The Pharma Innovation Journal 2021; 10(5): 655-660

www.ThePharmaJournal.com

The Pharma Innovation

ISSN (E): 2277- 7695
ISSN (P): 2349-8242
NAAS Rating: 5.23
TPI 2021; 10 (5): 655-660

www.thepharmajournal.com
Received: 07-02-2021
Accepted: 21-03-2021

Bineetkaur S Singh
Regional Rice Research Station, Vyara, Navsari Agricultural University, Gujarat, India

Vipul P Patel
Regional Rice Research Station, Vyara, Navsari Agricultural University, Gujarat, India

Corresponding Author:
Bineetkaur S Singh
Regional Rice Research Station, Vyara, Navsari Agricultural University, Gujarat, India

Study of heterosis and inbreeding depression in F_2 generation of upland rice (*Oryza sativa* L.)

Bineetkaur S Singh and Vipul P Patel

Abstract

A field experiment was conducted during *Kharif*-2017 and *Kharif*-2018 involving six elite lines of rice, six F_1 hybrids and their corresponding F_2 populations to study the inbreeding depression and heterosis for grain yield, yield contributing traits. Relative heterosis and/or heterobeltiosis in desired direction were observed for productive tillers per plant, panicle length, number of grains per panicle, 100 seed weight, grain length, grain yield per plant and straw yield per plant. Heterosis breeding would be more practical approach for improvement of these traits. Therefore, the present study was carried out with an objective to estimate extent of heterosis and inbreeding depression for yield and grain characters. Out of six hybrids studied five hybrids exhibited positive and significant heterosis for grain yield per plant. The findings of present study indicated that majority of the hybrids recorded high heterosis for grain yield. Among the various hybrids exhibiting desirable value of heterosis, Purna x NVSR-2227, Purna x IR-28, GR-5 x GNR-6, GR-5 x GR-7and GR-7 x Purna were top performers for grain yield per plant.

Keywords: Upland rice, heterosis, heterobeltosis, inbreeding depression

Introduction

Rice is one of the most important food crops in the world. The world population is expected to reach 8.27 billion by 2030 demanding an increased rice production of 771 million tons (Badawi, 2004) [6]. Hence, with the rapid increase in the growing population it is very essential to enhance the production and productivity of rice. The present scenario, rice is cultivated in 43.79 million hectares with production of 116.42 million tons and productivity of 2659 kg per hectare (Anon[a]., 2019) [4] in India and in Gujarat it is cultivated in 9.04 lakh hectares with production of 19.72 lakh tons and productivity of 2180 kg per hectare (Anon[b]., 2019) [5]. The uplands have traditionally suffered from drought and infertile soils, weeds and plant diseases and it is grown about 13% of the area in India but contributes to only 4% of the rice production. The uplands have traditionally suffered from drought and infertile soils, weeds and plant diseases. Soils there have been badly eroded and degraded as a result of the slash-and-burn agriculture that for many years followed logging. This, in turn, destroys the watershed, producing problems in the lands below. Already the new upward pressures are resulting in a movement toward permanent agriculture and intensification of land use in upland areas. Those involved find themselves faced in addition to the usual upland problems with an urgent need to conserve the soil and the diversity of plant species, and to cope with increasingly frequent and severe weed and disease infestations. Till today work on the production technology has main concentration to the low land transplanted paddy and well managed conditions for higher yield and fine grain with aroma quality, but very little work has been done on the upland rice.

The heterosis expresses the superiority of F_1 hybrid over its parents in term 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 conventional breeding program to enable and create 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 appropriate breeding methodology. To know the magnitude and direction potentiality of crosses is important (Singh *et al.*, 1995). Both positive and negatisve heterosis is useful in crop improvement. The objective of this study was to find the high magnitude of heterotic crosses for grain yield and its component characters under upland condition.

Materials and Methods

The material comprising of six diversified rice lines *viz*., Purna, NVSR-2227, IR-28, GNR-6, GR-5 and GR-7 which were selected on the basis of their geographic origin and wide variation in the morphological traits. The F_1s were generated by crossing of above six parents during *kharif*-2017. Selfing of F_1's was done in the *kharif*-2018 to get F_2's at regional rice research station, Navsari agricultural university, Vyara, distict Tapi, Gujarat. All recommended agronomic practices along with necessary plant protection measures were timely adopted. Five plants were randomly selected per replication and observations were recorded for the characters *viz*., days to flowering, days to maturity, plant height (cm), productive tillers per plant, panicle length (cm), number of grains per panicle, spikelet fertility (%), 100 seed weight (g), grain length (cm), grain breadth (cm), grain l/b ratio, grain yield per plant (g), straw yield per plant (g) and harvest index (%).

The analysis of variance for different characters was done as formula suggested by Panse and Sukhatme (1967) [17]. Heterosis expressed as percent increase or decrease of F_1 hybrid over its mid-parent (relative heterosis) and over its better or superior parent (heterobeltiosis) were computed as follow:

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

$$\text{Heterobeltiosis (\%)} = \frac{\bar{F}_1 - \overline{BP}}{\overline{BP}} \times 100$$

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

BP = Mean value of better parent

The standard errors and calculated 't' value for test of significance for heterosis and heterobeltiosis were calculated as under:

Standard errors

$$\text{S.E. } (\overline{F_1} - \overline{MP}) = \sqrt{\frac{3Me}{r}}$$

(Standard error for heterosis)

$$\text{S.E. } (\overline{F_1} - \overline{BP}) = \sqrt{\frac{2Me}{r}}$$

(Standard error for heterobeltiosis)

Where

Me = Error mean square

r = Number of replication

't' test

$$t = \frac{\bar{F}_1 - \overline{MP}}{\text{S.E. } (\overline{F_1} - \overline{MP})} \quad \text{. for relative heterosis}$$

$$t = \frac{\bar{F}_1 - \overline{BP}}{\text{S.E. } (\overline{F_1} - \overline{BP})} \quad \text{. for heterobeltiosis}$$

The test of significance of the heterosis, heterobeltiosis and standard heterosis were carried out by comparing the calculated values of 't' with the tabulated values 't' at five percent (1.96) and one percent (2.57) levels of significance.

Inbreeding depression was computed by using the following formulae given by (Kempthorne, 1957).

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

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

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

$$t = \frac{\bar{F}_1 - \bar{F}_2}{\text{S. E. } (\bar{F}_1 - \bar{F}_2)}$$

Where

$\overline{F_1}$ = Mean value of the F_1 hybrid

$\overline{F_2}$ = Mean value of the F_2 generation

V (F_1) = Variance of the F_1 generation

V (F_2) = Variance of the F_2 generation

n_1 = Number of observations in F_1 generation

n_2 = Number of observations in F_2 generation

The significance of the inbreeding depression was tested by comparing the calculated 't' value with the table 't' value at 5 percent (1.96) and 1 percent (2.57) levels of significance.

Results and Discussion

There are two important pre-requisites for a successful heterosis breeding program in rice, there must be sufficient evidence of the presence of significant heterotic effect in the hybrids and another is the production of hybrid seed at commercial scale must be economically feasible. The direction of future breeding programs depends on heterosis and heterobeltiosis which is useful to isolate promising cross combinations. Now, inbreeding depression refers to decrease in fitness and vigour due to continuous inbreeding and decreased heterozygosity which results due to fixation of unfavorable recessive genes in F_2, while in case of heterosis undesirable recessive genes of one parent are suppressed by favorable dominant genes of another parent.

The grain yield is very complex trait. It is multiplicative end product of several basic components of yield (Grafius, 1959) [11]. A number of workers have reported wide range of variation in the expression of heterosis for this character. Among all the crosses under this study depicted highly significant relative heterosis and significant heterobeltiosis was found in cross-II (Purna x IR-28). Higher positive heterosis for grain yield per plant in rice had been reported by several earlier *viz*., Panwar and Ali (2010) [18], Adilakshmi and Reddy (2011) [1], Patil *et al*. (2011) [20], Soni and Sharma (2011) [28], Tiwari *et al*. (2011) [31], Reddy *et al*. (2013) [23], Latha *et al*. (2013) [13]. Ghara *et al*. (2014) [10], Venkanna *et al*. (2014) [32], Anis *et al*. (2016) [3], Borah *et al*. (2017) [9], Rumanti *et al*. (2017) [24], Sravan and Jaiswal (2017) [29], Thorat *et al*. (2017) [30], Makwana et al. (2018) [14], Balat *et al*. (2018) [8], Solanke *et al*. (2019) [27] and Patel and Patel (2020) [19]. All the traits exhibited non-significant inbreeding depression which indicates the chances of transgressive segregants for this trait. Non-significant results were obtained for all six crosses for inbreeding depression and was also reported by Alam *et al*. (2004) [2], Panwar and Ali (2010) [18], Adilakshmi and Reddy (2011) [1], Reddy *et al*. (2013) [23], Venkanna *et al*. (2014) [32] and Patel and Patel (2020) [19].

The analysis of variance revealed the significant differences among the generations of all the six crosses for all fourteen traits except in spikelet fertility for all the crosses and grain breadth in cross-II (Purna x IR-28) grain L/B ratio in cross-II (Purna x IR-28) and cross-IV (GR-5 x GNR-6) and harvest index (%) cross-IV (GR-5 x GNR-6) and cross-VI (GR-7 x Purna) which indicated sufficient variability among the material under study is presented in Table 1 and Table 2. The extent of heterotic effects *i.e.*, relative heterosis (RH) and heterobeltiosis (HB) as well as inbreeding depression (ID) were estimated for thirteen characters under study. The relative heterosis, heterobeltiosis and inbreeding depression for various characters in six crosses are presented in Table 3 and Table 4.

In case of days to flowering, all the six crosses under study depicted significant and positive relative heterosis (RH). Out of six hybrids no hybrid flower was early than best early parent. However, in this study all the hybrid were late flowering. Also, showed non-significant inbreeding depression in all the six crosses. It was reported that heterosis in positive directions for days to flowering was also found by Patil *et al*. (2011) [20] and Soni and Sharma (2011) [28]. Non-significant for inbreeding depression, was also reported by Reddy (2004) and Balat *et al*. (2018) [8]. In case of days to maturity, revealed that all the six crosses manifested significant positive relative heterosis (RH) and heterobeltiosis. However, no hybrid possessed gene for earliness. Inbreeding depression was found non-significant all six crosses. while, positive heterosis were also reported by Rahimi *et al.* (2010) [21], Rani *et al.* (2015) and Nayak *et al.* (2015). Non-significant inbreeding depression, were also reported by Reddy (2004) and Balat *et al*. (2018) [8]. The highly positive and significant heterosis was observed in total four crosses for plant height trait while the estimate of heterobeltiosis was also found highly positive significant in all the crosses. Similar and positive heterosis also reported by Khirasagar *et al.* (2005), Patil *et al*. (2011) [20], Soni and Sharma (2011) [28], Venkanna *et al*. (2014) [32], Thorat *et al.* (2017) [30], Sravan and Jaiswal (2017) [29], Solanke *et al.* (2019) [27] and Patel and Patel (2020) [19].

Higher number of tillers per plant contributes to higher grain yield. In case of productive tillers per plant, among all six crosses only four crosses were highly significant and positive relative heterosis and heterobeltiosis was found 23.29 percent in cross IV GR-5 X GNR-6. For positive heterosis and heterobeltiosis were recorded by Soni and Sharma (2011) [28], Ghara *et al*. (2014) [10], Venkanna *et al*. (2014) [32], Anis *et al*. (2016) [3], Borah *et al*. (2017) [9], Rumanti *et al*. (2017) [24], Thorat *et al*. (2017) [30], Balat *et al*. (2018) [8], Solanke *et al*. (2019) [27] and Patel and Patel (2020) [19]. Panicle length with positive and significant heterosis always contribute to enhance the number of spikelets/panicles, subsequently boost the grain yield / plant. Moreover, longer panicle length is associated with a greater number of spikelets per panicle resulting in higher productivity. In this study, four crosses for panicle length had positive and highly significant heterosis and in one cross significant heterobeltiosis was registered Similar finding were also reported by Tiwari *et al*. (2011) [31], Venkanna *et al*. (2014) [32], Ghara *et al*. (2014) [10], Thorat *et al*. (2017) [30], Makwana *et al*. (2018) [14], Balat *et al*. (2018) [8], Solanke *et al*. (2019) [27] and Patel and Patel (2020) [19].

Number of grains per panicle is the major yield attributing character, hence significant positive heterobeltiosis and standard heterosis is desirable. In the present investigation, three crosses manifested by highly significant hetersosis showed significant and heterobeltiosis. These observations positive significant heterosis results also reported by Ghara *et al*. (2014) [10], Venkanna *et al*. (2014) [32], Anis *et al*. (2016) [3], Borah *et al*. (2017) [9] and Rumanti *et al*. (2017) [24], Thorat *et al*. (2017) [30], Makwana *et al*. (2018) [14], Balat *et al*. (2018) [8], Solanke *et al*. (2019) [27] and Patel and Patel (2020) [19]. The character 100 seed weight, is one of the important common traits which influence the yield. In this study, four crosses showed positive and significant relative heterosis while two crosses had positive and significant heterobeltiosis. Similar results were reported by Soni and Sharma (2011) [28], Latha *et al.* (2013) [13], Venkanna *et al*. (2014) [32], Balakrishna and Satyanarayana (2015), Rani *et al.* (2015), Anis *et al*. (2016) [3], Borah *et al*. (2017) [9], Rumanti *et al*. (2017) [24], Sravan and Jaiswal (2017) [29], Thorat *et al*. (2017) [30], Makwana *et al*. (2018) [14], Balat *et al*. (2018) [8] and Solanke *et al*. (2019) [27].

For grain length, positive heterosis is desirable, in the present study, two crosses were found highly significant for relative heterosis and estimates of heterobeltiosis was observed positive and significant in all the crosses except cross-I. Venkanna *et al.* (2010) and Sravan and Jaiswal (2017) [29] also reported significant heterosis and heterobeltiosis for this trait. Less grain breadth is desirable quality traits. None of the six crosses showed significant negative heterosis in present investigation. Two crosses were registered highly positive significant relative heterosis whereas significant heterobeltiosis was reported in four crosses. Venkanna *et al.* (2010) and Sravan and Jaiswal (2017) [29] reported for positive heterosis and heterobeltiosis. Only one cross exhibited the positive and significant relative heterosis and highly significant heterobeltiosis which was observed for character gain L/B ratio. and similar results were reported by Patil *et al*. (2011) [20], Venkanna *et al.* (2010) and Sravan and Jaiswal (2017) [29], Makwana *et al.* (2018) [14] and Patel and Patel (2020) [19]. For straw yield per plant, positive and highly significant heterosis was found in the four crosses and results are in agreement with those obtained by Borah *et al*. (2017) [9], Rumanti *et al*. (2017) [24], Sravan and Jaiswal (2017) [29], Venkanna *et al*. (2014) [32], Thorat *et al*. (2017) [30], Makwana *et al*. (2018) [14], Balat *et al*. (2018) [8] and Patel and Patel (2020) [19].

Harvest Index which indirectly influences the grain yield through controlling the mechanism of distribution of photosynthesis to economic and non-economic part of plant as such is not a yield component. Therefore, it is an important consideration for genetic improvement. In the present investigation, positive and significant heterosis was recorded in two crosses out of six. Non-significant results for all the crosses were obtained for the heterobeltosis and inbreeding depression. These results are in agreement with those obtained by Borah *et al*. (2017) [9], Rumanti *et al*. (2017) [24], Sravan and Jaiswal (2017) [29], Venkanna *et al*. (2014) [32], Thorat *et al*. (2017) [30], Makwana *et al*. (2018) [14], Balat *et al*. (2018) [8], Solanke *et al*. (2019) [27] and Patel and Patel (2020) [19].

Conclusion

Out of six hybrids studied five hybrids exhibited positive and significant heterosis for grain yield per plant. The findings of present study indicated that majority of the hybrids recorded high heterosis for grain yield. Among the various hybrids exhibiting desirable value of heterosis *viz.*, Purna x NVSR-

2227, Purna x IR-28, GR-5 x GNR-6, GR-5 x GR-7and GR-7 x Purna were top performers for grain yield per plant.

In the present investigation, heterosis for grain yield per plant was observed due to heterosis for component *viz.*, days to flowering, days to maturity, plant height, productive tillers per plant, panicle length, number of grains per panicle, 100 seed weight, grain length, grain breadth, grain L/B ratio, straw yield per plant and harvest index which resulted in increased yield. So, these characters should be given due consideration while improving yield. Heterosis followed by absence of inbreeding depression were recorded in all the crosses for all the characters indicated that absence of inbreeding depression and increase in performance of F_2 was accompanied by fixation of genes *i.e.*, additive gene action.

Table 1: Analysis of variance (mean sum of squares) for six generations for days to flowering, days to maturity, plant height (cm), productive tillers per plant, panicle length (cm), no. of grains per panicle and spikelet fertility (%) in six crosses of rice for different characters

Sources	d.f.	Days to flowering	Days to maturity	Plant height (cm)	Productive tillers per plant	Panicle length (cm)	No. of grains per panicle	Spikelet fertility (%)
Cross-I (Purna x NVSR-2227)								
Replications	2	0.526	0.861	24.343	0.187	0.062	64.757	0.355
Generations	5	75.285**	70.314**	426.465**	1.926**	5.972*	1233.992**	3.884
Error	10	0.149	0.323	17.355	0.065	1.743	60.463	2.166
Cross-II (Purna x IR-28)								
Replications	2	3.028	4.575	4.446	0.575	5.025	190.242	10.968
Generations	5	83.884**	69.661**	287.427**	1.050*	4.468*	482.987**	4.165
Error	10	7.552	6.904	7.083	0.206	1.336	72.287	2.758
Cross-III (Purna x GNR-6)								
Replications	2	0.597	0.953	0.890	0.090	1.108	1.452	0.361
Generations	5	59.646**	58.118**	388.500**	3.695**	6.602*	248.855**	0.578
Error	10	1.403	1.586	3.407	0.086	1.422	7.224	0.312
Cross-IV (GR-5 x GNR-6)								
Replications	2	0.311	0.154	54.121	0.983	0.923	122.614	1.446
Generations	5	47.242**	45.917**	295.589**	2.523*	7.486**	469.412**	3.107
Error	10	2.313	2.676	13.474	0.543	0.261	62.920	2.419
Cross-V (GR-5 x GR-7)								
Replications	2	0.247	0.288	0.660	0.566	0.423	77.223	13.902
Generations	5	193.429**	197.613**	198.318**	2.539*	2.212*	783.048*	3.291
Error	10	3.229	3.648	6.014	0.502	0.418	149.279	4.979
Cross-VI (GR-7 x Purna)								
Replications	2	0.750	0.452	4.970	0.417	0.595	15.681	3.701
Generations	5	170.345**	163.297**	344.592**	3.994**	4.230**	386.769**	1.683
Error	10	2.253	2.377	2.496	0.148	0.398	21.465	0.905

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

Table 2: Analysis of variance (mean sum of squares) for six generations for 100 seed weight (g), grain length (mm), grain breadth (mm), grain L/B ratio, grain yield per plant (g), straw yield per plant (g) and harvest index (%) in six crosses of rice for different characters

Sources	d.f.	100 seed weight (g)	Grain length (mm)	Grain breadth (mm)	Grain L/B ratio	Grain yield per plant (g)	Straw yield per plant (g)	Harvest index (%)
Cross-I (Purna x NVSR-2227)								
Replications	2	0.001	0.011	0.000	0.003	2.871	0.432	39.981
Generations	5	0.123**	1.451**	0.020*	0.263**	16.645**	43.890**	96.789**
Error	10	0.000	0.048	0.005	0.017	1.582	4.894	11.546
Cross-II (Purna x IR-28)								
Replications	2	0.014	0.004	0.181	0.193	0.478	14.251	9.783
Generations	5	0.061**	1.611**	0.050	0.131	21.466**	122.873**	24.416*
Error	10	0.004	0.012	0.057	0.065	0.266	5.823	6.726
Cross-III (Purna x GNR-6)								
Replications	2	0.008	0.007	0.005	0.007	0.208	0.383	0.062
Generations	5	0.358**	1.241**	0.048**	0.190**	1.097**	79.815**	25.252**
Error	10	0.008	0.011	0.003	0.004	0.160	0.205	1.611
Cross-IV (GR-5 x GNR-6)								
Replications	2	0.031	0.034	0.008	0.016	0.449	4.453	0.572
Generations	5	0.047*	1.044**	0.120**	0.058	16.574**	120.425**	5.628
Error	10	0.013	0.132	0.002	0.022	1.098	4.076	4.783
Cross-V (GR-5 x GR-7)								
Replications	2	0.021	0.007	0.000	0.003	0.066	4.919	1.172
Generations	5	0.223**	0.080**	0.118**	0.201**	8.368**	54.896**	26.439*
Error	10	0.028	0.005	0.012	0.022	0.820	1.380	5.047
Cross-VI (GR-7 x Purna)								
Replications	2	0.000	0.004	0.003	0.005	3.038	0.478	13.188
Generations	5	0.116**	1.222**	0.039**	0.343	8.854	30.365*	25.439
Error	10	0.003	0.004	0.002	0.005	2.285	6.690	14.313

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

Table 3: Estimates of relative heterosis (RH%), heterobeltiosis (HB%) and inbreeding depression (ID%) for days to flowering, days to maturity, plant height (cm), productive tillers per plant, panicle length (cm) and no. of grains per panicle in six crosses of rice

Parameter	Days to flowering	Days to maturity	Plant height (cm)	Productive tillers per plant	Panicle length (cm)	No. of grains per panicle
	Estimate SE	Estimate SE	Estimate SE	Estimate SE	Estimate SE	Estimate SE
	Cross-I (Purna x NVSR-2227)					
RH%	10.12** ± 0.27	6.99** ± 0.40	9.25** ± 2.95	16.19** ± 0.18	13.54** ± 0.93	5.89 ± 5.50
HB%	21.64** ± 0.32	14.06** ± 0.46	19.06** ± 3.40	3.67 ± 0.21	12.04* ± 1.08	-10.37 ± 6.35
ID%	0.11 ± 3.15	0.11 ± 3.38	11.70 ± 8.48	15.38 ± 1.80	7.37 ± 2.70	-22.18 ± 25.58
	Cross-II (Purna x IR-28)					
RH%	14.32** ± 1.94	9.09** ± 1.86	17.46** ± 1.88	14.60** ± 0.32	-0.74 ± 0.82	-6.13 ± 6.01
HB%	23.27** ± 2.24	14.09** ± 2.15	34.48** ± 2.17	8.68 ± 0.37	-8.34 ± 0.94	-16.75 ± 6.94
ID%	-1.07 ± 6.32	-0.53 ± 6.30	9.82 ± 13.22	8.93 ± 2.58	-0.15 ± 2.59	-10.82 ± 30.06
	Cross-III (Purna x GNR-6)					
RH%	10.09** ± 0.84	7.20** ± 0.89	16.47** ± 1.31	9.57** ± 0.21	10.22** ± 0.84	7.03** ± 1.90
HB%	19.23** ± 0.97	13.01** ± 1.03	32.92** ± 1.51	2.02 ± 0.24	4.15 ± 0.97	0.36 ± 2.19
ID%	1.63 ± 7.21	1.28 ± 7.20	14.58 ± 9.35	0.00 ± 2.05	4.08 ± 2.78	9.15 ± 20.13
	Cross-IV (GR-5 x GNR-6)					
RH%	8.56** ± 1.08	5.99** ± 1.16	5.12 ± 2.60	28.45** ± 0.52	9.57** ± 0.36	17.83** ± 5.61
HB%	17.26** ± 1.24	11.61** ± 1.34	14.18** ± 3.00	23.29** ± 0.60	2.74 ± 0.42	0.12 ± 6.48
ID%	3.75 ± 5.23	2.27 ± 5.26	16.80 ± 9.53	16.12 ± 2.19	10.30 ± 2.36	4.16 ± 20.04
	Cross-V (GR-5 x GR-7)					
RH%	15.32** ± 1.27	11.00** ± 1.35	10.63** ± 1.73	10.50 ± 0.50	3.61 ± 0.46	12.53 ± 8.64
HB%	33.98** ± 1.47	23.40** ± 1.56	23.14** ± 2.00	2.33 ± 0.58	1.56 ± 0.53	-0.81 ± 9.98
ID%	7.12 ± 4.95	5.14 ± 4.92	7.61 ± 9.45	-6.37 ± 2.38	0.46 ± 2.16	-17.79 ± 23.35
	Cross-VI (GR-7 x Purna)					
RH%	15.05** ± 1.06	10.93** ± 1.09	-6.33 ± 1.12	-7.88 ± 0.27	6.30** ± 0.45	14.45** ± 3.28
HB%	33.53** ± 1.23	22.46** ± 1.26	7.67** ± 1.29	-17.69 ± 0.31	0.99 ± 0.52	9.71** ± 3.78
ID%	9.16 ± 5.74	6.35 ± 5.63	9.99 ± 10.50	16.66 ± 1.56	9.24 ± 2.31	17.15 ± 24.82

Table 4: Estimates of relative heterosis (RH%), heterobeltiosis (HB%) and inbreeding depression (ID%) for 100 seed weight (g), grain length (mm), grain breadth (mm), grain l/b ratio, grain yield per plant (g), straw yield per plant (g) and harvest index (%) in six crosses of rice

Parameter	100 Seed weight (g)	Grain length (mm)	Grain breadth (mm)	Grain L/B ratio	Grain yield per plant (g)	Straw yield per plant (g)	Harvest index (%)
	Estimate SE	Estimate SE	Estimate SE	Estimate SE	Estimate SE	Estimate SE	Estimate SE
	Cross-I (Purna x NVSR-2227)						
RH%	14.52** ± 0.01	-11.61 ± 0.16	2.37 ± 0.05	-13.76 ± 0.09	32.53** ± 0.89	22.65** ± 1.56	10.84 ± 2.40
HB%	3.26** ± 0.02	-2.02 ± 0.18	3.91 ± 0.06	-2.97 ± 0.11	4.88 ± 1.03	13.25** ± 1.81	-6.17 ± 2.77
ID%	3.01 ± 0.19	-0.21 ± 0.78	-1.15 ± 0.19	0.67 ± 0.35	1.94 ± 4.69	-9.52 ± 7.20	12.49 ± 10.17
	Cross-II (Purna x IR-28)						
RH%	11.88** ± 0.05	-9.15 ± 0.08	3.15 ± 0.17	-12.36 ± 0.18	30.97** ± 0.37	22.46** ± 1.71	6.00 ± 1.83
HB%	4.27 ± 0.05	2.82* ± 0.09	9.39 ± 0.19	-5.48 ± 0.21	9.59** ± 0.42	0.67** ± 1.97	2.67 ± 2.12
ID%	8.03 ± 0.20	-0.76 ± 0.67	4.84 ± 0.25	-5.68 ± 0.37	-6.46 ± 2.88	5.13 ± 8.28	-14.36 ± 7.42
	Cross-III (Purna x GNR-6)						
RH%	27.97** ± 0.06	-7.15 ± 0.07	3.94* ± 0.04	-10.84 ± 0.04	2.26 ± 0.28	19.56** ± 0.32	-13.63 ± 0.90
HB%	14.79** ± 0.07	3.94** ± 0.08	4.60* ± 0.05	0.47 ± 0.05	-4.48 ± 0.33	13.67** ± 0.37	-14.86 ± 1.04
ID%	1.17 ± 0.34	-3.53 ± 0.60	2.93 ± 0.17	-7.01 ± 0.29	0.46 ± 3.69	-12.38 ± 8.55	10.41 ± 8.26
	Cross-IV (GR-5 x GNR-6)						
RH%	3.68 ± 0.08	5.65 ± 0.26	-1.48 ± 0.03	7.55* ± 0.10	23.97** ± 0.74	20.88** ± 1.43	2.75 ± 1.55
HB%	2.60 ± 0.09	8.76* ± 0.30	4.48** ± 0.04	11.38** ± 0.12	5.50 ± 0.86	1.00** ± 1.65	0.42 ± 1.79
ID%	-4.50 ± 0.34	10.54 ± 0.52	1.13 ± 0.18	7.79 ± 0.26	10.34 ± 3.08	14.32 ± 6.07	-4.27 ± 6.23
	Cross-V (GR-5 x GR-7)						
RH%	10.42* ± 0.12	2.10** ± 0.05	1.01 ± 0.08	-0.49 ± 0.11	11.41** ± 0.64	-1.56 ± 0.83	10.79* ± 1.59
HB%	9.54 ± 0.14	3.97** ± 0.06	12.74** ± 0.09	12.90** ± 0.12	9.21 ± 0.74	-8.46* ± 0.96	1.46 ± 1.83
ID%	-9.61 ± 0.34	0.55 ± 0.28	-1.56 ± 0.24	1.68 ± 0.33	4.01 ± 3.46	-1.27 ± 8.84	3.00 ± 7.92
	Cross-VI (GR-7 x Purna)						
RH%	-11.04 ± 0.04	3.79** ± 0.04	7.35** ± 0.03	-4.94 ± 0.05	21.68** ± 1.07	2.69 ± 1.83	17.36* ± 2.68
HB%	-19.03 ± 0.05	16.18** ± 0.05	11.78** ± 0.03	12.56** ± 0.06	16.63 ± 1.23	0.46 ± 2.11	10.66 ± 3.09
ID%	-17.81 ± 0.19	7.78 ± 0.46	3.50 ± 0.16	4.31 ± 0.24	-1.80 ± 3.89	-13.68 ± 11.03	7.99 ± 9.72

References

1. Adilakshmi D, Reddy PR. Heterosis and inbreeding depression for grain quality traits in rice (*Oryza sativa* L.). Research on Crops 2011;12(2):489-492.
2. Alam MF, Khan MR, Nuruzzaman M, Parvez S, Swaraz AM, Alam I *et al.* Genetic basis of heterosis and inbreeding depression in rice (*Oryza sativa* L.). J Zhejiang University Sci 2004;5(4):406-411.
3. Anis G, El-Sabagh A, El-badry A, Barutcular C. Improving grain yield of rice (*Oryza sativa* L.) by estimation of heterosis, genetic components and correlation coefficient. Int. J Current Res 2016;8(1):25080-25085.
4. Anonymous a. Directorate of Agriculture, A.F.W. &

C.D., Government of Gujarat 2019.
5. Anonymous b. Directorate of Economics and Statistics, D.A.C & F.W., Department of Agriculture and Cooperation, Government of India 2019.
6. Badawi AT. Rice based production systems for food security and poverty alleviation in the near East and North Africa: New Challenges and Technological Opportunities FAO Rice Conference Rome, Italy 2004.
7. Balakrishna B, Satyanarayana PV. Heterosis for yield and yield component traits in rice (*Oryza sativa* L.). Electronic Journal of Plant Breeding 2015;6(2):639-643.
8. Balat JR, Thakor RP, Delvadiya IR, Rathva SR. Heterosis and inbreeding depression in F2 population of rice (*Oryza sativa* L.) for yield and related traits. Journal of Pharmacognosy and Phytochemistry 2018;7(3):3224-3226.
9. Borah P, Sharma D, Hazarika GN. Magnitude of heterosis for yield and its components in hybrid rice (*Oryza sativa* L.). International Journal of Agricultural Science and Research 2017;7(2):2250 -2257.
10. Ghara AG, Nematzadeh G, Oladi NBM Bagheri A. Heritability and heterosis of agronomic traits in rice lines. Int. J Farming and Alli. Sci 2014;3(1):66-70.
11. Grafius JE. Heterosis in barley. Agronomy Journal 1959;51:551-554.
12. Kempthrone O. An introduction to genetic statistics. John Wiley and Sons. Inc., New York 1957.
13. Latha S, Sharma D, Sanghera GS. Combining ability and heterosis for grain yield and its component traits in rice (*Oryza sativa* L.). Notulae Scientia Biologicae 2013;5(1):90-97.
14. Makwana RR, Patel VP, Pandya MM, Chaudhary BA. Heterosis and inbreeding depression for morpho-physiological traits in rice (*Oryza sativa* L.). Int. J Pure App. Biosci 2018;6(2):1477-1482.
15. Nagesh V, Ravindrababu G, Reddy T. Heterosis studies for grain iron and zinc content in rice. Annals Biol. Res 2012;3(1):179-184.
16. Nayak AR, Chaudhury D, Reddy JN. Genetics of yield and yield components in scented rice. Oryza 2007;44(3):227-230.
17. Panse VG, Sukhatme PV. Statistical Methods for Agricultural Workers. Indian Council of Agricultural Research, New Delhi 1967.
18. Panwar LL, Ali M. Heterosis and inbreeding depression for yield and kernel characters in scented rice. Oryza 2010;47(3):179-187.
19. Patel HR, Patel PB. Estimation of heterosis and inbreeding depression for yield, its components and qualitative traits in rice (*Oryza sativa* L.). The Pharma Innov. Journal 2020;9(10):217-220.
20. Patil PP, Vashi RD, Shinde DA, Lodam VA. Nature and magnitude of heterosis for grain yield and yield attributing traits in rice (*Oryza sativa* L.). Plant Archieves 2011;11(1):423-427.
21. Rahimi M, Rabiei B, Samizadeh H, KafiGhasemi A. Combining ability and heterosis in rice (*Oryza sativa* L.) cultivars. J Agr. Sci. Tech 2010;12:223-231.
22. Rani PJ, Satyanarayana PV, Chamundeswari N, Ahamed ML, Rani MG. Studies on genetic control of quality traits in rice (*Oryza sativa* L.) using six parameter model of generation mean analysis. Electronic Journal of Plant Breeding 2015;6(3):658-662.
23. Reddy MR, Raju CS, Sravani D, Reddy SM, Reddy N. Estimation of heterosis, residual heterosis and inbreeding depression for yield characteristics in F2 generation involving aromatic rice genotypes (*Oryza sativa* L.). Research on Crops 2013;14(1):28-32.
24. Rumanti IA, Purwoko BS, Dewi IS, Aswidinnoor H, Widyastuti Y. Combining ability for yield and agronomic traits in hybrid rice derived from wild abortive, gambiaca and kalinga cytoplasmic male sterile lines. SABRAO J 2017;49(1):69-76.
25. Shahi K, Dwivedi S, Devi A, Dwivedi R, Singh P, Dwivedi D. Heterosis in diverse ecotypes of rice under saline-alkali environment. Int. J Current Res 2012;4(9):106-110.
26. Singh AK, Mall AK, Singh PK, Singh S, Singh AK, Verma OP. Genetic architecture, heterosis and inbreeding depression for yield and yield associated physiological traits in rice (*Oryza sativa* L.) under drought condition. SAARC J Agri 2015;13(1):50-62.
27. Solanke AC, Patel PB, Patel PK. Study of heterosis and inbreeding depression in F2 generation of aromatic rice. The Pharma Innov. Journal 2019;8 (8):10-15.
28. Soni S, Sharma D. Studies on heterosis for grain yield and its component traits for developing new plant type hybrids in rice (*Oryza sativa* L.). Elec. J of Plant Breeding 2011;2(4):543-548.
29. Sravan T, Jaiswal HK. Heterosis and inbreeding depression in aromatic rice (*Oryza sativa* L.). Trends in Biosciences 2017;10(8):1677-1687.
30. Thorat BS, Kunkerkar RL, Bagkar TA. Studies on heterosis for yield and its contributing traits in hybrid rice (*Oryza sativa* L.). International Journal of Chemical Studies 2017;5(5):07-12.
31. Tiwari DK, Pandey P, Giri SP, Dwivedi JL. Heterosis studies for yield and its components in rice hybrids using CMS system. Asian J of Pl. Sci 2011;10(1):29-42.
32. Venkanna V, Raju CS, Lingaiah N, Rao VT. Studies on heterosis and inbreeding depression for grain yield and grain quality traits in rice (*Oryza Sativa* L.). Int. J Sci., Envt. and Technol 2014;3(3):910–916.
33. Kharbuli D, Bhattacharjee B, Pala S. "A review on Improving Phosphorus use efficiency of upland rice with emerging opportunities of breeding". International Journal of Agriculture and Plant Science. 2020;2(3):22-28.