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Assessment of heterosis and inbreeding depression for yield, its components and qualitative traits in rice (*Oryza sativa* L.)

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Abstract
The present investigation was carried out at Main Rice Research Centre, Navsari Agricultural University, Navsari during *kharif*-2020-2021. This study comprised three crosses using four diverse lines to study heterosis and inbreeding depression for yield, its components and qualitative traits in rice (*Oryza sativa* L.) through generation mean analysis (each having P_1, P_2, F_1, F_2, BC_1 and BC_2 generations) in a Compact Family Block Design (CFBD) with three replications. For grain yield per plant (g), best heterotic combination for relative heterosis and heterobeltiosis was recorded for cross III (IR-64 x GR-11) which also recorded significant relative heterosis in desired direction for days to flowering, plant height (cm), productive tillers per plant, grains per panicle, 100-grain weight (g), kernel length (mm), kernel breadth (mm), L:B ratio and amylose content (%) and also showed significant heterobeltiosis in the desired direction for plant height (cm), productive tillers per plant and grains per panicle. Standard heterosis for grain yield per plant (g) in cross I stood significant with its all components except panicle length (cm), 100-grain weight (g) as well as amylose content (%). So, heterosis breeding might be effective for this cross.

Keywords: Heterosis, inbreeding depression, generation mean analysis, rice (*Oryza sativa* L.)

Introduction
Rice is an important cereal crop. To indicate its overwhelming importance in sense of highly consumed food, year 2004 was celebrated as the international year of rice with the theme "Rice is life". Rice stands second most cultivated crop species in the world after wheat and its food grain of billions of lives for survival (Nguyen and Ferrero, 2006) [13] as it remains a source of staple food for the majority of the population around the world. In addition to food grains, its an important source of fiber, energy, minerals, vitamins, and other biomolecules that could act as synergy and made use of beneficial effects on health (Burlando and Cornara, 2014; Juliano, 1993; Goufo and Trindade, 2014) [3, 6, 5]. Among the different options available, hybrid rice technology is considered as one of the better, practicable, sustainable and eco-friendly options to break the yield ceiling witnessed in rice. Therefore, the choice of an effective rice breeding approach to select for a particular characteristic depends substantially on the knowledge of the genetic system controlling these characters. The genetic improvement also depends primarily on the effectiveness of selection among the progenies that differ in genetic value.
Heterosis expresses the superiority of F_1 hybrid over its parents in terms of yield and other traits. On the other hand, the inbreeding depression reflects on reduction or loss in vigour, fertility and yield as a result of inbreeding. The magnitude of heterosis helps in the identification of potential cross combinations to be used in a conventional breeding programme to enable create a wide array of variability in segregating generations. The knowledge of heterosis accompanied by the extent of inbreeding depression in subsequent generations is essential for maximum exploitation of such heterosis by adopting the appropriate breeding methodology.

Materials and Methods
The material comprising of four genetically diverse parents of rice (Improved Sambha Mahsuri, GNR-7, IR-64 and GR-11) selected on the basis of their geographic origin, variation in morphological characters and behaviour towards bacterial leaf blight resistance of rice. The crossing program was initiated during *kharif*-2020 to produce among four selected genotypes,

while backcrossing and selfing of F_1 were done in *rabi*-2021 to obtain BC_1, BC_2 and F_2 generations of respective crosses. The evaluation trial consisting of three F_1 hybrids *i.e.*, Improved Samba Mahsuri x GNR-7, Improved Samba Mahsuri x IR-64 and IR-64 x GR-11. Trial was conducted during *kharif*-2021 at Main Rice Research Centre, Navsari Agricultural University, Navsari. The experimental material consisting of six generations (P_1, P_2, F_1, F_2, BC_1 and BC_2) of each of the three single crosses were sown during *kharif*-2021 in Compact Family Block Design (CFBD) with three replications. Six generations were then randomly allotted to each plot within a block. Each plot consisted of one row of each parent and F_{1s}, two rows of the back cross generation and twenty rows of the F_2 generations of each cross.

Estimation of heterosis

Heterosis was estimated as % increase or decrease in the mean value of F_1 hybrid over the mid-parent, *i.e.*, relative heterosis (Briggle, 1963) [2], over the better parent, *i.e.*, heterobeltiosis (Fonseca and Patterson, 1968) [4] and standard check, *i.e.*, standard heterosis (Meredith and Bridge, 1972) [11] for each character.

$$\text{Relative heterosis (\%)} = \frac{\overline{F}_1 - \overline{MP}}{\overline{MP}} x100$$

$$\text{Heterobeltiosis (\%)} = \frac{\overline{F}_1 - \overline{BP}}{\overline{BP}} x100$$

$$\text{Heterobeltiosis (\%)} = \frac{\overline{F}_1 - \overline{BP}}{\overline{BP}} x100$$

Where,

$\overline{F}_1$= Mean performance of the F_1 hybrid

$\overline{MP}$=Mean value of the parents (P_1 and P_2) of a hybrid

$\overline{BP}$= Mean value of better parent

$\overline{SC}$= Mean value of standard check

Estimation of inbreeding depression

Inbreeding depression was computed by using the following formulae:

$$\text{Inbreeding depression (\%)} = \frac{\overline{F}_1 - \overline{F}_2}{\overline{F}_2} \times 100$$

The standard error and 't' value for the test of significance for inbreeding depression were estimated as under:

$$\mathrm{S.E.}\left(\overline{F}_1 - \overline{F}_2\right) = \sqrt{\frac{[V(F_1)(n_1 - 1)] + [V(F_2)(n_2 - 1)]}{n_1 + n_2 - 2}}$$

$$t = \frac{\overline{F}_1 - \overline{F}_2}{\mathrm{S.E.}\left(\overline{F}_1 - \overline{F}_2\right)}$$

Where,

$\overline{F}_1$= Mean value of the F1 hybrid

$\overline{F}_2$= Mean value of the F2 generation

$V(F_1)$= Variance of the F1 generation

$V(F_2)$= Variance of the F2 generation

n_1= Number of observations in the F1 generation

n_2= Number of observations in the F2 generation

The significance of the inbreeding depression was tested by comparing the Calculated 't' value with the Table 't' value at 5% (1.96) and 1% (2.58) levels of significance.

Result and discussion

The extent of heterotic effects *i.e.*, relative heterosis (RH), heterobeltiosis (HB) and standard heterosis as well as inbreeding depression (ID) were estimated for all the twelve characters under study. The relative heterosis, heterobeltiosis, standard heterosis (SH) and inbreeding depression for twelve characters in study of three crosses are presented in Table 1 and 2.

Among the three crosses, cross III (IR-64 x GR- 11) recorded best heterotic combination for relative heterosis and heterobeltiosis for grain yield per plant (g). This cross also recorded significant relative heterosis in desired direction for days to flowering, plant height (cm), productive tillers per plant, grains per panicle, 100-grain weight (g), kernel length (mm), kernel breadth (mm), L: B ratio and amylose content (%) with significant heterobeltiosis in the desired direction for plant height (cm), productive tillers per plant and grains per panicle. Swarna sub-1 were utilized as standard check. Out of three crosses, Improved Samba Mahsuri x GNR-7 had highest and significant standard heterosis for grain yield per plant (g) and all its component traits under study except panicle length (cm) and 100-grain weight (g) as well as amylose content (%).

From three crosses, only cross III (IR-64 x GR-11) recorded significant negative relative heterosis in the desirable direction, for days to flowering. Similar findings for negative mid parental heterosis was reported earlier by Latha *et al*. (2013) [8] and Mohammad (2022) [12]. The result of standard heterosis depicts that all three crosses showed negative and significant heterosis in desirable direction. The range of standard heterosis was varied from -9.59% (Improved Samba Mahsuri x GNR-7) to -5.49% (Improved Samba Mahsuri x IR-64). In F_2 generation there was observable inbreeding depression in an undesirable direction for cross I (-4.72%) and cross III (-3.65%). While in cross II (3.98%) inbreeding depression was observed in the desirable direction for days to flowering. Similar findings were reported earlier by Sravan and Jaiswal (2017) [18] and Balat *et al*. (2018) [1].

For plant height (cm), two crosses, Improved Samba Mahsuri x GNR-7 and IR-64 x
GR-11 recorded -5.44% and -6.49% significant negative heterosis in desirable direction, respectively. Significant better parent heterosis in negative direction was recorded by only cross III (IR-64 x GR-11) which valued -3.54%. Further, range of inbreeding depression was varied from -4.36% in cross III (IR-64 x GR 11) to 6.34% in cross II (Improved Samba Mahsuri x IR-64). Significant positive estimate of inbreeding depression in a desirable direction was observed in cross II (6.34%).

For productive tillers per plant lowest and highest relative heterosis was recorded from -5.50% (Improved Samba Mahsuri x IR-64) to 14.61% (IR-64 x GR-11). Two crosses, Improved Samba Mahsuri x GNR-7 (10.40%) and IR-64 x GR-11 (14.61%) recorded highly significant positive relative heterosis in desired direction. Similar findings were recorded earlier by Lingaiah *et al*. (2019) [9], Patel *et al*. (2019) [14] and Mohammad (2022) [12]. Among the three crosses, IR-64 x GR-11 (8.05%) depicted significantly positive heterobeltiosis in desired direction which depicts the importance of dominance gene action. Similar findings were reported for positive better parent heterosis by Thakor *et al*. (2018) [19] and Kumari and Senapati (2019) [7]. Comparison of mean value of F_1 with standard check (Swarna sub -1) recorded highly significant heterosis for Improved Samba Mahsuri x GNR-7 (22.78%). While other two crosses recorded significant negative heterosis (-8.19% and -9.25%). Estimate of inbreeding depression was significant and positive in cross, Improved Samba Mahsuri x GNR-7 (7.10%). While rest of two crosses (Improved Samba Mahsuri x IR-64 and IR-64 x GR-11) showed non-significant inbreeding depression. Similar findings were reported for positive inbreeding depression by Balat *et al*. (2018) [1], Makwana *et al*. (2018) [10], Lingaiah *et al*. (2019) [9] and Patel *et al*. (2019) [14].

For character panicle length, the minimum and maximum values of relative heterosis were 1.42% (IR-64 x GR-11) to 3.29% (Improved Samba Mahsuri x GNR-7). Only, cross I (Improved Samba Mahsuri x GNR-7) recorded highly significant and positive relative heterosis (3.29%). Moreover, none of the crosses recorded significant positive better parent heterosis and standard heterosis. The range of the better parent heterosis was -7.35% (IR-64 x GR 11) to -1.97% (Improved Samba Mahsuri x GNR-7). While range of standard heterosis was -14.13 (%) for IR-64 x GR 11 to 2.66 (%) in Improved Samba Mahsuri x GNR-7. Estimates of inbreeding depression were significant and positive in all crosses and ranged from 3.87% (IR-64 x GR-11) to 7.67% in (Improved Samba Mahsuri x GNR-7). Similar findings for positive inbreeding depression were reported earlier by Balat *et al*. (2018) [1] and Makwana *et al*. (2018) [10].

Highest mid parent heterosis was recorded in cross Improved Samba Mahsuri x IR-64 (20.42%) followed by IR-64 x GR-11 (13.04%), which is desirable for grains per panicle. Similar findings related to positive heterosis for grains per panicle were reported earlier by Makwana *et al.* (2018) [10], Singh and Patel (2021) [17] and Mohammad (2022) [12]. Out of three, only one cross (IR-64 x GR-11) reported significant positive heterobeltiosis (4.90%) while, rest of two crosses observed better parent heterosis in negative direction which would be not rewarding for improvement of this trait through heterosis breeding Sravan and Jaiswal (2017) [18] and Thakor *et al*. (2018) [19]. Estimates of standard heterosis were found highly significant and positive in Improved Samba Mahsuri x GNR-7 (49.49%) followed by Improved Samba Mahsuri x IR-64 (31.58%). While cross IR-64 x GR-11 recorded significant negative heterosis (-5.37%) in an undesirable direction. The highest positive inbreeding depression was recorded by cross I (Improved Samba Mahsuri x GNR-7) (6.05%) followed by cross III (IR-64 x GR-11) (4.29%) and cross II (Improved Samba Mahsuri x IR-64) (-1.12%). The result is in accordance with Kumari and Senapati (2019) [7] and Lingaiah *et al*. (2019) [9].

For 100-grain weight, the highest and positively significant relative heterosis was exhibited by the cross Improved Samba Mahsuri x IR-64 (14.62%). Two crosses, Improved Samba Mahsuri x IR-64 (14.62%) and IR-64 x GR-11 (4.59%) recorded significant positive heterosis in a desirable direction. These results have similarities with Latha *et al*. (2013) [8] and Singh and Patel (2021) [17]. Moreover, both better parent and standard heterosis was found significant in negative direction and was not useful. The result of inbreeding depression was found desirable and in negative direction for Improved Samba Mahsuri x GNR-7 (-1.21%).

Out of three crosses, two crosses namely, Improved Samba Mahsuri x IR-64 (13.78%) and IR-64 x GR-11 (20.99%) showed significant positive relative heterosis for grain yield per plant (g) which is desirable for this trait. The values of heterobeltiosis ranged from -1.37% (Improved Samba Mahsuri x IR-64) to 11.00% (IR-64 x GR-11) and it was found significantly positive for cross IR-64 x GR-11 (11.00%) in the desired direction. In addition, one (Improved Samba Mahsuri x GNR-7) out of three crosses recorded significant and positive standard heterosis in the desired direction which was valued at 4.82%. Further, Improved Samba Mahsuri x IR-64 (9.24%) and IR-64 x GR-11 (4.59%) exhibited significantly positive inbreeding depression which is not desirable for this trait. These results are concurrence with Venkanna *et al*. (2014) [20], Lingaiah *et al*. (2019) [9] and Singh and Patel (2020) [16].

Two crosses, Improved Samba Mahsuri x IR-64 (8.78%) and IR-64 x GR-11 (9.16%) recorded significant positive heterosis for straw yield per plant (g). Similar findings were observed by Patel *et al*. (2019) [14] and Singh and Patel (2021) [17]. Further none of them recorded significantly positive heterobeltiosis for straw yield per plant (g). This indicates the value of F_1 was not useful for getting desirable hybrids. Two crosses Improved Samba Mahsuri x IR-64 (9.99%) and IR-64 x GR-11 (8.57%) exhibited significantly positive inbreeding depression while cross Improved Samba Mahsuri x GNR-7 showed non-significant (1.66%) inbreeding depression. Similar results were reported by Venkanna *et al*. (2014) [20], Lingaiah *et al*. (2019) [9] and Singh and Patel (2020) [16] for straw yield per plant (g).

The highest and positively significant relative heterosis was exhibited by Improved Samba Mahsuri x IR-64 (8.62%) followed by IR-64 x GR-11 (5.74%) and Improved Samba Mahsuri x GNR-7 (0.62%) for kernel length (mm). Further, all these crosses were found to record significant heterobeltiosis in a negative direction. Moreover, all three crosses were recorded significant and positive standard heterosis over their respective F_{1S} and the range was recorded from -3.27 (IR-64 x GR-11) to -1.49 (Improved Samba Mahsuri x GNR-7) %. For inbreeding depression cross IR-64 x GR-11 depicted negative value (-1.03%) which revealed there would be chances to get better individuals in upcoming generation for this trait. These results were in accordance with Venkanna *et al*. (2014) [20] and Balat *et al.* (2018) [1].

The result depicts that, cross Improved Samba Mahsuri x GNR-7 (-2.46%) exhibited significantly negative relative heterosis and may be desirable for fine kernel. While, cross-II (9.63%) and cross-III (3.25%) expressed positive relative heterosis. Similar result was reported earlier by Venkanna *et al*. (2014) [20], Balat *et al*. (2018) [1] and Singh and Patel (2021) [17]. In addition, all three crosses were found to record significant negative standard heterosis for kernel breadth and it recorded from -26.89 (Improved Samba Mahsuri x GNR-7) to -9.74 (IR-64 x GR-11)%. Similar findings were reported by Sravan and Jaiswal (2017) [18] and Balat *et al*. (2018) [1]. The estimates of inbreeding depression were ranged from -1.29% (IR-64 x GR-11) to 3.08% (Improved Samba Mahsuri x GNR-7). Cross Improved Samba Mahsuri x GNR-7 found to have inbreeding depression in desirable direction (3.08%) for this trait indicating the possibility to obtain desirable plant for fine grain in further generations.

Range of relative heterosis for L: B ratio was observed from -0.79% (Improved Samba Mahsuri x IR-64) to 3.17%

(Improved Samba Mahsuri x GNR-7) Balat *et al*. (2018) [1] and Singh and Patel (2020) [16] recorded similar results for this trait. Further, all three crosses were observed significantly positive heterosis over standard check for this trait. The range of standard heterosis was 36.59 (Improved Samba Mahsuri x IR-64) to 41.36 (Improved Samba Mahsuri x GNR-7) %. Similar findings were observed by Sravan and Jaiswal (2017) [18]. The range of inbreeding depression was found from -0.71 (IR-64 x GR-11) to 0.64 (Improved Samba Mahsuri x IR-64) % for this trait. Balat *et al*. (2018) [1] and Patel *et al*. (2019) [14] reported supporting results for this trait.

Two out of three crosses namely, Improved Samba Mahsuri x GNR-7 (-1.52%) and Improved Samba Mahsuri x IR-64 (-2.89%) depicted negative relative heterosis for amylose content. While single cross, IR-64 x GR-11 (3.76%) recorded significantly positive heterosis. Similar result for positive relative heterosis were observed by Venkanna *et al*. (2014) [20], Patel *et al*. (2019) [14], Patel and Patel (2020) [15] and Singh and Patel (2020) [16] for amylose content (%). In addition, none of the parents were found to record significant better parent heterosis and standard heterosis in desirable direction. The range of inbreeding depression was recorded from -3.20% in Improved Samba Mahsuri x IR-64 to 1.67% for IR-64 x GR-11. Similar findings for this trait were reported by Venkanna *et al*. (2014) [20], Patel *et al*. (2019) [14] and Singh and Patel (2020) [16].

Table 1: Estimates of relative heterosis (RH%), heterobeltiosis (HB%), standard heterosis (SH%) and inbreeding depression (ID%) for days to flowering, plant height (cm), productive tillers per plant, grains per panicle, panicle length (cm) and 100- grain weight (g) in three crosses of rice

Particulars	Days to flowering		Plant height (cm)		Productive tillers per plant		Panicle length (cm)		Grains per panicle		100-grain weight (g)	
Cross I (Improved Samba Mahsuri x GNR-7)												
	Estimates	SE	Estimates	SE	Estimates	SE	Estimates	SE	Estimates	SE	Estimates	SE
RH%	-1.16	±0.81	-5.44**	±1.86	10.40**	±0.37	3.29**	±0.28	2.29	±5.97	1.48	±0.01
HB%	7.06**	±0.95	2.82	±1.88	2.99	±0.42	-1.97	±0.29	-2.82	±7.74	-1.85	±0.01
SH%	-9.59**	±1.00	-3.98*	±1.91	22.78**	±0.45	2.66	±0.34	49.49**	±4.79	-31.67**	±0.01
ID%	-4.72**	±0.85	-2.03	±1.86	7.10*	±0.36	7.67**	±0.29	6.05**	±4.83	-1.21	±0.01
Cross II (Improved Samba Mahsuri x IR-64)												
RH%	0.84	±0.76	6.65**	±1.03	-5.50	±0.26	1.59	±0.31	20.42**	4.23	14.62**	±0.01
HB%	5.90**	±0.84	20.71**	±1.13	-21.10**	0.33	-3.00	0.44	-6.27**	5.39	-5.77**	±0.01
SH%	-5.49**	±0.98	14.04**	±1.04	-8.19*	±0.37	-0.95	±0.30	31.58**	±3.85	-3.93**	±0.01
ID%	3.98**	±0.75	6.34**	±1.08	-0.29	±0.24	4.60**	±0.22	-1.12	±3.79	13.63**	±0.01
Cross III (IR-64 x GR-11)												
RH%	-1.46*	±0.58	-6.49**	±1.26	14.61**	±0.27	1.42	±0.37	13.04**	±2.01	4.59**	±0.01
HB%	3.89**	±0.69	-3.54**	±1.28	8.05*	±0.31	-7.35**	±0.44	4.90**	±2.63	-11.99**	±0.01
SH%	-8.14**	±0.85	8.85**	±1.31	-9.25*	±0.39	-14.13**	±0.39	-5.37**	±1.99	-11.05**	±0.01
ID%	-3.65**	±0.60	-4.36**	±1.27	1.57	±0.26	3.87	±0.35	4.29**	±1.38	4.14**	±0.01

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

Table 2: Estimates of relative heterosis (RH%), heterobeltiosis (HB%), standard heterosis (SC%) and inbreeding depression (ID%) for grain yield per plant (g), straw yield per plant (g), kernel length (mm), kernel breadth (mm), L:B ratio and amylose content (%) in three crosses of rice

Particulars	Grain yield per plant (g)		Straw yield per plant (g)		Kernel length (mm)		Kernel breadth (mm)		L:B ratio		Amylose content (%)	
Cross I (Improved Samba Mahsuri x GNR-7)												
	Estimates	SE	Estimates	SE	Estimates	SE	Estimates	SE	Estimates	SE	Estimates	SE
RH%	0.89	±0.43	0.83	±0.51	0.62	±0.03	-2.46**	±0.01	3.17**	±0.03	-1.52**	±0.18
HB%	-0.15	±0.51	-2.62	±0.54	-1.49**	±0.02	0.94	±0.01	1.94	±0.03	-2.24**	±0.20
SH%	4.82*	±0.45	8.60**	±0.59	3.29**	±0.02	-26.89**	±0.01	41.36**	±0.03	-1.18	±0.20
ID%	3.56	±0.41	1.66	±0.51	3.17**	±0.02	3.08**	±0.01	-0.51	±0.03	1.43	±0.16
Cross II (Improved Samba Mahsuri x IR-64)												
RH%	13.78**	±0.50	8.78**	±0.58	8.62**	±0.04	9.63**	±0.01	-0.79	±0.03	-2.89**	±0.18
HB%	-1.37	±0.59	-3.78*	±0.61	-2.79**	±0.04	26.38**	±0.01	-0.07	±0.03	-6.71**	±0.20
SH%	-0.58	±0.52	3.81	±0.63	23.61**	±0.03	-9.48**	±0.01	36.59**	±0.02	-5.62**	±0.19
ID%	9.24**	±0.48	9.99**	±0.55	1.27*	±0.04	0.44	±0.01	0.64	±0.02	-3.20**	±0.15
Cross III (IR-64 x GR-11)												
RH%	20.99**	±0.47	9.16**	±0.60	5.74**	±0.03	3.25**	±0.01	2.54**	±0.02	3.76**	±0.17
HB%	11.00**	±0.60	3.89	0.64	-3.27**	±0.03	11.31**	±0.01	0.48	±0.02	0.58	±0.21
SH%	-5.07*	±0.48	-1.20	±0.67	23.96**	±0.03	-9.74**	±0.01	37.35**	±0.02	-1.79*	±0.19
ID%	4.59*	±0.43	8.57**	±0.60	-1.03*	±0.03	-1.29	±0.01	-0.71	±0.02	1.67**	±0.14

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

Conclusion

In present investigation, result of significant and desirable relative heterosis, heterobeltiosis, standard heterosis and inbreeding depression were varied from cross to cross for same characters and characters to characters for same cross indicated the presence of differed behavior of alleles and their effects. Significant heterosis over mid-parent and better parent, along with positive inbreeding depression, may be attributed to a major contribution from dominance (h) and dominance x dominance (l) gene effects, where use of heterosis breeding would be effective.

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