Materials and Methods

In this study, six generations, *viz.*, P_1, P_2, F_1, F_2, BC_1, and BC_2 of three crosses were generated from three parental genotypes (Indrayani, NVSR-403 and GR-4) of rice selected based on aroma were utilized to investigate the genetics of twelve traits, as shown in Table 1. The crossing program was initiated during *Kharif*-2019 to produce three F_1 hybrids (Indrayani × GR-4, GR-4 × Indrayani, and Indrayani × NVSR-403) among three selected genotypes while backcrossing and selling of F_1 were done in *Summer*-2020 to obtain BC_1, BC_2 and F_2 seeds of respective crosses. The experimental material consisted of six generations of each of the three single crosses grown in Compact Family Block Design with three replications at Navsari Agricultural University's Main Rice Research Centre during *kharif*-2020. Each replication was split into three compact blocks. Six generations were then assigned to each plot inside a block at random. Each plot had one row of each parent and F_1 generation, two rows of the back cross generation, and twenty rows of the F_2 generation of each cross. The distance between and within rows was 45 cm and 10 cm, respectively. Per replication, ten competitive plants were randomly chosen from each P_1, P_2, and F_1, two hundred plants from F_2, and twenty plants from each of the BC_1 and BC_2 generations, and observations were made on an individual plant basis for twelve distinct characteristics, *viz*., days to 50% flowering, days to maturity, plant height, productive tillers per plant, grains per panicle, panicle length (cm), 1000-grain weight (g), grain yield per plant (g), straw yield per plant (g), Length/Breadth ratio, protein content (%) and amylose content (%).

Table 1: Details of parental lines used in hybridization program

Sr. No.	Parent	Pedigree	Important characteristics	Source
1.	Indrayani	Ambemohar 157 × IR-8	Scented rice with moderate yield	M.R.R.C.,N.A.U., Navsari
2.	GR-4	Z-31 × IR-8-246	Non-scented rice with higher yield	
3.	NVSR 403	Gurjari × GAR-1	Medium scented rice with higher yield	

Heterosis was estimated as per cent increase or decrease in the mean value of F_1 hybrid over the mid-parent, *i.e.*, relative heterosis (Briggle, 1963), over the better parent, *i.e.*, heterobeltiosis (Fonseca and Patterson, 1968) and standard check, *i.e.*, standard heterosis (Meredith and Bridge, 1972) for each character.

$$\text{Relative heterosis (\%)} = \frac{\overline{F}_1 - \overline{MP}}{\overline{MP}} \times 100$$

$$\text{Heterobeltiosis (\%)} = \frac{F_1 - BP}{\overline{BP}} \times 100$$

$$\text{Standard heterosis (\%)} = \frac{\overline{F}_1 - \overline{SC}}{\overline{SC}} \times 100$$

Where
F1 = Mean performance of the F1 hybrid
MP = Mean value of the parents (P1 and P2) of a hybrid
BP = Mean value of better parent
SC = Mean value of the standard check

The following formulas were used to calculate inbreeding depression:

$$\text{ID (\%)} = \frac{F_1 - F_2}{\overline{F}_2} \times 100$$

As stated by Warner (1952), the narrow-sense heritability was estimated as follows:

$$h^2_{(n)}(\%) = \frac{\hat{\sigma}^2_A}{\hat{\sigma}^2_P} \times 100$$

Where,
H ((n)) ^2 = Heritability in a narrow sense
σ̂ A^2 = Additive genotypic variance (d)
σ Ƥ^2 = Phenotypic variance

After a single generation of selection, the expected genetic advance represents the change in a population mean towards the superior side under selection pressure. It was computed using the approach proposed by Johnson *et al.* (1955) [6].

$$\text{Expected genetic advance} = k \cdot h^2_{(ns)} \cdot \hat{\sigma}_P$$

Where,
〖h^2〗 ((ns)) = Heritability in a narrow-sense
σ Ƥ = Phenotypic standard deviation
k = Selection differential (k = 2.06 at 5 per cent selection pressure intensity as suggested by Allard, 1960).

Result and discussion

Analysis of variance and *per se* performance

The analysis of variance between generations within each family indicated significant differences among six-generation means for all the characters studied in all the three crosses except productive tillers per plant and protein content in cross III (GR-4 × Indrayani) and straw yield per plant in cross I (Indrayani x NVSR-403). Hence, further genetic analysis of generation mean and calculation of heterosis, inbreeding depression, heritability and genetic advance were done. The results obtained on these aspects for different characters studied in three crosses of rice *viz.*, cross I (Indrayani x NVSR-403), cross II (Indrayani x GR-4) and cross III (GR-4 x Indrayani) here after referred to as cross I, cross II and cross III, respectively are presented and discussed in the following paragraphs.

Variation among the generation's mean was highly significant for days to maturity, plant height, panicle length, grains per panicle, grain yield per plant and L:B ratio in (cross I, cross II and cross III), days to 50% flowering, productive tillers per plant, protein content(cross I and cross II), 1000 grain weight (cross I and cross III), straw yield per plant (cross II) and amylose content (cross I) in all the three crosses.

Moreover, a significant difference was recorded among the generations for days to 50 per cent flowering, straw yield per plant (cross III), 1000 grain weight (cross II) and amylose content in (cross II and cross III).While anon-significant difference was observed between generations in cross I for straw yield per plant and productive tillers per plant, protein content in cross III. Therefore, further analysis was not carried out for these traits in cross I and cross III.

For most of the traits studied, the mean sum of squares exhibited substantial variations across generations in all crosses, suggesting high variability in the experimental material. Significant variation in the expression of many traits under investigation might be attributable to more diversity between parents, resulting in high variability across generations and less environmental effect on the expression of these traits.

Based on *per se* performance, F_1s fell outside the range of both the parent indicating the presence of over dominance in cross I (Indrayani × NVSR-403) for days to 50% flowering and protein grain yield per plant, while cross II (Indrayani × GR-4) and cross III (GR-4 × indrayani) exhibited over-dominance for the trait grain yield per plant. The mean performance of F_1s was observed at par with one of the parents, indicating the presence of complete dominance in cross I (Indrayani × NVSR-403) for plant height, 1000 grains weight, length/breath ratio and protein content, while in cross

II (Indrayani × GR-4) for straw yield per plant and protein content. The presence of partial dominance was observed in cross II (Indrayani × GR-4) for panicle length. The presence of no dominance was observed by at par value of F_1s with a mid-parental value which

Table 2: Analysis of variance (mean sum of squares) for six generations in three crosses of rice for different characters

Sources	df	Mean sum of squares					
		Days to 50% flowering	Days to maturity	Plant height (cm)	Productive tillers per plant	Grains per panicle	Panicle length (cm)
Analysis of variance between families							
Replications	2	1.32	0.26	4.37	0.06	13.68	0.30
Crosses	2	14.98*	0.27	68.47**	0.04*	139.85**	1.09**
Error	4	1.08	0.20	2.36	0.04	0.64	0.11
Analysis of variance between progenies within family							
Cross I (Indrayani × NVSR-403)							
Replications	2	0.55	0.60	2.09	0.11	24.52	0.92
Generations	5	31.81**	17.32**	51.26**	0.94**	545.04**	12.63**
Error	10	0.73	1.48	1.97	0.08	10.10	0.61
Cross II (Indrayani × GR-4)							
Replications	2	1.58	3.31	13.16	0.09	33.63	1.16
Generations	5	69.77**	23.21**	126.83**	0.89**	116.30**	7.76**
Error	10	1.16	2.67	17.69	0.14	12.98	0.16
Cross III (GR-4 × Indrayani)							
Replications	2	18.80	0.03	39.29	0.70	31.71	1.04
Generations	5	41.45*	15.23**	150.49**	0.59	183.12**	7.73**
Error	10	10.27	1.52	18.70	0.38	25.79	1.04
Sources	df	Mean sum of squares					
		1000 grain weight (g)	Grain yield per plant (g)	Straw yield per plant (g)	L:B ratio	Protein content (%)	Amylose content (%)
Analysis of variance between families							
Replications	2	1.32	0.38	0.76	0.01	0.01	0.08
Crosses	2	12.19**	0.49	10.19	0.25**	1.57**	1.48
Error	4	0.13	0.09	0.09	0.002	0.01	0.08
Analysis of variance between progenies within family							
Cross I (Indrayani × NVSR-403)							
Replications	2	6.28	1.32	1.59	0.06	0.04	0.22
Generations	5	13.12**	7.39**	2.79	1.21**	2.56**	3.08**
Error	10	1.25	0.49	1.12	0.01	0.03	0.26
Cross II (Indrayani × GR-4)							
Replications	2	1.36	0.46	3.37	0.004	0.04	0.44
Generations	5	2.80*	6.58**	8.62**	0.33**	0.30**	2.14*
Error	10	0.87	0.21	1.42	0.01	0.02	0.43
Cross III (GR-4 × Indrayani)							
Replications	2	1.22	1.28	0.77	0.01	0.07	0.79
Generations	5	10.55**	3.42**	9.44*	0.17**	0.21	1.25*
Error	10	0.43	0.42	2.25	0.01	0.18	0.29

Table 3: *Per se* performance of six generations for days to 50%flowering, days to maturity, plant height and productive tillers per plant in three crosses of rice

Generations	Cross I		Cross II		Cross III	
	Days to 50% flowering					
	Mean	SE	Mean	SE	Mean	SE
P_1	96.37	±0.71	96.70	±0.85	93.50	±1.44
P_2	90.73	±0.51	92.23	±1.20	92.73	±1.39
F_1	98.03	±0.51	93.07	±1.10	91.40	±1.47
F_2	92.33	±0.22	87.15	±0.25	88.70	±0.24
BC_1	89.68	±0.38	86.35	±0.66	86.88	±0.60
BC_2	94.32	±0.42	84.03	±0.30	83.88	±0.33
CD	1.55		1.96		5.83	
Generations	Days to maturity					
	Mean	SE	Mean	SE	Mean	SE
P_1	124.17	±0.78	125.20	±0.77	119.87	±1.12
P_2	119.70	±0.57	122.60	±1.19	125.57	±0.64
F_1	123.33	±0.48	123.27	±0.89	120.60	±1.08
F_2	119.92	±0.22	117.12	±0.29	119.26	±0.28
BC_1	117.98	±0.45	120.18	±0.86	121.27	±0.53
BC_2	122.33	±0.45	122.00	±1.23	120.57	±0.53

CD	2.21		2.97		2.24	
Generations	**Plant height (cm)**					
	Mean	**SE**	**Mean**	**SE**	**Mean**	**SE**
P_1	89.93	±0.87	93.13	±1.03	108.33	±1.67
P_2	98.73	±0.88	112.70	±1.63	90.10	±1.12
F_1	97.80	±1.02	98.00	±1.50	105.53	±2.06
F_2	98.07	±0.42	99.28	±0.63	109.17	±0.66
BC_1	94.52	±1.47	99.95	±1.86	105.95	±1.70
BC_2	89.65	±1.13	100.03	±1.63	106.53	±2.28
CD	2.55		7.65		7.86	
Generations	**Productive tillers per plant**					
	Mean	**SE**	**Mean**	**SE**	**Mean**	**SE**
P_1	10.13	±0.20	10.23	±0.21	9.07	±0.23
P_2	9.63	±0.23	8.83	±0.27	10.00	±0.19
F_1	9.37	±0.27	9.30	±0.27	8.87	±0.29
F_2	8.76	±0.08	9.01	±0.10	8.75	±0.07
BC_1	8.75	±0.26	8.95	±0.26	9.32	±0.20
BC_2	9.77	±0.18	9.75	±0.17	9.12	±0.24
CD	0.51		0.67		1.12	

Cross I: Indrayani × NVSR-403 Cross III : GR-4 × Indrayani
Cross II: Indrayani × GR-4

Table 4: *Per se* performance of six generations for grains per panicle, panicle length, 1000 grain weight and grain yield per plant in three crosses of rice

	Cross I		**Cross II**		**Cross III**	
Generations	**Grains per panicle**					
	Mean	SE	Mean	SE	Mean	SE
P_1	175.17	±3.23	169.57	±3.00	139.73	±2.45
P_2	183.23	±3.61	154.13	±3.51	163.10	±3.28
F_1	169.33	±2.55	157.30	±3.24	151.83	±2.05
F_2	158.90	±0.73	158.40	±1.07	154.25	±0.76
BC_1	148.40	±1.53	156.50	±2.15	146.47	±1.93
BC_2	153.10	±1.77	151.50	±1.83	150.82	±2.39
CD	5.783		6.555		9.239	
Generations	**Panicle length (cm)**					
	Mean	**SE**	**Mean**	**SE**	**Mean**	**SE**
P_1	24.98	±0.33	24.75	±0.29	19.65	±0.36
P_2	19.33	±0.30	20.00	±0.36	24.41	±0.24
F_1	22.61	±0.31	21.51	±0.38	20.72	±0.30
F_2	24.52	±0.15	21.36	±0.12	21.33	±0.10
BC_1	21.81	±0.35	21.54	±0.28	20.92	±0.25
BC_2	21.98	±0.31	20.96	±0.22	21.08	±0.28
CD	1.420		0.726		1.854	
Generations	**1000 grain weight (g)**					
	Mean	**SE**	**Mean**	**SE**	**Mean**	**SE**
P_1	19.32	±0.17	18.76	±0.15	15.21	±0.26
P_2	21.18	±0.62	18.02	±0.44	16.74	±0.16
F_1	23.14	±0.49	19.08	±0.26	16.23	±0.35
F_2	21.85	±0.11	19.97	±0.14	18.90	±0.14
BC_1	22.05	±0.15	18.48	±0.19	19.56	±0.20
BC_2	21.68	±0.27	19.36	±0.22	19.54	±0.19
CD	2.278		1.372		1.190	
Generations	**Grain yield per plant (g)**					
	Mean	**SE**	**Mean**	**SE**	**Mean**	**SE**
P_1	17.98	±0.27	19.92	±0.22	17.91	±0.18
P_2	20.83	±0.31	18.31	±0.16	19.15	±0.23
F_1	22.19	±0.29	22.61	±0.28	20.73	±0.33
F_2	21.63	±0.15	21.69	±0.13	19.65	±0.11
BC_1	19.89	±0.27	20.46	±0.25	19.27	±0.25
BC_2	21.79	±0.26	20.79	±0.23	19.02	±0.28
CD	1.277		0.838		0.738	

Cross I: Indrayani × NVSR-403 Cross III: GR-4 × Indrayani Cross II: Indrayani × GR-4

Table 5: *Per se* performance of six generations for straw yield per plant, length/breadth ratio, protein content and amylose content in three crosses of rice

	Cross I		Cross II		Cross III	
Generations	Straw yield per plant (g)					
	Mean	SE	Mean	SE	Mean	SE
P_1	27.27	±0.42	28.54	±0.43	26.21	±0.51
P_2	29.93	±0.42	26.47	±0.45	26.97	±0.48
F_1	28.81	±0.28	28.15	±0.47	26.99	±0.48
F_2	29.70	±0.14	25.76	±0.18	22.85	±0.17
BC_1	28.38	±0.32	26.49	±0.36	23.60	±0.46
BC_2	29.08	±0.30	23.87	±0.41	24.68	±0.48
CD	1.925		2.168		2.729	
Generations	Length/Breadth ratio					
	Mean	SE	Mean	SE	Mean	SE
P_1	3.66	±0.06	3.68	±0.05	3.16	±0.09
P_2	2.00	±0.02	3.04	±0.10	3.48	±0.05
F_1	2.14	±0.05	2.67	±0.06	2.79	±0.07
F_2	3.05	±0.03	2.97	±0.03	2.95	±0.02
BC_1	2.34	±0.03	3.09	±0.04	3.03	±0.04
BC_2	2.34	±0.03	3.02	±0.04	3.20	±0.04
CD	0.192		0.190		0.212	
Generations	Protein content (%)					
	Mean	SE	Mean	SE	Mean	SE
P_1	6.64	±0.07	6.64	±0.07	7.12	±0.22
P_2	8.66	±0.07	7.16	±0.17	6.59	±0.08
F_1	8.60	±0.08	7.35	±0.10	7.23	±0.14
F_2	8.13	±0.04	7.56	±0.04	7.00	±0.04
BC_1	8.95	±0.06	7.00	±0.07	7.35	±0.10
BC_2	9.24	±0.06	7.26	±0.09	7.16	±0.07
CD	0.304		0.258		0.764	
Generations	Amylose content (%)					
	Mean	SE	Mean	SE	Mean	SE
P_1	23.02	±0.20	23.00	±0.20	20.62	±0.25
P_2	24.10	±0.11	20.53	±0.29	22.22	±0.13
F_1	23.25	±0.12	21.15	±0.11	21.68	±0.13
F_2	21.64	±0.23	21.13	±0.09	20.73	±0.08
BC_1	21.79	±0.17	21.13	±0.46	21.92	±0.25
BC_2	21.75	±0.20	21.15	±0.21	21.26	±0.27
CD	0.936		1.198		0.993	

Cross I: Indrayani × NVSR-403 Cross III: GR-4 × Indrayani Cross II: Indrayani × GR-4

was observed in cross I (Indrayani × NVSR-403) for the characters *viz.*, days to maturity, productive tillers per plant, grains per panicle, panicle length, straw yield per plant and amylose content, while in cross II (Indrayani × GR-4) for days to 50 per cent flowering, days to maturity, plant height, productive tillers per plant, grains per panicle, 1000 grain weight, straw yield per plant and amylose content and in cross III (GR-4 × indrayani) for all the characters except grain yield per plant exhibited no-dominance.

F_2s were found to be at par with F_1s in all the crosses for days to maturity and plant height, while at par for 1000 grain weight in cross I and II, grain yield per plant and straw yield per plant in cross I, while in cross II (Indrayani × GR-4) for productive tillers per plant, grains per pancle, panicle length, protein content and amylose content, while in cross III (GR-4 × indrayani) for all the traits except 1000 grain weight, grain yield per plant and straw yield per plant showing absence of inbreeding depression.

Further presence of inbreeding depression was confirmed by the significantly lower value of F_2s as compared to F_1s in cross I (Indrayani × NVSR-403) for days to 50 per cent flowering, productive tillers per plant, grains per panicle, protein content and amylose content, while in crossII (Indrayani × GR-4) and cross III (GR-4 × indrayani) for grain yield per plant and straw yield per plant.

BC_1 generation was found to be significantly higher in magnitude than the female parent or/and F_1s in cross I (Indrayani × NVSR-403) for plant height, 1000 grains weight, grain yield per plant, length/breath ratio and protein content; cross II (Indrayani × GR-4) for length/breath ratio and protein content; cross III (GR-4 × indrayani) for 1000 grain weight, grain yield per plant and amylose content, which revealed that the genes for the trait under study were present in respective parents and even backcross selection will be effective for further improvement.

BC_2 generations were found to be significantly higher in magnitude than male parent or/and F_1s in cross I (Indrayani × NVSR-403) for days to 50 per cent flowering, days to maturity, panicle length, length/breath ratio and protein content; cross II (Indrayani × GR-4) for productive tillers per plant, panicle length, 1000 grain weight, grain yield per plant and length/breath ratio; cross III (GR-4 × indrayani) for length/breadth ratio, which revealed that genes for the trait under study were present in respective parents and even backcross selection scheme will be effective for further improvement. While significantly lower in magnitude in cross I (Indrayani × NVSR-403) for plant height, grains per panicle, 1000 grain weight and amylose content; cross II (Indrayani × GR-4) for days to 50 per cent flowering, plant height and straw yield per plant, while in cross III (GR-4 × indrayani) for days to 50 per cent flowering, plant height, grains per panicle, panicle length, grain yield per plant and length/breath ratio which showed the presence of epistatic gene interaction and their F_1s might have performed well as compared to parents due to accumulation of divergent alleles.

Heterosis and inbreeding depression

For a successful heterosis breeding program in rice, there must be adequate proof of the existence of a major heterotic impact in the hybrids, as well as the production of hybrid seed on a commercial scale being economically possible. Future breeding initiatives will be guided by heterosis and heterobeltiosis, which may be used to identify potential cross combinations.

In cross I, the considerable relative heterosis in the intended direction was observed for days to maturity, days to 50% flowering, 1000-grain weight, grain yield per plant and protein content. Substantial heterobeltiosis in the anticipated direction was observed for days to 50% flowering, days to maturity, plant height and grain yield per plant. All the traits exhibited positively significant inbreeding depression except in grain yield per plant and plant height indicates the more chances of getting desired transgressive segregants. Positive inbreeding depression in days to 50% flowering and days to maturity is desired as early flowering, and dwarf stature is anticipated in rice (Table 6 and 7).

The substantial relative heterosis in the intended direction was detected in cross II for plant height, grains yield per plant and protein content. Substantial heterobeltiosis in the intended direction was found for plant height and grain yield per plant. Substantial and negative inbreeding depression observed for 1000 grain weight, length/breath ratio and protein content increases the likelihood of obtaining desired transgressive segregants. While, substantial positive inbreeding depression was observed for panicle length, grain length, 100-grain weight, productive tillers per plant, and protein content. Significant positive inbreeding depression for days to flowering and days to maturity is desired. The results suggested that the selection of desired recombinants can be made in cross II (Table 6 and 7).

In cross III, the characters, *viz.*, plant height, grain yield per plant and protein content expressed substantial relative heterosis in the intended direction. The traits, *viz.*, grain yield per plant depicted substantial heterobeltiosis in the intended direction, while all other characteristics showed heterobeltiosis in the undesired direction. Significant negative inbreeding depression was observed for 1000-grain weight and length/breath ratio which indicates the chances of getting transgressive segregants for 1000-grain weight and length/breath ratio (Table 6 and 7).

The results of the present study for heterosis and inbreeding depression are in accordance with the results of Soni and Sharma (2011) [11], Vennila *et al.* (2011) [14], Ghara *et al.* (2014) [5], Anis *et al.* (2016) [1], Borah *et al.* (2017) [2], Rumanti *et al.* (2017) [9], Lingaiah (2019) [7] and Singh and Patel (2021) [10] for different characteristics.

Table 6: Estimates of relative heterosis (RH%), heterobeltiosis (HB%) and inbreeding depression (ID%) for days to 50% flowering, days to maturity, plant height (cm), productive tillers per plant, grains per panicle and panicle length (cm) in three crosses of rice

Particulars	Days to 50% flowering		Days to maturity		Plant height (cm)		Productive tillers per plant		Grains per panicle		Panicle length (cm)	
Cross I (Indrayani × NVSR-403)												
	Estimates	**SE**	**Estimates**	**SE**	**Estimates**	**SE**	**Estimates**	**SE**	**Estimates**	**SE**	**Estimates**	**SE**
RH%	4.79**	±0.67	1.15*	±0.68	3.68**	±1.19	-5.23	±0.31	-5.51**	±3.51	2.06	±0.38
HB%	8.05**	±0.72	3.04**	±0.74	8.75**	±1.34	-7.57*	±0.33	-7.59**	±4.41	-9.49**	±0.45
ID%	5.82**	±0.55	2.77**	±0.53	-0.27	±1.10	6.50*	±0.28	6.16**	±2.65	-8.44**	±0.35
Cross II (Indrayani × GR-4)												
RH%	-1.48	±1.33	-0.51	±1.14	-4.78**	±1.78	-2.45	±0.32	-2.81	±3.98	-3.84	±0.45
HB%	0.90	±1.63	0.54	±1.49	5.23**	±1.82	-9.12**	±0.34	-7.23**	±4.41	-13.08**	±0.48
ID%	6.36**	±1.13	4.99**	±0.94	-1.30	±1.62	3.14	±0.29	-0.70	±3.41	0.70	±0.40
Cross III (GR-4 × Indrayani)												
RH%	-1.84	±1.78	-1.73	±1.26	6.37**	±2.29	-6.99*	±0.33	0.28	±2.90	-5.95**	±0.37
HB%	-2.25	±2.05	0.61	±1.56	17.13**	±2.35	-11.33**	±0.35	-6.91**	±3.86	-15.11**	±0.38
ID%	2.95	±1.49	1.11	±1.11	-3.44	±2.17	1.28	±0.30	-1.59	±2.18	-2.98	±0.31

* And **, significant at 5% and 1% of respectively

Table 7: Estimates of relative heterosis (RH%), heterobeltiosis (HB%) and inbreeding depression (ID%) for 1000 grain weight, grain yield per plant (g), straw yield per plant (g), length/breadth ratio, protein content (%) and amylose content (%) in three crosses of rice

Particulars	1000 grain weight		Grain yield per plant		Straw yield per plant		Length/breadth ratio		Protein content		Amylose content	
Cross I (Indrayani × NVSR-403)												
	Estimates	**SE**	**Estimates**	**SE**	**Estimates**	**SE**	**Estimates**	**SE**	**Estimates**	**SE**	**Estimates**	**SE**
RH%	14.28**	±0.72	14.35**	±0.36	0.72	±0.41	-24.17**	±0.05	12.42**	±0.09	-1.33	±0.16
HB%	7.32	±0.60	6.54**	±0.43	-3.75*	±0.50	-41.34**	±0.07	-0.67	±0.10	-3.55**	±0.16
ID%	4.21*	±0.42	2.51	±0.33	-3.12**	±0.31	-42.39**	±0.05	5.42**	±0.09	6.89**	±0.26
Cross II (Indrayani × GR-4)												
RH%	3.20	±0.26	18.27**	±0.31	2.34	±0.57	-20.42**	±0.09	6.53**	±0.13	-2.80**	±0.21
HB%	1.65	±0.22	13.48**	±0.36	-1.37	±0.64	-27.36**	±0.08	2.66	±0.20	-8.03**	±0.23
ID%	-3.36**	±0.28	4.08**	±0.31	8.50**	±0.51	-11.00**	±0.07	-2.91*	±0.11	0.10	±0.15
Cross III (GR-4 × Indrayani)												
RH%	1.59	±0.38	10.27**	±0.42	1.53	±0.60	-15.93**	±0.08	5.51*	±0.18	1.19	±0.19
HB%	-3.06	±0.39	6.32*	±0.21	0.11	±0.68	-19.75**	±0.08	1.55	±0.26	-2.46**	±0.19
ID%	-16.45**	±0.38	7.12**	±0.36	15.36**	±0.51	-5.89*	±0.07	3.23	±0.14	4.37**	±0.15

* And **, significant at 5% and 1% of respectively

Conclusions

For the majority of the characteristics, very substantial and positive relative heterosis, heterobeltiosis and inbreeding depression were seen in all crosses. Significant heterosis over mid-parent and better parent, as well as positive inbreeding depression, may be ascribed to a significant contribution from dominance (h) and additive × additive (i) gene effects, where selection will be effective only in later generations. The best heterotic cross for grain yield per plant was cross II (Indrayani x GR-4), which showed significant heterosis in the desired direction for days to 50% flowering, days to maturity, productive tiller per plant, grains per panicle, panicle length, 1000-grain weight, grain yield per plant, straw yield per plant, protein content, and amylose content. So, heterosis breeding in cross II would be a more feasible technique for higher grain yield.

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Conflict of Interest
Conflict of interest none declared.

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