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Study of Heterosis for Grain Yield and Its Components in Aerobic Rice (*Oryza sativa* L.)

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ABSTRACT

Line × tester analysis using a set of 4 females (lines) and 12 males (testers) having diverse genetic background was carried out to study the nature and magnitude of heterosis for yield and its components of rice under aerobic condition. Experimental material comprising 16 parents and their 48 hybrids were planted in a Randomized Block Design with three replications during Kharif- 2015 at the Main Rice Research Centre, Navsari Agricultural University, Navsari. Considerable magnitude of relative heterosis and heterobeltiosis was observed for all characters. Crosses NAUR-1 × CR DHAN 201, Gurjari × GR-7 and GNR-3 × IET 23449 were found to be most heterotic hybrids for grain yield per plant and also exhibited increase in number of productive tillers per plant, number of grains per panicle, panicle weight and 1000 grain weight had positive effects towards higher grain yield.

Key words: *Rice, Aerobic condition, Line × Testers, Relative heterosis, Heterobeltiosis*

INTRODUCTION

Rice (*Oryza sativa* L.) is diploid with a chromosome number of (2n = 24) and the world's second most important cereal crop belonging to the family Poaceae. It is the staple food for over one third of the world's population. Asia is considered as a 'rice bowl' of the world. Approximately 90 per cent of the world's rice is grown in the Asian continent and it ranks second in the grain production in India. Rice is placed on second position in cereal cultivation around globe and occupies an important position in the economy of India as an export item as well as staple food. India is the largest rice cultivator which accounts for almost 30 per cent of the world's rice area. Area under rice cultivation in India is 43.08 million hectares, production of 106.64 million tonnes with productivity of 2462.1 kg/ha. In Gujarat, rice is cultivated on an area of 8.08 lakh ha with total production as 16.36 lakh tonnes and productivity about 2076 kg/ha.

Aerobic rice refers to growing of rice germplasm in non-puddled and non-flooded condition. Aerobic rice is a new method of cultivating rice that requires less water than low land rice.

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It entails the growing of rice in aerobic soil, with the use of external inputs such as supplementary irrigation and fertilizers and aiming at high yields[16]. The water use of aerobic rice was about 60 per cent less than that of flooded rice and total water productivity was 1.6 to 1.9 times higher[15].

Hybrid rice technology had also shown increased yield, farmer profitability and better adaptability to stress environments such as water scarce and aerobic conditions. Considering all these issues, the main objective of this study is to develop rice hybrids with high yield potential for aerobic conditions to overcome the existing water crisis in India. Elevated heterosis level of selected hybrids could prove to be key component in breeding strategies. Exploitation of heterosis in rice has been recognized as practical tool in providing the breeders a means of improving yield and other important traits for developing promising varieties through hybridization. The choice of parent is a matter of great concern to the plant breeders. In the past, the performance and adaptability of genetic stocks have been used as the main criteria in selection of parents for hybridization programme.

The application of heterosis breeding is considered to be an outstanding application of principles of genetics to agriculture. Existence of a significant amount of dominance variance is essential for undertaking heterosis breeding programme. The dominance effects are associated with heterozygosity. For a successful heterosis breeding programme in any crop, there are two important strategies involved (1) There must be presence of significant heterotic effect in the hybrids that can be exploited easily and (2) The feasibility of the hybrid seed production on commercial base. Heterosis is useful to decide the direction of future breeding programme and to identify the cross combinations which are promising in conventional breeding programme. In this study several cross combinations exhibited conspicuous relative heterosis and heterobeltiosis for different traits.

MATERIAL AND METHODS

The experimental material for present investigation consisted of 64 entries including 4 genotypes (NAUR-1, GNR-3, Gurjari and GAR-13) designated as females and 12 genotypes (IET 23467, IET 23445, IR-28, IET 22704, IET 23449, CR DHAN 201, IET 23459, GR-7, IET 23448, IET 23455, AAUDR-1 and IET 23471) designated as males. These parents were crossed to produce 48 F_1s according to Line × Testers mating design. The experiment was laid out in a Randomized Block Design with three replications at Main Rice Research Center, Navsari Agricultural University, Navsari during *Kharif* - 2015. Each entry was planted in a single row consist of ten plants in each row with a spacing 20 × 15 cm. The standard agronomical practices were followed to raise the good experimental crop. In this study, Five competitive plants were randomly selected to record the observations on thirteen characters *viz.,* days to 50 per cent flowering, days to maturity, plant height (cm), number of productive tillers per plant, panicle length (cm), number of grains per panicle, panicle weight (g), 1000 grain weight (g), harvest index (%), grain yield per plant (g), straw yield per plant (g), amylose content (%) and protein content (%) were recorded and mean values over five plants were subjected to statistical analysis.

RESULTS AND DISCUSSION

The results showed, mean squares of genotypes were highly significant for all characters, (Table 1) which indicated the considerable amount of variability among genotypes for various characters. Mean squares due to genotypes were further partitioned into parents, hybrids and parents *vs.* hybrids. The differences between parents were highly significant for all characters except plant height. Mean squares due to parents *vs.* hybrids comparison were found significant for all characters except harvest index, grain yield per plant, straw yield per plant and amylose content indicating substantial amount of heterosis among hybrids.

The analysis of variance further revealed that hybrids differed significantly for all characters except days to maturity which showed variability in performance of hybrids and their parents by revealing presence of heterosis for most of the traits.

The information on number of hybrids showing significant heterosis and range of heterosis for various characters in rice are presented in Table 2. For heterosis, large number of crosses manifested significant relative heterosis in desired direction for all 13 characters, except days to 50 per cent flowering and days to maturity (Figure 1). In consideration to heterobeltiosis, many crosses manifested significant shift in desired direction for all 13 characters, except harvest index (Figure 2).

For grain yield per plant, cross NAUR-1 × CR DHAN 201 recorded significant higher heterosis over their respective mid and better parent, while this hybrid was followed by cross Gurjari × GR-7 and GNR-3 × IET 23449 (Table 5). High heterosis for grain yield per plant was recorded by Singh *et al.*[12], Amudha and Thiyagara[1], Parihar and Pathak[6], Venkatesan *et al.*[14], Roy *et al.*[10], Kumar *et al.*[2], Reddy *et al.*[9], Veeresha *et al.*[13], Shinde and Patel[11], Mistry *et al.*[4], and Nayak *et al.*[5].

Significant number of relative heterosis in favorable direction was recorded in variable crosses (Figure 1), *viz.*, for plant height (10), number of productive tillers per plant (4), panicle length (19), number of grains per panicle (17), panicle weight (22), 1000 grain weight (32), harvest index (3), grain yield per plant (3), straw yield per plant (6), amylose content (12) and protein content (27). Similarly, for heterobeltiosis (Figure 2), days to 50 per cent flowering (1), days to maturity (3), plant height (15), number of productive tillers per plant (4), panicle length (7), number of grains per panicle (10), panicle weight (15), 1000 grain weight (15), grain yield per plant (1), straw yield per plant (2), amylose content (5) and protein content (14). More or less numbers of hybrids reported significant relative and better parent heterosis was reported by earlier workers Kumar *et al.*[2], Patil *et al.*[7], Veeresha *et al.*[13], and Shinde and Patel[11].

Among all the characters under study, negative heterotic effect was desirable for three characters *viz.*, days to 50 per cent flowering, days to maturity and plant height and for all other characters included in present investigation *viz.*, number of productive tillers per plant, panicle length, number of grains per panicle, panicle weight, 1000 grain weight, harvest index, grain yield per plant, straw yield per plant, amylose content and protein content; heterotic effect in positive direction was desirable.

With regard to days to 50 per cent flowering, one hybrid GNR-3 × CR DHAN 201 showed significant negative heterobeltiosis for earliness (Table 4). The result was in accordance with findings of Roy *et al.*[10], Patil *et al.*[7], and Reddy *et al.*[9], as they reported high degree of heterosis for earliness. For days to maturity, three crosses showed significant and desirable heterobeltiosis. Cross GAR-13 × IET 23450 manifested significantly highest negative heterosis over better parent. The findings are in comparison with Parihar and Pathak[6] and Kumar *et al.*[2]. For plant height, ten and 15 hybrids exhibited significant negative relative heterosis and heterobeltiosis, respectively. Cross combination GAR-13 × CR DHAN 201 had the least significant heterosis over both mid and better parent. Venkatesan *et al.*[14], and Roy *et al*.[10], reported the similar results for plant height. In case of number of productive tillers per plant, four crosses GNR-3 × IET 23449, NAUR-1 × CR DHAN 201, GNR-3 × AAUDR-1 and Gurjari × GR-7 had significant and positive heterosis and heterobeltiosis. Highest positive heterosis over mid and better parent being exhibited by cross GNR-3 × IET 23449. Similar results were recorded by Amudha and Thiyagara[1], Reddy *et al.*[9], Shinde and Patel[11] and Nayak *et al*.[5]. For panicle length, 19 crosses expressed significant positive relative heterosis and seven crosses exhibited significant positive heterobeltiosis. Cross GAR-13 × IET 23455 exhibited significantly highest positive relative heterosis and heterobeltiosis for this character. These results akin with Singh *et al.*[12], Parihar and Pathak[6], Kumar *et al.*[2], Veeresha *et al.*[13], Shinde and Patel[11] and Mistry *et al.*[4]. With respect to number of grains per panicle, 17 and ten crosses showed significantly positive heterosis over mid and better parent, respectively. Cross combination Gurjari × IET 23471 depicted significantly highest positive relative heterosis as well as heterobeltiosis. The results were in agreement with reports of Parihar and Pathak[6], Venkatesan *et al.*[14], Veeresha *et al.*[13], Mistry *et al.*[4] and Nayak *et al.*[5]. In case of panicle weight, 22 and 15 crosses expressed significantly positive relative heterosis and heterobeltiosis, respectively. Hybrid NAUR-1 × GR-7 recorded significantly highest positive heterosis over mid parent while hybrid Gurjari × GR-7 recorded significantly highest positive heterosis over better parent. The results were in agreement with reports of Veeresha *et al.*[13]. For 1000 grain weight, 32 and 15 crosses expressed significant positive relative heterosis and heterobeltiosis, respectively. Hybrid GAR-13 × AAUDR-1 recorded significantly highest positive heterosis over mid parent while hybrid NAUR-1 × CR DHAN 201 showed highest positive heterosis over better parent. Positive heterosis for 1000 grain weight was also reported by Singh *et al.*[12], Parihar and Pathak[6], Roy *et al*[10], Kumar *et al.*[2], Rahimi *et al.*[8], Patil *et al.*[7], Veeresha *et al.*[13], and Shinde and Patel[11]. Only three hybrids NAUR-1 × CR DHAN 201, GNR-3 × IET 22704 and Gurjari × GR-7 manifested significant positive heterotic effects for harvest index over mid parent, out of which hybrid Gurjari × GR-7 showed highest positive heterosis. Similar results were found by Parihar and Pathak[6] and Kumar *et al.*[2].

Table 1. Variance components of parents and hybrids for yield and its components in Aerobic rice

Source of variation	d.f.	Characters												
		Days to 50% flowering	Days to maturity	Plant height (cm)	No. of productive tillers per plant	Panicle length (cm)	No. of grains per panicle	Panicle weight (g)	1000 Grain weight (g)	Harvest index (%)	Grain yield per plant (g)	Straw yield per plant (g)	Amylose content (%)	Protein content (%)
Replications	2	7.61	0.89	72.69	0.72	0.37	54.43	0.02	0.20	1.50	23.95	50.13	0.18	0.02
Genotypes	63	50.03**	69.38**	299.27**	14.17**	21.47**	2911.88**	3.16**	40.81**	70.58**	52.27**	58.82**	27.59**	2.25**
Parents	15	90.62**	138.64**	186.48	8.78**	20.32**	2704.77**	1.42**	41.90**	49.84*	45.81**	81.15**	27.66**	1.22**
Females	3	74.00**	63.33	323.79	2.85*	36.39**	4867.93**	1.04**	65.06**	6.95	46.08*	82.87**	10.68**	2.54**
Males	11	94.45**	119.05**	165.29	10.07**	15.88**	2197.29**	1.34**	38.32**	61.10**	47.72**	56.88**	27.34**	0.80**
Females *vs* Males	1	98.34*	580.01**	7.61	12.46**	21.05*	1797.69**	3.43**	11.82**	54.64	24.03	342.95**	82.14**	1.95**
Parents *vs* Hybrids	1	140.03**	218.79*	918.21**	51.89**	127.42**	427.92*	7.17**	163.04**	29.88	7.95	9.34	1.93	6.79**
Hybrids	47	35.16**	44.10	322.10**	15.09**	19.59**	3030.82**	3.63**	37.86**	78.06**	55.27**	52.75**	28.11**	2.48**
Error	126	17.39	34.35	124.66	0.92	4.00	95.95	0.04	1.62	24.53	13.97	17.78	0.81	0.03

* and ** indicates significance at 5 per cent and 1 per cent levels of probability, respectively.

Table 2. Number of hybrids showing significant heterosis and range of heterosis for yield and its components in Aerobic rice

Characters	Number of hybrids showing significant heterosis over				Range of heterosis (%) over	
	Mid parent		Better parent		Mid parent	Better parent
	P (+)	N (-)	P (+)	N (-)		
Days to 50 per cent flowering	5	0	0	1	-5.60 to 12.86	-9.26 to 7.32
Days to maturity	0	0	0	3	-5.64 to 6.23	-10.41 to 2.18
Plant height (cm)	4	10	0	15	-34.43 to 17.70	-35.45 to 12.68
No. of productive tillers per plant	4	29	4	33	-48.64 to 51.18	-48.68 to 39.18
Panicle Length (cm)	19	6	7	10	-27.04 to 36.16	-28.75 to 31.19
No. of grains per panicle	17	24	10	29	-44.95 to 51.49	-49.52 to 45.76
Panicle weight (g)	22	15	15	23	-42.12 to 66.80	-51.60 to 51.06
1000 grain weight (g)	32	5	15	8	-34.90 to 43.68	-38.49 to 25.11
Harvest index (%)	3	4	0	4	-24.21 to 20.78	-30.28 to 19.08
Grain yield per plant (g)	3	3	1	10	-30.61 to 26.25	-41.16 to 23.16
Straw yield per plant (g)	6	10	2	21	-27.42 to 37.20	-34.06 to 33.36
Amylose content (%)	12	14	5	27	-35.43 to 32.09	-39.96 to 15.97
Protein content (%)	27	14	14	20	-28.02 to 70.00	-38.54 to 60.97

Figure 1. Number of hybrids showing significant heterosis over Mid parent value for yield and its components in Aerobic Rice

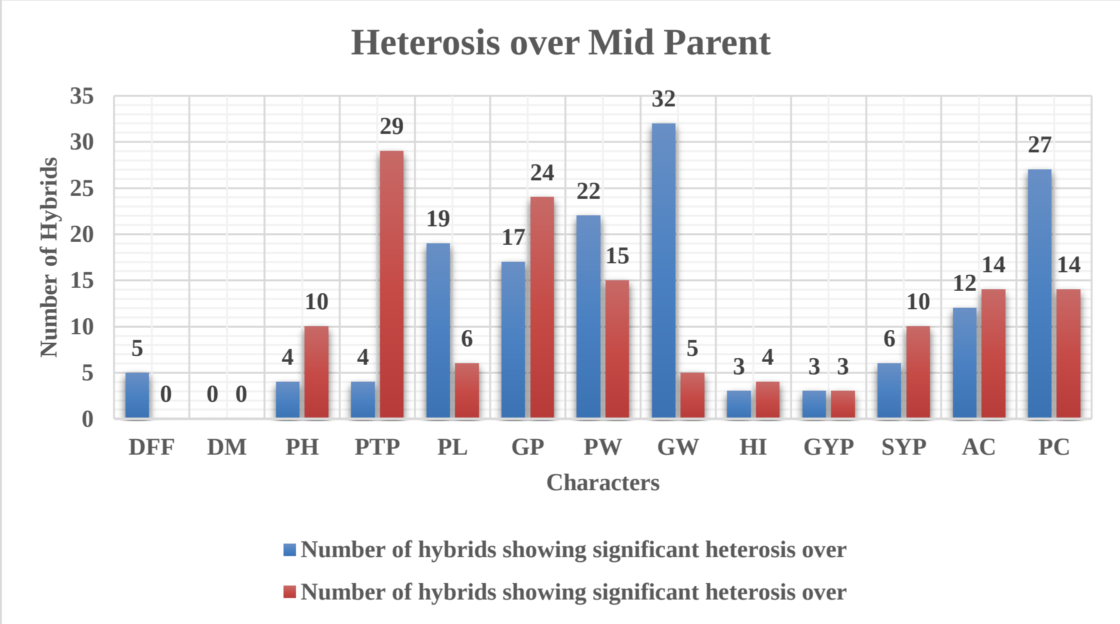
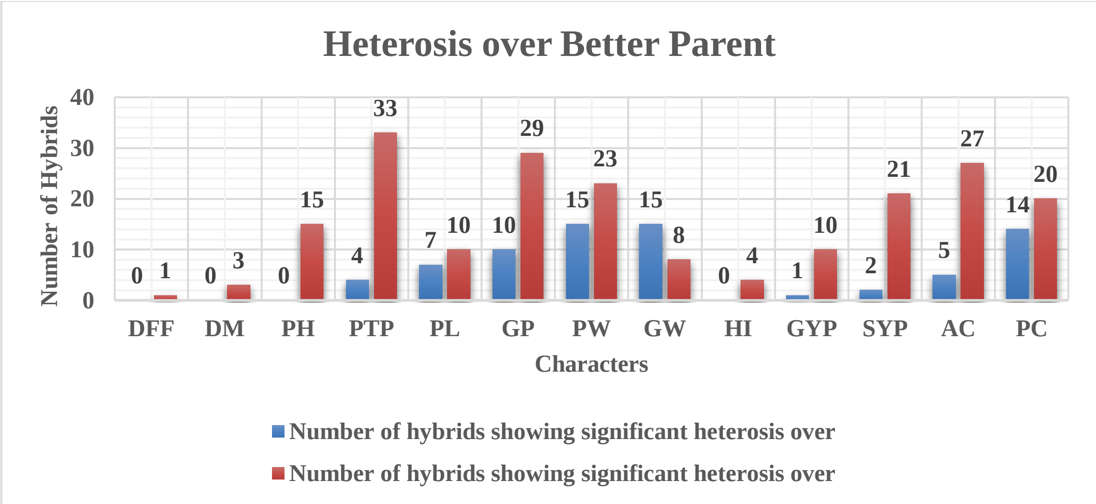


Figure 2. Number of hybrids showing significant heterosis over Better parent value for yield and its components in Aerobic rice



(**Note:** Where, DFF- Days to 50 per cent flowering; DM- Days to maturity; PH- Plant height; PTP- Number of productive tillers per plant; PL- Panicle length; GP- Number of grains per panicle; PW- Panicle weight; GW- 1000 grain weight; HI- Harvest index; GYP- Grain yield per plant; SYP- Straw yield per plant; AC- Amylose content; PC- Protein content)

Table 3. Estimates of heterosis in F_1 over Mid parent (MP) and Better parent (BP) for yield and its components in Aerobic rice

Sr. no.	Crosses	Days to 50% flowering		Days to maturity		Plant height (cm)	
		MP	BP	MP	BP	MP	BP
1	NAUR-1 × IET 23467	-0.58	-0.77	0.54	-1.33	-0.84	-1.35
2	NAUR-1 × IET 23450	2.01	-1.55	-0.55	-4.26	-6.25	-9.70
3	NAUR-1 × IR 28	0.58	0.00	0.29	-7.45	-7.15	-9.85
4	NAUR-1 × IET 22704	-3.08	-3.82	3.10	1.60	2.07	0.11
5	NAUR-1 × IET 23449	2.80	-0.39	0.96	-2.13	-11.90	-15.27*
6	NAUR-1 × CR DHAN 201	4.55	2.22	-3.99	-3.99	-9.97	-14.93*
7	NAUR-1 × IET 23459	-1.95	-2.33	-1.36	-3.19	-10.13	-12.24
8	NAUR-1 × GR-7	2.55	1.16	-5.64	-8.78*	-0.91	-1.41
9	NAUR-1 × IET 23448	-4.71	-5.81	-2.70	-4.26	1.25	0.92
10	NAUR-1 × IET 23455	4.61	1.16	0.83	-3.46	-2.19	-5.35
11	NAUR-1 × AAUDR-1	12.36**	0.39	1.45	-7.18	-14.51*	-15.97*
12	NAUR-1 × IET 23471	-0.79	-3.10	0.82	-1.86	-5.79	-9.64
13	GNR-3 × IET 23467	-2.97	-5.41	1.78	1.09	12.80*	12.68

14	GNR-3 × IET 23450	1.23	0.00	2.38	-0.27	3.06	-0.33
15	GNR-3 × IR 28	2.99	1.18	3.94	-3.00	-1.56	-4.80
16	GNR-3 × IET 22704	-3.54	-6.49	2.46	2.18	7.45	4.97
17	GNR-3 × IET 23449	2.46	1.63	0.00	-1.91	-14.75*	-17.69*
18	GNR-3 × CR DHAN 201	-5.04	-9.26*	-1.48	-2.66	2.75	-2.54
19	GNR-3 × IET 23459	-3.98	-5.86	-2.06	-2.72	0.09	-1.87
20	GNR-3 × GR-7	-0.60	-1.59	1.39	-0.82	2.29	2.19
21	GNR-3 × IET 23448	-0.40	-1.59	-2.60	-3.00	-8.94	-9.01
22	GNR-3 × IET 23455	8.42*	7.32	0.14	-3.00	4.76	0.97
23	GNR-3 × AAUDR-1	12.25**	2.44	-1.33	-8.72*	-0.21	-1.52
24	GNR-3 × IET 23471	4.88	4.88	-0.41	-1.91	-7.37	-10.81
25	Gurjari × IET 23467	-1.97	-3.86	1.52	1.38	13.83*	11.59
26	Gurjari × IET 23450	3.48	1.61	1.27	-0.83	-6.84	-11.53
27	Gurjari × IR 28	-1.59	-2.75	0.73	-5.51	11.81	10.15
28	Gurjari × IET 22704	-3.33	-5.73	0.82	0.55	0.29	-0.18
29	Gurjari × IET 23449	1.83	0.40	0.00	-1.38	-1.20	-6.32
30	Gurjari × CR DHAN 201	-3.66	-7.41	-1.49	-3.19	4.40	-2.71
31	Gurjari × IET 23459	2.57	1.17	0.69	0.55	-7.19	-10.67
32	Gurjari × GR-7	-5.60	-5.98	0.84	-0.83	5.92	3.85
33	Gurjari × IET 23448	1.40	0.79	-0.14	-0.27	3.29	1.44
34	Gurjari × IET 23455	2.86	1.20	0.71	-1.93	5.80	3.88
35	Gurjari × AAUDR-1	12.83**	2.41	4.00	-3.31	14.45*	10.87
36	Gurjari × IET 23471	0.20	-0.40	1.53	0.55	17.70**	11.30
37	GAR-13 × IET 23467	0.37	-3.23	2.12	-2.03	-12.36*	-18.00**
38	GAR-13 × IET 23450	4.05	-3.23	-4.85	-10.41**	-18.75**	-21.57**
39	GAR-13 × IR 28	-1.12	-5.38	4.78	-5.33	-7.42	-16.12*
40	GAR-13 × IET 22704	-4.25	-7.17	-3.03	-6.60	-13.62*	-21.00**
41	GAR-13 × IET 23449	4.41	-2.51	4.42	-1.02	-22.97**	-25.52**
42	GAR-13 × CR DHAN 201	-1.28	-2.87	-2.86	-5.08	-34.43**	-35.45**
43	GAR-13 × IET 23459	-3.18	-7.17	-1.06	-5.08	-16.65**	-20.62**
44	GAR-13 × GR-7	6.04	0.72	4.43	-1.27	-21.18**	-26.27**
45	GAR-13 × IET 23448	3.58	-1.43	0.79	-3.05	-3.99	-10.33
46	GAR-13 × IET 23455	3.08	-3.94	0.27	-6.09	-8.45	-17.31**
47	GAR-13 × AAUDR-1	12.86**	-2.51	6.23	-4.82	-8.08	-13.01*
48	GAR-13 × IET 23471	2.86	-3.23	-0.27	-5.08	-13.52*	-16.15*
	S.E. (d) ±	**2.95**	**3.40**	**4.14**	**4.78**	**7.89**	**9.12**
	C.D. at 5%	**5.85**	**6.76**	**8.23**	**9.50**	**15.67**	**18.10**
	C.D.at 1%	**7.75**	**8.95**	**10.90**	**12.58**	**20.76**	**23.97**
	Range	**-5.60 to 12.86**	**-9.26 to 7.32**	**-5.64 to 6.23**	**-10.41 to 2.18**	**-34.43 to 17.70**	**-35.45 to 12.68**

* and ** shows significance at 5 per cent and 1 per cent levels of probability, respectively.

Table 3. Continue…

Sr. no.	Crosses	No. of productive tillers per plant		Panicle length (cm)		No. of grains per panicle	
		MP	BP	MP	BP	MP	BP
1	NAUR-1 × IET 23467	7.90	-7.14	13.79*	7.21	23.11**	20.95**
2	NAUR-1 × IET 23450	-33.14**	-48.56**	-16.26**	-18.72**	-35.92**	-39.27**
3	NAUR-1 × IR 28	-17.44**	-25.24**	-0.21	-5.42	2.61	-8.47*
4	NAUR-1 × IET 22704	-37.17**	-44.76**	20.83**	3.53	-22.83**	-26.69**
5	NAUR-1 × IET 23449	-28.48**	-38.85**	7.48	-2.12	-11.11**	-17.95**
6	NAUR-1 × CR DHAN 201	29.83**	28.11**	14.16*	9.27	39.80**	35.61**
7	NAUR-1 × IET 23459	-18.33**	-23.18**	-12.86*	-15.81*	10.79*	-1.67
8	NAUR-1 × GR-7	-9.31	-14.21*	17.96**	8.66	46.22**	32.97**
9	NAUR-1 × IET 23448	-23.55**	-34.06**	-10.00	-12.54*	25.96**	8.37
10	NAUR-1 × IET 23455	-11.76	-26.98**	12.67*	0.93	-22.05**	-27.35**
11	NAUR-1 × AAUDR-1	-13.53*	-20.57**	10.09	1.41	-26.66**	-27.97**
12	NAUR-1 × IET 23471	-22.19**	-36.99**	8.02	-0.95	2.10	-9.80
13	GNR-3 × IET 23467	0.30	-7.01	1.47	-4.87	-31.78**	-33.92**
14	GNR-3 × IET 23450	-30.19**	-42.82**	-22.39**	-25.06**	-42.10**	-42.38**
15	GNR-3 × IR 28	-31.65**	-32.99**	1.70	-4.08	-32.67**	-37.15**
16	GNR-3 × IET 22704	-6.37	-11.13	17.82**	0.51	-13.04**	-21.14**
17	GNR-3 × IET 23449	51.18**	39.18**	26.52**	14.68*	15.78**	12.06**
18	GNR-3 × CR DHAN 201	-42.00**	-45.86**	1.86	-3.00	-21.79**	-27.65**
19	GNR-3 × IET 23459	-9.41	-11.32	-13.07*	-16.43**	24.01**	5.47
20	GNR-3 × GR-7	-33.69**	-41.87**	-0.78	-9.04	-16.55**	-27.38**
21	GNR-3 × IET 23448	-14.25	-20.31*	-6.17	-8.35	34.11**	10.76*
22	GNR-3 × IET 23455	-25.74**	-34.05**	1.72	-9.29	-1.80	-12.53**
23	GNR-3 × AAUDR-1	21.64**	21.13*	22.05**	11.89	33.32**	24.79**
24	GNR-3 × IET 23471	-26.32**	-36.12**	5.51	-3.71	-1.03	-16.19**
25	Gurjari × IET 23467	-16.00*	-23.57**	-1.00	-5.76	16.52**	-1.89
26	Gurjari × IET 23450	-12.43	-29.41**	-9.67	-11.38	-16.40**	-31.66**

27	Gurjari × IR 28	-27.77**	-30.60**	2.83	-1.51	-14.60**	-33.57**
28	Gurjari × IET 22704	-35.97**	-40.39**	-1.51	-14.83*	-14.57*	-23.63**
29	Gurjari × IET 23449	-32.82**	-39.30**	14.35*	5.17	14.56**	-8.36
30	Gurjari × CR DHAN 201	-35.76**	-38.86**	-11.27*	-14.17*	34.71**	18.14**
31	Gurjari × IET 23459	-48.64**	-48.68**	-27.04**	-28.75**	-15.44*	-19.06**
32	Gurjari × GR-7	32.23**	18.01**	23.15**	14.60*	39.92**	30.53**
33	Gurjari × IET 23448	-31.13**	-37.19**	-8.85	-12.35*	45.17**	43.98**
34	Gurjari × IET 23455	10.64	-3.49	6.58	-3.59	17.51**	6.95
35	Gurjari × AAUDR-1	-32.93**	-34.55**	8.18	0.66	15.01**	-0.23
36	Gurjari × IET 23471	0.25	-14.57	-3.62	-10.72	51.49**	45.76**
37	GAR-13 × IET 23467	-19.72*	-23.81**	13.62*	3.95	-40.79**	-47.47**
38	GAR-13 × IET 23450	-26.18**	-38.33**	-4.34	-14.88*	-44.95**	-49.52**
39	GAR-13 × IR 28	-34.47**	-34.80**	19.96**	9.12	-31.10**	-32.72**
40	GAR-13 × IET 22704	-10.70	-13.19	30.47**	28.68**	-14.45**	-28.47**
41	GAR-13 × IET 23449	-0.38	-6.14	22.36**	15.85*	-31.84**	-35.83**
42	GAR-13 × CR DHAN 201	-32.04**	-37.99**	18.68**	6.97	-30.32**	-40.69**
43	GAR-13 × IET 23459	-29.31**	-32.46**	23.18**	10.06	-22.20**	-38.57**
44	GAR-13 × GR-7	-28.44**	-38.59**	32.25**	23.74**	-8.02	-25.88**
45	GAR-13 × IET 23448	2.60	-2.38	10.61	-6.40	-18.28**	-37.14**
46	GAR-13 × IET 23455	-24.31**	-31.29**	36.16**	31.19**	-26.85**	-39.82**
47	GAR-13 × AAUDR-1	5.66	3.50	34.43**	25.78**	7.44	-7.58
48	GAR-13 × IET 23471	-2.41	-13.55	10.88	4.22	3.43	-18.66**
	S.E. (d) ±	**0.68**	**0.78**	**1.41**	**1.63**	**6.93**	**8.00**
	C.D. at 5%	**1.35**	**1.56**	**2.80**	**3.24**	**13.75**	**15.88**
	C.D.at 1%	**1.78**	**2.06**	**3.72**	**4.29**	**18.21**	**21.03**
	Range	**-48.64 to 51.18**	**-48.68 to 39.18**	**-27.04 to 36.16**	**-28.75 to 31.19**	**-44.95 to 51.49**	**-49.52 to 45.76**

* and ** shows significance at 5 per cent and 1 per cent levels of probability, respectively.

Table 3. Continue…

Sr. no.	Crosses	Panicle weight (g)		1000 grain weight (g)		Harvest index (%)	
		MP	**BP**	**MP**	**BP**	**MP**	**BP**
1	NAUR-1 × IET 23467	30.27**	19.87**	9.28**	-2.69	3.63	0.49
2	NAUR-1 × IET 23450	-25.08**	-32.57**	-7.86	-20.89**	-6.15	-7.53
3	NAUR-1 × IR 28	45.65**	29.60**	8.12*	2.53	-5.74	-13.52
4	NAUR-1 × IET 22704	-20.12**	-26.85**	9.35*	6.12	2.77	-0.90
5	NAUR-1 × IET 23449	0.08	-1.53	21.23**	20.46**	-1.48	-7.54
6	NAUR-1 × CR DHAN 201	44.49**	42.88**	27.39**	25.11**	18.34*	13.06
7	NAUR-1 × IET 23459	20.79**	-2.29	-4.07	-5.49	1.05	-5.84
8	NAUR-1 × GR-7	66.80**	44.47**	15.32**	7.26	10.52	5.25
9	NAUR-1 × IET 23448	24.92**	19.68**	-2.54	-6.07	9.45	1.33
10	NAUR-1 × IET 23455	29.13**	26.62**	-12.38**	-20.14**	4.90	2.09
11	NAUR-1 × AAUDR-1	-21.04**	-26.85**	-3.32	-4.90	-8.23	-14.09
12	NAUR-1 × IET 23471	-14.45**	-25.25**	2.16	-0.20	-4.68	-6.25
13	GNR-3 × IET 23467	-28.91**	-28.91**	-12.03**	-17.46**	-2.87	-9.23
14	GNR-3 × IET 23450	-42.12**	-51.60**	-19.50**	-34.02**	-4.92	-7.16
15	GNR-3 × IR 28	-11.70**	-26.92**	17.66**	5.83	4.21	-7.65
16	GNR-3 × IET 22704	-1.21	-16.09**	19.02**	9.40*	19.31*	19.08
17	GNR-3 × IET 23449	23.01**	11.54**	25.60**	18.05**	9.29	-1.02
18	GNR-3 × CR DHAN 201	11.62**	3.78	14.05**	6.02	1.23	-6.73
19	GNR-3 × IET 23459	37.47**	4.42	16.13**	8.27*	-12.06	-14.97
20	GNR-3 × GR-7	8.73*	-12.18**	0.65	-1.09	14.81	5.44
21	GNR-3 × IET 23448	16.04**	2.69	-4.12	-6.02	4.36	0.22
22	GNR-3 × IET 23455	-21.28**	-28.85**	-1.62	-5.38	17.28	9.98
23	GNR-3 × AAUDR-1	45.56**	24.94**	20.03**	15.29**	-22.84**	-30.28**
24	GNR-3 × IET 23471	4.88	-14.62**	7.87*	4.32	-0.85	-6.08
25	Gurjari × IET 23467	3.34	-10.83**	2.67	-4.94	-5.70	-8.14
26	Gurjari × IET 23450	-2.71	-6.27	14.59**	-5.03	7.28	5.21
27	Gurjari × IR 28	25.44**	19.35**	9.98*	0.19	-5.37	-12.81
28	Gurjari × IET 22704	-17.55**	-19.08**	-19.00**	-24.56**	-3.04	-6.92

29	Gurjari × IET 23449	-1.54	-6.86	15.94**	10.44*	11.05	4.68
30	Gurjari × CR DHAN 201	28.51**	18.49**	17.66**	10.83**	-7.89	-11.60
31	Gurjari × IET 23459	-24.82**	-35.51**	-34.90**	-38.49**	-19.23*	-25.06*
32	Gurjari × GR-7	63.48**	51.06**	9.55**	6.17	20.78*	15.53
33	Gurjari × IET 23448	-16.85**	-19.23**	14.20**	13.54**	-5.76	-13.13
34	Gurjari × IET 23455	11.20**	5.56	6.68*	1.22	0.40	-1.84
35	Gurjari × AAUDR-1	12.71**	12.01**	6.45	3.68	1.72	-4.35
36	Gurjari × IET 23471	47.82**	37.90**	13.81**	11.61**	-15.59	-16.59
37	GAR-13 × IET 23467	1.02	-7.69*	16.58**	-10.21**	6.64	2.06
38	GAR-13 × IET 23450	-32.48**	-38.81**	10.78*	8.82	-24.21**	-24.30*
39	GAR-13 × IR 28	14.05**	2.17	34.66**	19.29**	-7.88	-16.53
40	GAR-13 × IET 22704	-4.16	-11.62**	41.09**	22.42**	-13.81	-15.78
41	GAR-13 × IET 23449	-12.50**	-13.25**	26.88**	7.91	-7.04	-13.86
42	GAR-13 × CR DHAN 201	-27.13**	-28.49**	27.64**	9.63*	1.48	-4.29
43	GAR-13 × IET 23459	2.71	-16.42**	35.79**	16.30**	12.21	5.91
44	GAR-13 × GR-7	-5.20	-17.35**	2.92	-17.91**	12.57	5.82
45	GAR-13 × IET 23448	-14.93**	-17.89**	28.72**	5.68	-8.65	-14.35
46	GAR-13 × IET 23455	1.92	0.70	25.88**	-1.22	-12.98	-16.43
47	GAR-13 × AAUDR-1	46.95**	37.10**	43.68**	19.93**	-5.67	-12.80
48	GAR-13 × IET 23471	37.38**	20.84**	29.21**	7.24	-19.34*	-21.72*
	S.E. (d) ±	**0.15**	**0.17**	**0.90**	**1.04**	**3.50**	**4.04**
	C.D. at 5%	**0.29**	**0.34**	**1.79**	**2.06**	**6.95**	**8.03**
	C.D.at 1%	**0.39**	**0.45**	**2.36**	**2.73**	**9.21**	**10.63**
	Range	**-42.12 to 66.80**	**-51.60 to 51.06**	**-34.90 to 43.68**	**-38.49 to 25.11**	**-24.21 to 20.78**	**-30.28 to 19.08**

* and ** shows significance at 5 per cent and 1 per cent levels of probability, respectively.

Table 3. Continue…

Sr. no.	Crosses	Grain yield per plant (g)		Straw yield per plant (g)		Amylose content (%)		Protein content (%)	
		MP	BP	MP	BP	MP	BP	MP	BP
1	NAUR-1 × IET 23467	2.56	-2.59	-3.93	-13.34	4.63	-4.11	70.00**	60.97**
2	NAUR-1 × IET 23450	-27.21*	-41.16**	-19.72*	-34.06**	3.99	-8.38**	20.83**	7.36**
3	NAUR-1 × IR 28	-16.35	-24.10*	-10.28	-29.03**	-10.12**	-13.46**	-1.94	-9.42**
4	NAUR-1 × IET 22704	-17.17	-29.37**	-20.61**	-29.11**	6.23*	-3.43	-11.03**	-20.35**
5	NAUR-1 × IET 23449	-8.21	-13.93	-7.96	-22.13**	13.94**	1.11	16.35**	5.30
6	NAUR-1 × CR DHAN 201	26.25**	23.16*	-8.17	-17.16*	13.22**	-6.80*	0.80	-9.47**
7	NAUR-1 × IET 23459	-4.86	-26.46*	-5.30	-20.00*	-11.33**	-14.81**	-23.15**	-25.93**
8	NAUR-1 × GR-7	1.54	-1.20	-15.46*	-24.39**	-25.17**	-25.28**	29.91**	15.00**
9	NAUR-1 × IET 23448	-6.66	-19.60	-19.45**	-22.36**	-29.44**	-33.53**	45.38**	31.95**
10	NAUR-1 × IET 23455	-7.29	-15.10	-14.99	-25.72**	-18.03**	-31.94**	15.98**	2.17
11	NAUR-1 × AAUDR-1	-13.45	-18.91	-1.31	-17.14*	-11.98**	-22.02**	9.14**	6.98
12	NAUR-1 × IET 23471	-2.29	-19.51	4.45	-15.97*	-28.75**	-32.39**	53.61**	50.75**
13	GNR-3 × IET 23467	-8.89	-14.22	-5.41	-10.38	-35.43**	-39.96**	-5.26	-8.71**
14	GNR-3 × IET 23450	-18.62	-27.73*	-12.52	-24.97**	-0.86	-11.44**	17.03**	13.39**
15	GNR-3 × IR 28	9.86	8.50	-1.25	-18.65*	2.29	0.00	12.52**	11.28**
16	GNR-3 × IET 22704	-2.33	-7.79	-27.42**	-31.97**	-3.08	-10.62**	-19.93**	-21.78**
17	GNR-3 × IET 23449	23.60*	17.88	4.61	-7.40	3.40	-6.96*	28.02**	26.59**
18	GNR-3 × CR DHAN 201	8.95	-0.02	6.62	1.02	-0.65	-17.19**	4.30	2.26
19	GNR-3 × IET 23459	-8.39	-22.71	11.57	-1.40	3.59	1.06	9.36**	-3.28
20	GNR-3 × GR-7	5.54	-2.92	-17.66*	-22.70*	-18.08**	-19.24**	23.25**	18.91**
21	GNR-3 × IET 23448	-7.39	-11.57	-14.62	-15.96	1.07	-3.36	25.81**	24.79**
22	GNR-3 × IET 23455	1.96	-0.31	-23.24**	-29.69**	-21.28**	-33.81**	-1.13	-5.12
23	GNR-3 × AAUDR-1	-19.68	-23.33	19.72*	5.10	2.47	-7.95**	46.58**	31.62**
24	GNR-3 × IET 23471	-11.30	-19.51	-12.55	-26.63**	-3.56	-7.09**	20.60**	12.21**
25	Gurjari × IET 23467	-13.21	-14.03	-4.14	-7.50	-30.32**	-33.23**	14.84**	1.11
26	Gurjari × IET 23450	6.83	-9.26	-5.14	-17.32	1.39	-6.79*	23.15**	15.47**
27	Gurjari × IR 28	-3.29	-7.02	5.08	-12.11	-15.61**	-16.37**	10.17**	-0.70
28	Gurjari × IET 22704	-23.31*	-31.00**	-19.89*	-23.54*	-0.78	-5.74*	11.02**	3.28
29	Gurjari × IET 23449	-1.57	-1.97	-19.90*	-27.90**	8.98**	0.94	-22.99**	-29.17**
30	Gurjari × CR DHAN 201	-9.99	-13.23	3.32	-0.31	32.09**	13.00**	-25.43**	-30.87**
31	Gurjari × IET 23459	-20.00	-35.25**	13.47	1.97	3.54	2.82	13.15**	-7.73**
32	Gurjari × GR-7	23.96*	19.80	-12.77	-16.61	3.71	-0.88	6.66**	0.41
33	Gurjari × IET 23448	-20.65	-27.84*	-12.85	-15.80	-1.11	-2.46	-5.21*	-13.06**
34	Gurjari × IET 23455	-3.57	-6.36	-4.64	-11.11	12.62**	-2.77	-21.26**	-25.48**
35	Gurjari × AAUDR-1	-5.98	-6.45	-9.86	-19.54*	-0.76	-8.24**	41.81**	17.22**
36	Gurjari × IET 23471	-9.52	-21.57	18.56*	1.03	16.68**	15.97**	-4.84	-18.80**
37	GAR-13 × IET 23467	10.26	-2.73	0.08	-5.60	2.36	1.41	14.96**	0.17
38	GAR-13 × IET 23450	-11.26	-15.83	37.20**	30.45**	5.82*	0.42	-12.80**	-19.15**
39	GAR-13 × IR 28	-2.12	-9.76	12.04	1.75	-4.35	-8.32**	16.45**	3.83
40	GAR-13 × IET 22704	-5.42	-6.63	20.90*	15.28	16.89**	14.78**	5.34*	-3.09
41	GAR-13 × IET 23449	1.53	-9.37	15.31	13.63	-4.90	-9.05**	-8.49**	-16.75**
42	GAR-13 × CR DHAN 201	-20.57	-31.58**	-23.80**	-28.12**	18.87**	4.70	-13.50**	-20.70**

43	GAR-13 × IET 23459	-30.61**	-37.75**	22.22*	20.22	-0.98	-4.89	-23.92**	-38.54**
44	GAR-13 × GR-7	-2.41	-15.75	-12.80	-16.99	-10.53**	-17.19**	-3.75	-10.41**
45	GAR-13 × IET 23448	-10.27	-12.45	3.38	-8.59	13.33**	11.07**	-28.02**	-34.71**
46	GAR-13 × IET 23455	8.52	-0.88	36.52**	33.36**	21.85**	8.34**	-15.31**	-20.75**
47	GAR-13 × AAUDR-1	2.74	-8.21	14.99	12.27	3.53	-1.16	19.62**	-2.06
48	GAR-13 × IET 23471	-16.36	-18.80	17.53	8.97	-7.50**	-10.04**	-14.45**	-27.73**
	S.E. (d) ±	**2.64**	**3.05**	**2.98**	**3.44**	**0.63**	**0.73**	**0.12**	**0.14**
	C.D. at 5%	**5.25**	**6.06**	**5.92**	**6.83**	**1.26**	**1.46**	**0.24**	**0.28**
	C.D. at 1%	**6.95**	**8.02**	**7.84**	**9.05**	**1.67**	**1.93**	**0.32**	**0.37**
	Range	**-30.61 to 26.25**	**-41.16 to 23.16**	**-27.42 to 37.20**	**-34.06 to 33.36**	**-35.43 to 32.09**	**-39.96 to 15.97**	**-28.02 to 70.00**	**-38.54 to 60.97**

* and ** shows significance at 5 per cent and 1 per cent levels of probability, respectively.

Table 4. Promising hybrids based on heterosis for yield and its components in Aerobic rice

Characters	Hybrids with significant heterosis over	
	Mid parent	Better parent
Days to 50 per cent flowering	-	GNR-3 × CR DHAN 201
Days to maturity	-	GAR-13 × IET 23450 NAUR-1 × GR-7 GNR-3 × AAUDR-1
Plant height (cm)	GAR-13 × CR DHAN 201 GAR-13 × IET 23449 GAR-13 × GR-7	GAR-13 × CR DHAN 201 GAR-13 × IET 23449 GAR-13 × GR-7
No. of productive tillers per plant	GNR-3 × IET 23449 Gurjari × GR-7 NAUR-1 × CR DHAN 201	GNR-3 × IET 23449 NAUR-1 × CR DHAN 201 GNR-3 × AAUDR-1
Panicle length (cm)	GAR-13 × IET 23455 GAR-13 × AAUDR-1 GAR-13 × GR-7	GAR-13 × IET 23455 GAR-13 × IET 22704 GAR-13 × AAUDR-1
No. of grains per panicle	Gurjari × IET 23471 NAUR-1 × GR-7 Gurjari × IET 23448	Gurjari × IET 23471 Gurjari × IET 23448 NAUR-1 × CR DHAN 201
Panicle weight (g)	NAUR-1 × GR-7 Gurjari × GR-7 Gurjari × IET 23471	Gurjari × GR-7 NAUR-1 × GR-7 NAUR-1 × CR DHAN 201
1000 grain weight (g)	GAR-13 × AAUDR-1 GAR-13 × IET 22704 GAR-13 × IET 23459	NAUR-1 × CR DHAN 201 GAR-13 × IET 22704 NAUR-1 × IET 23449
Harvest index (%)	Gurjari × GR-7 GNR-3 × IET 22704 NAUR-1 × CR DHAN 201	-
Grain yield per plant (g)	NAUR-1 × CR DHAN 201 Gurjari × GR-7 GNR-3 × IET 23449	NAUR-1 × CR DHAN 201
Straw yield per plant (g)	GAR-13 × IET 23450 GAR-13 × IET 23455 GAR-13 × IET 23459	GAR-13 × IET 23455 GAR-13 × IET 23450
Amylose content (%)	Gurjari × CR DHAN 201 GAR-13 × IET 23455 GAR-13 × CR DHAN 201	Gurjari × IET 23471 GAR-13 × IET 22704 Gurjari × CR DHAN 201
Protein content (%)	NAUR-1 × IET 23467 NAUR-1 × IET 23471 GNR-3 × AAUDR-1	NAUR-1 × IET 23467 NAUR-1 × IET 23471 NAUR-1 × IET 23448

Table 5. Best heterotic crosses and its *per se* performance for grain yield per plant and its components

Best crosses	Mean yield (g)	Significant heterosis for grain yield over		Other traits with significant heterosis over	
		MP	BP	MP	BP
NAUR-1 × CR DHAN 201	36.40	26.25**	23.16*	PTP, PL, GP, PW, GW, HI, AC	PH, PTP, GP, PW, GW
Gurjari × GR-7	33.50	23.96*	19.80	PTP, PL, GP, PW, GW, HI, PC	PTP, PL, GP, PW
GNR-3 × IET 23449	30.50	23.60*	17.88	PH, PTP, PL, GP, PW, GW, PC	PH, PTP, PL, GP, PW, GW, PC

(**Note:** Where, PH= Plant height; PTP= Number of productive tillers per plant; PL= Panicle length; GP= Number of grains per panicle; PW= Panicle weight; GW= 1000 grain weight; HI= Harvest index; AC= Amylose content; PC= Protein content)

Total six hybrids manifested significant positive heterotic effect for straw yield per plant and two hybrids exhibited positive heterobeltiosis. Cross combination GAR-13 × IET 23450 exhibited significantly highest positive relative heterosis, while cross combination GAR-13 × IET 23455 had significantly highest positive heterobeltiosis. These results akin with Kumar *et al.*[2]. For amylose content, 12 and five crosses exhibited significant and positive heterosis over mid parent and better parent, respectively. Cross Gurjari × CR DHAN 201 exhibited significantly highest positive relative heterosis while, highest significant positive heterobeltiosis was reported in Gurjari × IET 23471. Patil *et al*.[7], and Mistry *et al.*[4], reported the similar instances. For protein content, total 27 and 14 crosses showed significant and positive heterosis over mid parent and better parent, respectively. Crosses NAUR-1 × IET 23467 exhibited significantly highest positive relative heterosis and heterobeltiosis. Comparable harmony for this character was recorded by Patil *et al.*[7], and Nayak *et al.*[5].

Among 48 hybrids, Crosses NAUR-1 × CR DHAN 201, Gurjari × GR-7 and GNR-3 × IET 23449 were found to be most heterotic hybrids for grain yield per plant and also exhibited increase in number of productive tillers per plant, number of grains per panicle, panicle weight and 1000 grain weight had positive effects towards higher grain yield (Table 5). It was also noted that top ranking hybrids based on *per se* performance and better parent heterosis were same. High level of heterosis in crosses resulted mainly due to significant heterosis for yield attributing traits *viz.*, number of productive tillers per plant, number of grains per panicle and panicle weight. Chandra *et al*., and Naseem *et al*., recorded number of productive tillers, number of grains per panicle and panicle weight to be in positive correlation with grain yield in rice. Results of the present investigation was in accordance with the results of Singh *et al.*[12], Parihar and Pathak[6], Venkatesan *et al.*[14], Jelodar and Bagheri, Kumar *et al.*[2], Veeresha *et al*.[13], and Shinde and Patel[11].

Top hybrid combinations, NAUR-1 × CR DHAN 201 and GNR-3 × IET 23449 could help to develop ideotype plant. These hybrids recorded negative heterobeltiosis for plant height and maturity (Table 3). These results were in accordance with the results of Mishra and Pandey[3]. The transformed reproductive growth out of vegetative growth could be the possible reason behind early maturity of varieties.

Improving yield and nutritional quality considered as two sides of a coin and we can only choose one at a time but present investigation exhibited considerable improvement in both i.e. yield and protein content (Table 3). These results akin with Nayak *et al.*[5]. These hybrids can be used to obtain transgressive segregants for higher grain yield along with protein content.

CONCLUSION

From present investigation it is concluded that heterosis in both positive and negative direction is important based on character under study. For characters *viz.*, days to 50% flowering, days to maturity and plant height negative heterosis is desirable whereas for characters viz., number of productive tillers per plant, panicle length, number of grains per panicle, panicle weight, 1000 grain weight, harvest index, grain and straw yield per plant, amylose and protein content positive heterosis is desirable. It was also observed that hybrid showing high heterosis for grain yield per plant also manifested heterotic effects for number of productive tillers per plant, panicle length, number of grains per panicle, panicle weight and 1000 grain weight.

All the promising hybrids developed from 4 lines and 12 testers, showed significant positive heterosis over their respective mid and better parents which supporting high relative heterosis as well as heterobeltiosis for yield and its components in rice. So, it is clear that rice crop holds great potential to develop high yielding hybrids and rice ideotype for aerobic condition. Further, it is observed that yield components play major role in yield maximization and most of the best hybrids exhibiting higher heterosis involve parents such NAUR-1, CR DHAN 201 and GR-7. Such genetic material could be utilized for developing high yielding aerobic rice hybrids that will sustain limited environmental sources.

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