RESEARCH ARTICLE https://doi.org/10.58297/SRNZ2394

Line x Tester analysis for deducing heterosis in rice (*Oryza sativa* L.)

Modunshim Maring K[1], Madhu Bala[1] and Patel PB[2]

[1]*Genetics and Plant Breeding,* [2]*Main Rice Research Centre, N.M. College of Agriculture,*
Navsari Agricultural University, Navsari-396 450, Gujarat, India
Corresponding author email: *modunshim123@gmail.com*

Received: 11th May 2022; Accepted: 13th June 2022

Abstract

An experiment consisting of twelve genotypes (four lines and eight testers) along with their thirty-two crosses was conducted in Line x Tester design to study the heterobeltiosis and standard heterosis for grain yield per plant and its component traits in rice at Main Rice Research Centre, Navsari. The result indicated that significant heterosis in a desirable direction was observed in all the characters except days to 50% flowering where none of the crosses showed significant heterobeltiosis in a negative direction for this trait. The best heterobeltiosis and standard heterosis for grain yield per plant was exhibited by the cross NVSR-453 x NVSR-475 followed by Gurjari x NAUR-1 and NVSR-453 x NVSR-409.

Keywords: Heterosis, Hybrid, Line x Tester, Rice, Yield.

Introduction

Rice (*Oryza sativa* L., 2n = 2x = 24) is one of the most consumed food grains in the world. It is regarded to be first cultivated in South-East Asia. Rice belongs to the family poaceae and the genus *Oryza*. The genus *Oryza* has twenty-one wild and two cultivated species. i.e., *Oryza sativa* (Asian rice) and *Oryza glaberrima* (African rice). Based on the number of morphological, physiological, biochemical and molecular traits, Asian rice cultivars are broadly grouped into two major subspecies, i.e., *Oryza sativa indica* and *Oryza sativa japonica* (Glaszmann, 1987).

Rice is mainly a self-pollinating crop, hydrophilic, short-day and C_3 plant. It is best suited to moist humid weather during vegetative growth and dry sunny weather during the ripening period. With optimum temperature requirement between 25°C to 35°C and optimum humidity between 60-80%, rice cultivation extends from 40°S to 45°N latitude, 70°W to 140°E longitude at an altitude range of 1500-2200 m amsl (above mean sea level). Rice serves as a good source of B-vitamins, iron, manganese and magnesium. Rice bran oil is used as medicine as well as cooking oil and its straw is used as fodder in many countries. Global production of milled rice is 450.38 million tonnes from 162.43 million ha area and its productivity is 2.77 kg/ha during 2018-19 (Anonymous, 2020). In India, rice is cultivated in 44.16 million ha along with the production of 105.67 million tonnes and productivity of 2.39 kg/ha during 2018-19 (Anonymous, 2020). The major rice producing countries in Asia are India, China, Indonesia, Thailand, Myanmar and Bangladesh (IRRI-World Rice Statistics, 2010).

Heterosis breeding ensures extensive and detailed genetic assessment of existing germplasm as well as newly evolved promising lines which could be used in future breeding programme or could be directly released as cultivars after proper evaluation. Line x Tester analysis (Kempthorne, 1957) is the most popular method for the exploitation of heterosis in self-pollinated crops, especially in rice breeding programme (Peng and Virmani, 1990). Therefore, the present investigation was undertaken to study heterosis for yield and its component traits in rice.

Materials and Methods

The crossing programme was carried out at Main Rice Research Centre (M. R. R. C.), N.A.U., Navsari during *rabi*-2019 and evaluation was carried out during *kharif*-2019. The experimental materials consisted of 45 entries including 4 lines (Gurjari, NVSR-452, NVSR-453 and GNR-3) and eight testers (NVSR-6157, NVSR-473, NVSR-475, NVSR-486, Dandi, NVSR-403, NVSR-409 and NAUR-1), their 32 crosses (Line × tester mating design) and one check variety (GNR-5). The crossing was carried out by hand emasculation and pollination. The experiment was laid out in a randomized block design with three replications. Each entry was planted in a single row consisting of 10 plants with a spacing of 20 cm x 15 cm. The standard agronomical practices were followed to raise the good experimental crop. Five competitive plants excluding the border plants were randomly selected in each replication to record all the observations for its components characters *viz*., Plant height (cm), productive tillers per plant, panicle length (cm), grains per panicle, kernel length (mm), kernel width (mm), L: B ratio, 100 grain weight (g), protein content (%) by Kjeldahl method, amylose content (%) and straw yield per plant. The traits days to 50 % flowering and grain yield were recorded on a net plot basis, taking border plants into consideration. Heterosis was estimated over better parent and standard check by using the formula suggested by Fonseca and Patterson (1968).

Results and discussion

The highest percent contribution of line has been noticed for days to 50 % flowering, followed by 100 grain weight, kernel length, plant height, grain yield per plant and grains per panicle. The highest contribution of tester was shown in protein content, followed by L : B ratio, kernel width, straw yield per plant, kernel length and 100 grain weight. The highest percent contribution of line x tester was exhibited by productive tillers per plant, followed by amylose content, panicle length, grain yield per plant, grains per panicle and plant height.

Significance in the negative direction is desirable for the trait days to 50 % flowering. The heterosis for these characters ranged from -5.88 % (Gurjari x NVSR-6157) to 19.09 % (NVSR-452 x NVSR-6157) over the better parent while it ranged from -14.83 % (Gurjari x NVSR-6157) to 10.87 % (NVSR-452 x NAUR-1) over the standard check. Significant negative standard heterosis was observed for eight crosses, of which the three highly significant cross combinations were Gurjari x NVSR-6157 (-14.83 %), Gurjari x NVSR-473 (-14.45 %), and Gurjari x Dandi (-12.93 %). But no hybrids showed significant heterobeltiosis in a negative direction. The above results were in accordance with the findings of Bhati *et al*. (2015), Sala *et al*. (2016), Kumari and Jaiswal (2017), Sahu *et al*. (2017a), Patel *et al*. (2018), Prajapati and Kathiria (2018), Thakor *et al*. (2018) and Sundaram *et al*. (2019). Besides days to 50 % flowering, a negative direction is also desirable for the trait plant height. The heterobeltiosis for this trait ranged from -17.19 % (NVSR-453 x Dandi) to 35.75 % (NVSR-453 x NVSR-475). Only one hybrid exhibited significant negative heterobeltiosis *i.e*. NVSR-453 x Dandi. Whereas the value of standard heterosis ranged from -22.36 % (GNR-3 x NVSR-486) to 24.65 % (NVSR-453 x NVSR-475). The crosses NVSR-453 x Dandi and GNR-3 x NVSR-486 had the least heterobeltiosis and standard heterosis, respectively. The present findings are in accordance with results reported by Bhati *et al.* (2015), Dar *et al*. (2015), Waza *et al*. (2016), Kumari and Jaiswal (2017), Sahu *et al*. (2017a), Thorat *et al*. (2017), Prajapati and Kathiria (2018), Thakor *et al*. (2018) and Sundaram *et al*. (2019).

The trait productive tillers per plant is associated with high grain yield. So, it is an important indirect trait for consideration while determining yield. The crosses that showed the highest percentage of heterosis over better parent and standard check are NVSR-453 x NVSR-475 and NVSR-452 x NVSR-486, respectively. Bano and Singh (2018), Patel *et al*., (2018), Prajapati and Kathiria (2018), and Thakor *et al*., (2018) also reported similar results in rice. For panicle length, two and eight crosses expressed significant and positive heterosis over better parent and standard check, respectively. The cross NVSR-453 x NVSR-475 exhibited the highest heterobeltiosis as well as the highest standard heterosis for this character. The results were in uniformity with the results reported by

Table 1. Estimates of heterobeltiosis and standard heterosis for days to 50 % flowering, plant height (cm), productive tillers per plant, panicle length, grains per panicle and kernel length in rice.

Sr. No..	Crosses	Days to 50 % flowering		Plant height (cm)		Productive tillers per plant		Panicle length (cm)		Grains per panicle		Kernel length (mm)	
		BP	SC	BP	SC	BP	SC	BP	SC	BP	SC	BP	SC
1.	Gurjari x NVSR-6157	-5.88	-14.83**	-11.80	-15.67*	-13.06	-12.39	-15.67*	-13.06	-12.39	-19.77**	-3.44	10.38**
2.	Gurjari x NVSR-473	-5.46	-14.45**	-14.16	-24.33**	-20.56**	-16.64*	-24.33**	-20.56**	-16.64*	-25.28**	18.57**	22.77**
3.	Gurjari x NVSR-475	-0.84	-10.27*	-2.19	-0.50	-1.82	2.63	-0.50	-1.82	2.63	-11.35	20.31**	11.31**
4.	Gurjari x NVSR-486	1.68	-7.98*	-8.30	-7.96	-9.18	-6.00	-7.96	-9.18	-6.00	-18.80**	-3.67	20.32**
5.	Gurjari x Dandi	-3.78	-12.93**	6.63	3.48	12.80	7.06	3.48	12.80	7.06	0.81	-14.05**	16.22**
6.	Gurjari x NVSR-403	-2.10	-11.41**	0.04	-2.85	-1.32	6.38	-2.85	-1.32	6.38	-8.10	41.62**	31.02**
7.	Gurjari x NVSR-409	2.10	-7.60	14.20	9.62	14.85*	9.22	9.62	14.85*	9.22	6.03	1.93	21.25**
8.	Gurjari x NAUR-1	5.04	-4.94	28.41**	10.97	26.44**	20.87**	10.97	26.44**	20.87**	22.24**	-30.86**	-1.75
9.	NVSR-452 x NVSR-6157	19.09**	9.13*	0.46	1.03	4.15	5.84	1.03	4.15	5.84	-3.08	-1.67	12.40**
10.	NVSR-452 x NVSR-473	12.10**	5.70	8.09	5.90	11.17	11.39	5.90	11.17	11.39	-0.16	-0.26	3.28
11.	NVSR-452 x NVSR-475	11.49**	10.65**	-9.30	-13.85*	-13.24	-11.48	-13.85*	-13.24	-11.48	-21.23**	-11.72**	-9.94**
12.	NVSR-452 x NVSR-486	9.20*	8.37*	19.58*	15.13*	15.94*	25.36**	15.13*	15.94*	25.36**	11.54	-5.64*	17.86**
13.	NVSR-452 x Dandi	12.25**	7.98*	8.71	3.16	12.44	8.81	3.16	12.44	8.81	2.46	-37.96**	-16.11**
14.	NVSR-452 x NVSR-403	9.20*	8.37*	2.40	0.80	2.38	6.92	0.80	2.38	6.92	-4.86	-5.57*	-3.66
15.	NVSR-452 x NVSR-409	8.14*	6.08	0.65	1.26	6.09	2.00	1.26	6.09	2.00	-0.97	-8.82**	8.47**
16.	NVSR-452 x NAUR-1	11.72**	10.87**	-8.27	-16.58**	-4.94	-14.74*	-16.58**	-4.94	-14.74*	-13.78*	-29.44**	0.27
17.	NVSR-453 x NVSR-6157	7.47	-1.52	3.32	3.05	12.09	1.28	3.05	12.09	1.28	0.49	-6.55**	6.83*
18.	NVSR-453 x NVSR-473	2.82	-3.04	22.04*	12.14	-13.06	15.03*	12.14	-13.06	15.03*	14.13*	18.14**	22.34**
19.	NVSR-453 x NVSR-475	1.57	-1.90	35.75**	24.65**	34.48**	19.10	18.14**	28.51**	22.55**	21.59**	-0.06	-14.04**
20.	NVSR-453 x NVSR-486	3.94	0.38	-0.40	-9.37	10.00	-1.49	-9.93	-2.03	-9.01	-9.72	-9.14**	13.49**
21.	NVSR-453 x Dandi	0.00	-3.80	-17.19*	-18.71*	-8.33	-17.91	-25.02**	-18.27**	-21.75**	-22.37**	-22.21**	5.19
22.	NVSR-453 x NVSR-403	6.69	3.04	6.24	-2.44	-17.43	-26.87*	-0.68	8.03	-0.19	-0.97	-3.62	-17.09**
23.	NVSR-453 x NVSR-409	7.48	3.80	18.45*	16.27*	-16.89	-14.93	8.97	18.53**	17.16**	16.24*	7.30**	27.64**
24.	NVSR-453 x NAUR-1	5.12	1.52	7.17	5.20	0.00	13.43	0.62	14.65*	4.04	5.22	3.73	47.41**
25.	GNR-3 x NVSR-6157	-0.83	-9.13*	-7.00	-13.45	-16.05	-11.94	-8.05	-5.21	-8.14	-15.88*	-19.30**	-7.76**
26.	GNR-3 x NVSR-473	2.02	-3.80	2.06	-6.03	-24.59*	-20.90*	-3.31	1.50	3.62	-7.13	-9.34**	-6.12*
27.	GNR-3 x NVSR-475	-1.20	-6.08	-6.21	-13.88	-24.59*	-20.90*	-1.69	-5.65	0.98	-16.53*	6.41	-9.39**

Sr. No..	Crosses	Days to 50 % flowering		Plant height (cm)		Productive tillers per plant		Panicle length (cm)		Grains per panicle		Kernel length (mm)	
		BP	SC	BP	SC	BP	SC	BP	SC	BP	SC	BP	SC
28.	GNR-3 x NVSR-486	5.20	0.00	-14.67	-22.36**	-18.90	-14.93	-15.79*	-22.33**	-11.76	-27.07**	-3.24	20.86**
29.	GNR-3 x Dandi	-5.60	-10.27*	16.15	8.09	2.76	7.79	6.32	15.89*	16.56*	9.76	-39.46**	-18.13**
30.	GNR-3 x NVSR-403	1.20	-3.80	-3.32	-11.21	18.10	23.88*	-3.81	-2.29	2.45	-11.83	12.51**	-4.21
31.	GNR-3 x NVSR-409	0.80	-4.18	3.24	-3.92	-21.74*	-17.91	-0.67	4.06	-1.34	-4.21	1.79	21.08**
32.	GNR-3 x NAUR-1	12.40**	6.84	10.78	3.09	4.61	18.66	0.31	14.30*	5.64	6.84	-32.01**	-3.39
	S.E. (d) ±	3.44	3.44	7.79	7.79	1.15	1.15	1.25	1.25	13.02	13.02	0.17	0.17
	C.D. at 5%	6.88	6.88	15.57	15.57	2.31	2.31	2.50	2.50	26.02	26.02	0.34	0.34
	C.D. at 1%	9.14	9.14	20.70	20.70	3.07	3.07	3.32	3.32	34.59	34.59	0.45	0.45
	Range	-5.88 to 19.09	-14.83 to 10.87	-17.19 to 35.75	-22.36 to 24.65	-34.21 to 34.48	-28.36 to 26.87	-25.02 to 18.14	-22.33 to 28.51	-21.75 to 25.36	-27.07 to 22.24	-39.46 to 41.62	-18.13 to 47.41

*-Significant at 5 % and **-Significant at 1 %, BP-Better Parent, SC-Standard Check

Table 2. Estimates of heterobeltiosis and standard heterosis for kernel width (mm), L : B ratio, 100 grain weight (g), protein content, amylose content, grain yield per plant and straw yield per plant in rice.

Sr. No.	Crosses	Kernel width (mm)		L : B ratio		100 grain weight (g)		Protein content (%)		Amylose content (%)		Grain yield per plant (g)		Straw yield per plant (g)	
		BP	SC	BP	SC	BP	SC	BP	SC	BP	SC	BP	SC	BP	SC
1.	Gurjari x NVSR-6157	-3.49*	10.09**	-19.05**	0.14	-10.44**	4.69*	-3.03**	29.67**	12.92**	20.64**	-22.12*	-28.93**	18.84	-20.18*
2.	Gurjari x NVSR-473	-6.98**	6.11**	20.57**	15.62**	3.85	9.74**	-14.78**	3.60*	-18.83**	-13.06**	-26.50*	-33.18**	3.05	2.36
3.	Gurjari x NVSR-475	-8.15**	4.78**	30.91**	6.16*	-3.38	2.10	-28.48**	-13.06**	-8.18*	-7.34	9.48	-11.94	6.95	-9.55
4.	Gurjari x NVSR-486	-3.38*	10.23**	-10.16**	9.04**	6.64**	14.80**	-17.89**	-0.18	-17.21**	-16.45**	-11.68	-29.21**	59.98**	7.45
5.	Gurjari x Dandi	-3.38*	10.23**	-17.58**	5.34**	2.68	8.51**	-17.67**	0.09	0.76	13.64**	23.04*	13.61	11.71	-24.97**
6.	Gurjari x NVSR-403	-6.87**	6.24**	52.03**	23.29**	12.02**	18.37**	-13.93**	4.64**	7.88*	18.84**	-0.58	-10.60	1.38	-31.91**
7.	Gurjari x NVSR-409	-28.87**	-18.86**	18.09**	49.32**	-16.80**	-12.08**	-27.04**	-11.30**	-3.88	2.29	23.41*	25.26*	40.14**	7.45
8.	Gurjari x NAUR-1	-9.55**	3.19	-29.15**	-4.79	-11.67**	-6.66**	-24.70**	-8.46**	-5.63	2.45	34.10**	38.87**	93.74**	55.37**
9.	NVSR-452 x NVSR-6157	-4.36**	4.78**	-13.40**	7.12**	-12.24**	2.59	-4.85**	27.24**	-23.35**	-12.09**	-8.48	-5.98	-9.26	3.78
10.	NVSR-452 x NVSR-473	-29.58**	-22.84**	39.57**	33.84**	-19.69**	-30.09**	-3.45**	13.46**	0.67	15.44**	0.98	3.74	-37.09**	-28.04**

Sr. No.	Crosses	Kernel width (mm)		L : B ratio		100 grain weight (g)		Protein content (%)		Amylose content (%)		Grain yield per plant (g)		Straw yield per plant (g)	
		BP	SC	BP	SC	BP	SC	BP	SC	BP	SC	BP	SC	BP	SC
11.		0.24	9.83**	-11.93**	-18.08**	5.67*	-8.01**	-17.32**	-2.84*	-7.91*	5.61	-33.65**	-31.83**	-58.04**	-52.00**
12.	NVSR-452 x NVSR-486	1.09	10.76**	-12.30**	6.44**	5.50*	13.56**	-18.47**	-4.19**	-0.80	13.76**	31.23**	34.82**	-48.28**	-40.85**
13.	NVSR-452 x Dandi	3.03	12.88**	-41.91**	-25.75**	-18.31**	-14.18**	-20.88**	-7.02**	-6.77*	6.91	10.66	13.68	-8.87	4.23
14.	NVSR-452 x NVSR-403	-2.67	6.64**	-2.95	-9.73**	5.83*	-5.92*	-1.95	15.22**	-0.13	14.53**	10.66	13.68	-27.33**	-16.89
15.	NVSR-452 x NVSR-409	-7.88**	0.93	-15.06**	7.40**	-3.87	-2.10	-37.78**	-26.88**	-3.20	11.01**	-8.09	-5.58	-52.54**	-45.71**
16.	NVSR-452 x NAUR-1	5.70**	15.80**	-35.58**	-13.42**	16.86**	1.73	-27.62**	-14.95**	4.57	19.92**	-21.81*	-19.03	-23.01**	-11.94
17.	NVSR-453 x NVSR-6157	1.99	8.76**	-20.60**	-1.78	-12.97**	1.73	-11.85**	17.87**	11.92**	19.57**	4.34	8.34	-3.96	-26.54**
18.	NVSR-453 x NVSR-473	-17.34**	-10.76**	42.86**	36.99**	12.32**	-2.22	12.69**	21.52**	7.78*	15.44**	31.69**	36.75**	-26.20**	-26.69**
19.	NVSR-453 x NVSR-475	0.74	9.03**	-2.38	-21.23**	4.92	-18.50**	-10.20**	-16.34**	-5.26	-2.60	36.25**	41.48**	20.41	1.83
20.	NVSR-453 x NVSR-486	2.49	9.30**	-14.45**	3.84	-1.37	6.17**	-14.71**	-19.32**	10.35**	13.46**	-14.82	-11.55	-10.62	-31.64**
21.	NVSR-453 x Dandi	0.50	7.17**	-23.26**	-1.92	-5.05*	-0.25	-2.85	-9.50**	5.56	19.05**	-35.23**	-32.74**	-29.52*	-46.09**
22.	NVSR-453 x NVSR-403	-2.12	4.38*	-1.70	-20.68**	-12.76**	-22.44**	-1.90	9.32**	-2.97	6.88	-0.10	3.74	8.47	-17.03
23.	NVSR-453 x NVSR-409	-6.97**	-0.80	1.63	28.49**	5.69*	7.64**	-21.27**	-26.65**	11.21**	18.35**	31.99**	37.06**	-31.54*	-47.51**
24.	NVSR-453 x NAUR-1	9.84**	17.13**	-6.42**	25.75**	39.80**	20.84**	-17.64**	-23.28**	-7.46*	0.46	19.45*	24.04*	38.66**	11.19
25.	GNR-3 x NVSR-6157	0.73	9.56**	-32.00**	-15.89**	-20.25**	-6.78**	-13.03**	16.30**	12.32**	20.00**	-14.19	-21.69*	-18.12	-45.86**
26.	GNR-3 x NVSR-473	-17.70**	-10.49**	9.43**	4.93	-36.06**	-27.62**	-2.09	5.58**	-0.50	6.57	-1.15	-10.13	-30.42**	-30.89**
27.	GNR-3 x NVSR-475	-1.71	6.91**	8.42*	-15.34**	-23.09**	-12.95**	-5.07**	-19.95**	12.57**	11.47**	-6.13	-24.49*	6.33	-10.07
28.	GNR-3 x NVSR-486	3.05	12.08**	-11.29**	7.67**	2.83	16.40**	-15.56**	-20.13**	6.73	1.38	-8.81	-33.72**	-13.25	-42.64**
29.	GNR-3 x Dandi	3.05	12.08**	-42.87**	-26.99**	-28.98**	-19.61**	8.63**	-10.45**	-27.20**	-17.89**	39.89**	29.17**	-25.14	-50.51**
30.	GNR-3 x NVSR-403	-5.13**	3.19	16.12**	-7.26**	-22.00**	-11.71**	-0.65	10.72**	3.55	14.07**	-7.78	-17.07	116.76**	43.32**
31.	GNR-3 x NVSR-409	-22.22**	-15.41**	13.22**	43.15**	-16.99**	-6.04**	-17.26**	-31.79**	-0.43	5.96	-7.09	-5.69	33.69**	2.51
32.	GNR-3 x NAUR-1	-22.34**	-15.54**	-14.98**	14.25**	-37.15**	-28.85**	-13.60**	-28.77**	-3.24	5.05	10.19	14.11	57.89**	26.62**
	S.E. (d) ±	0.04	0.04	0.06	0.06	0.06	0.06	0.10	0.10	0.81	0.81	2.37	2.37	4.13	4.13
	C.D. at 5%	0.09	0.09	0.12	0.12	0.12	0.12	0.21	0.21	1.61	1.61	4.73	4.73	8.26	8.26
	C.D. at 1%	0.12	0.12	0.16	0.16	0.16	0.16	0.28	0.28	2.15	2.15	6.29	6.29	10.99	10.99
	Range	-29.58 to 9.84	-22.84 to 17.13	-42.87 to 52.03	-26.99 to 49.32	-37.15 to 39.80	-30.09 to 20.84	-37.78 to 12.69	-31.79 to 29.67	-27.20 to 12.92	-17.89 to 20.64	-35.23 to 39.89	-33.72 to 41.48	-58.04 to 116.76	-52.00 to 55.37

*-Significant at 5 % and **-Significant at 1 %, BP-Better Parent, SC-Standard Check

Patel *et al*., (2018), Prajapati and Kathiria (2018), Thakor *et al*., (2018), and Sundaram *et al*., (2019).

Grains per panicle is an important trait to determine the grain yield in rice crop. The range of heterobeltiosis for grain per panicle was from -21.75 % (NVSR-453 x Dandi) to 25.36 % (NVSR-452 x NVSR-486). The estimates of standard heterosis varied from -27.07 % (GNR-3 x NVSR-486) to 22.24 % (Gurjari x NAUR-1). Six and four hybrids exhibited significant positive heterobeltiosis and standard heterosis, respectively in the desired direction for this trait. The results were akin to the findings of Rukmini (2014), Shinde and Patel (2014), Bhati *et al*., (2015), Sala *et al*., (2016), Kumari and Jaiswal (2017). The cross, Gurjari x NVSR-403 (41.62 %) recorded the maximum heterobeltiosis and the cross NVSR-453 x NAUR-1 (47.41 %) recorded maximum standard heterosis for kernel length. A total of six and seventeen crosses expressed significant heterobeltiosis and standard heterosis in positive direction, respectively. Positive heterosis for this trait was also reported by Sanghera and Hussain (2012), Sarial (2014), Bhatti *et al*., (2015), and Prajapati and Kathiria (2018).

The range of heterobeltiosis for kernel width was from -29.58 % (NVSR-452 x NVSR-473) to 9.84 % (NVSR-453 x NAUR-1). The estimates of standard heterosis varied from -22.84 % (NVSR-452 x NVSR-473) to 17.13 % (NVSR-453 x NAUR-1). Two and twenty-three crosses exhibited significant positive heterobeltiosis and standard heterosis, respectively. The results were similar to the findings of Sanghera and Hussain (2012), Bhatti *et al*. (2015), and Prajapati and Kathiria (2018). The L: B ratio is an important trait as it has a greater contribution towards seed quality. The cross combination Gurjari x NVSR-403 exhibited the maximum heterobeltiosis and the cross-combination Gurjari x NVSR-409 exhibited the maximum standard heterosis among all the crosses. The results were in agreement with the results reported by Shinde and Patel (2014), Dar *et.al.,* (2015) and Bano and Singh (2018). The heterobeltiosis for 100 grain weight varied between -37.15 % (GNR-3 x NAUR-1) to 39.80 % (NVSR-453 x NAUR-1). The standard heterosis ranged from -30.09 % (NVSR-452 x NVSR-473) to 20.84 % (NVSR-453 x NAUR-1). With regard to 100 grain weight, heterosis over better parent and standard check were exhibited by nine and ten crosses, respectively. Utharasu and Anandakumar (2013), Waza *et al*., (2016) and Sahu *et al*., (2017b) reported similar results.

The protein content of the hybrids is positively correlated with that of the protein content of the parents. However, it has a negative correlation with the grain yield per plant. The results for protein content revealed that only two crosses had significant and positive heterosis over better parent while twelve crosses had significant and positive heterosis over the standard check. The cross NVSR-453 x NVSR-473 had reported the highest magnitude of heterosis over better parent and the cross Gurjari x NVSR-6157 reported the highest heterosis over the standard check. Comparable harmony for this character was also recorded by Patel *et al*., (2018) and Thakor *et al*., (2018). The heterobeltiosis for amylose content ranged from -27.20 % (GNR-3 x Dandi) to 12.92 % (Gurjari x NVSR-6157). The value of standard heterosis ranged from -17.89 % (GNR-3 x Dandi) to 20.64 % (Gurjari x NVSR-6157). The amylose content of the hybrids has a positive correlation with that of the parents. Eight crosses depicted positive and significant heterosis over better parent and sixteen crosses over the standard check for amylose content. These results were in accordance with the results of Bano and Singh (2018), Patel *et al.,* (2018) and Thakor *et al.,* (2018).

Grain yield per plant is an attribute of economic importance which breeders attempt to improve by evolving new high yielding hybrids. The grain yield per plant for the hybrids is positively correlated with that of the parents. It also has positive correlation with the amylose content and negative correlation with the protein content. Among thirty-two hybrids, nine and eight hybrids exhibited significant and positive estimates of heterobeltiosis and standard heterosis, respectively for grain yield per plant. The crosses GNR-3 x Dandi and NVSR-453 x NVSR-475 expressed the highest positive and significant estimates for the heterosis over better parent and over the standard check, respectively. The results were in accordance with the findings of Sravan *et al*. (2016), Kumari and Jaiswal (2017), Sahu *et al*., (2017a), Sahu *et al*., (2017b), Bano and Singh (2018), Patel *et al*., (2018), Thakor *et al*., (2018) and Sundaram (2019). The range of heterobeltiosis for straw yield per plant was between -58.04 % (NVSR-452 x NVSR-475) to 116.76 % (GNR-3 x NVSR-403). The standard heterosis ranged from -52.00 % (NVSR-452 x NVSR-475) to 55.37 % (Gurjari x NAUR-1). Seven and three hybrids exhibited significant positive heterobeltiosis and standard heterosis, respectively. Similar results have been reported by Kumar *et al*., (2012), Patel *et al*., (2018) and Thakor *et al*., (2018).

In the present study, the magnitude of the heterosis varied from cross to cross. The top five crosses *viz.,* NVSR-453 x NVSR-475, Gurjari x NAUR-1, NVSR-453 x NVSR-409, NVSR-453 x NVSR-473 and NVSR-452 x NVSR-486 showed significant positive heterosis over better parent and check variety for grain yield and various yield component characters. So, these crosses can fully be exploited through the pedigree method to obtain higher yielding transgressive segregates.

References

1. Anonymous.2020. United State Department of Agriculture.
2. Bagheri N and Jelodar NB. (2010). Heterosis and combining ability analysis for yield and related-yield traits in hybrid rice. *International Journal of Biology*, 2(2): 222-231.
3. Bano DA and Singh SP. 2018. Heterosis for yield and yield related traits in aromatic rice [*Oryza sativa* (L.)] genotypes. *Current Journal of Applied Science and Technology*, 30(6): 1-18.
4. Bhati PK, Singh SK, Singh R, Sharma A and Dhurai SY. 2015. Estimation of heterosis for yield and yield related traits in rice [*Oryza sativa* (L.)]. *SABRAO Journal of Breeding and Genetics*, 47(4): 467-474.
5. Bhatti S, Pandey DP and Singh D. 2015. Combining ability and heterosis for yield and its component traits in rice [*Oryza sativa* (L.)]. *Electronic Journal of Plant Breeding*, 6(1): 12-18.
6. Dar SH, Rather AG, Najeeb S, Ahanger MA, Sanghera GS and Talib S. 2015. Heterosis study in rice [*Oryza sativa* (L.)] under temperate conditions. *International Journal of Agriculture Sciences,* 7(6): 540-545.
7. Fonseca S and Patterson FC. 1968. Hybrid vigour in a seven parent diallel cross in common winter wheat. *Crop Sciences*, 8(1): 85-88.
8. Glaszmann JC. 1987. A varietal classification of Asian cultivated rice (*Oryza sativa* L.) based on isozyme polymorphism. In: Rice genetics. *International Rice Research Institute*, pp 83–90.
9. http://ricestat.irri.org: World Rice Statistics.2010.
10. Kempthorne O. 1957. An introduction to genetic statistics. John Wiley and Sans Inc., New York, U.S.A.
11. Kumari P and Jaiswal HK. 2017. Heterosis studies for yield and yield related traits over seasons of boro rice. *International Journal of Pure and Applied Bioscience*, 5(6): 1000-1009.
12. Kumar S, Pratap N and Dwivedi DK. 2012. Estimation of heterosis for grain yield and yield attributing traits in rice. *Plant Archives*, 12(1): 159-164.
13. Patel A, Rathava K, Gajjar PD, Intwala CG and Patel P. 2018. Study of heterosis for grain yield and its components in aerobic rice [*Oryza sativa* (L.)]. *International Journal of Pure Applied Bioscience*, 6(6): 358-368.
14. Peng JY and Virmani SS. 1990. Combining ability for yield and four related traits in relation to breeding in rice. *Oryza*, 27(1): 1-10.
15. Prajapati KN and Kathiria KB. 2018. Heterosis studies for grain yield and related characters in rice [*Oryza sativa* (L.)]. *International Journal of Genetics,*10(3): 380-386.
16. Sanghera GS and Hussain W. 2012. Heterosis and Combining Ability Estimates using Line X Tester Analysis to Develop Rice Hybrids for Temperate Conditions. *Notulae Scientia Biologicae*, 4(3):131-142.
17. Rukmini DK, Parimala K and Cheralu C. 2014. Heterosis for yield and quality traits in rice [*Oryza sativa* (L.)]. *The Journal of Research of ANGRAU*, 42(1): 1-11.
18. Sahu PK, Sharma D, Singh S, Khute IK and Sao FC. 2017a. Heterotic expressions evaluation for grain yield and quality traits in CMS based rice hybrids. *International Journal of Genetics*, 9(3): 257-262.
19. Sahu R, Singh SK, Singh DK, Vennela PR, Reddy YS, Kumar D, Singh M and Rathan ND. 2017b. Heterosis studies for yield & yield traits in rice

[*Oryza sativa* (L.)] under rainfed condition. *International Journal of Agriculture, Environment and Biotechnology,* 10(1): 1-10.

20. Sala M, Shanti P, Selvi B and Ravi V. 2016. Heterosis study for yield and yield components in rice [*Oryza sativa* (L.)]. *International Journal of Plant Sciences*, 11(1): 98-102.
21. Sarial AK. 2014. Heterosis and combining ability analysis for grain quality and physico-chemical traits involving fertility restorers with basmati background in rice (*Oryza sativa* L.). *Electronic Journal of Plant Breeding*, 5(4): 615-625.
22. Shinde DA and Patel PB. 2014. Study of heterosis for improvement in aerobic rice [*Oryza sativa* (L.)]. *The Bioscan,* 9(2): 739-743.
23. Sravan T, Jaiswal HK, Waza SA and Kumari P. 2016. Heterosis for yield and yield attributes in rice [*Oryza sativa* (L.)]. *Journal of Applied and Natural Sciences*, 8(2): 622-625.
24. Sundaram MK, Rajeswari S, Saraswathi R and Jeyaprakash P. 2019. Heterosis and combining ability analysis for yield related traits in rice hybrids involving land races. *Electronic Journal of Plant Breeding*, 10(1): 92-100.
25. Thakor RP, Balat JR, Delvadiya IR. and Rathva SR. 2018. Heterosis and heterobeltosis studies for grain yield and yield attributing traits in rice [*Oryza sativa* (L.)]. *Electronic Journal of Plant Breeding*, 9(4): 1286-1294.
26. Thorat BS, Kunkerkar RL and Bagkar TA. 2017. Studies on heterosis for yield and its contributing traits in hybrid rice [*Oryza sativa* (L.)]. *International Journal of Chemical Studies*, 5(5): 07-12.
27. Utharasu S and Anandakumar CR. 2013. Heterosis and combining ability analysis for grain yield and its component traits in aerobic rice [*Oryza sativa* (L.)] cultivars. *Electronic Journal of Plant Breeding*, 4(4): 1271-1279.
28. Waza SA, Jaiswal HK, Sravan T, Bano DA, Priyanka K and Umesh. 2018. Heterosis for yield and quality traits in rice (*Oryza sativa* L.). *Journal of Applied and Natural Science*, 8(3): 1510-1522.