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Research Article

Estimation of heterosis for yield related traits and grain Zinc in rice (*Oryza sativa* L.)

S. Rudresha Naik, S. K. Singh, D. K. Singh, A. R. Khaire*, Mounika Korada, Sonali Habde, Prasanta Kumar Majhi

Department of Genetics and Plant Breeding, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi, Uttar Pradesh, India.
***E-Mail:** amrutlalr.khaire10@bhu.ac.in

Abstract
The experiment consists of thirty hybrids generated in a Line x Tester mating design by crossing six lines with five male parents and studied along with two checks (BPT5204 and DRR dhan-45) for 16 characters contributing to yield and grain Zn content in rice. Analysis of variance exhibited significant differences among the genotypes for all the traits under investigation indicating the presence of sufficient variability in material and can be exploited. Among all the crosses, the hybrid, HUR-3022 x Dudhkander exhibited the highest significant positive heterobeltiosis for the number of effective tillers (91.94%), the number of grains per panicle (16.44%), 1000 grain weight (26.28%), grain yield per plant (214.03%) and biomass (225.12 %). HUR-3022 x Sathi exhibited the highest positive better parent heterosis for grain Zn content (38.37%). Standard heterosis over checks BPT-5204 and DRR dhan-45 of 214.03 and 40.07 per cent respectively, were exhibited by the cross, HUR-3022 x Dudhkander for yield plant per plant HUR-3022 x Sathi exhibited the highest positive economic heterosis of 69.42 and 60.26 per cent over BPT-5204 and DRR dhan-45 for grain Zn, respectively. Hence, these two hybrids *viz.*, HUR-3022 x Dudhkander and HUR-3022 x Sathi can be exploited in breeding hybrids for high yield and high grain Zinc with further evaluation in multiple locations.

Key words: L x T mating design, Rice, Standard heterosis, Zinc content.

INTRODUCTION

Rice grain is rich in carbohydrates and contains a good amount of digestible protein but unfortunately, the popular high yielding rice varieties that are currently cultivated are a poor source of essential micronutrients such as Zn in their polished (white) form (Sharma *et al.,* 2013). Undernourishment is estimated to have reached around 82.1 crore people around the world (10.8 % of the world's population) and in India, to about 19.59 crore people which is about 14.8 % of the country's population. Crop biofortification is a very sustainable approach to increase the micronutrient content in staple food crops. The systematic efforts directed towards micronutrient improvement are in pipeline for major cereals. Nutrition-rich cereals such as rice are importantly considered for zinc and iron biofortification. As it is known that zinc deficiency is most critical not only for weakening the functional and structural integrity of immune systems but also for hampering growth and development. This deficiency is found in one-third of the world's population and it is associated with a higher mortality rate in children (Woods *et al.,* 2020). Zinc malnutrition was found to be a major concern in developing countries like India where rice is a staple food crop (Majumder *et al*., 2019).

Breeding rice varieties with high grain Zn has been suggested to be a sustainable, targeted, food-based and cost-effective approach in alleviating Zn deficiency. To develop and popularise the zinc biofortified rice varieties with combined nutritional education can help to retard increasing rates of micronutrient deficiency (Herrington *et al.,* 2019). A final product as a biofortified variety requires an understanding of the nature of inheritance and heterosis for micronutrients which can be useful for boosting breeding efficiency. (Govindaraj *et al*., 2013). Hence, in plant breeding programs, heterosis is considered one of the greatest achievements and the performance of hybrids can be used for commercial exploitation and can be released as a variety when promising recombinants attained homozygosity. The term heterosis was coined by Shull in 1914, who described it as the F_1's superiority, which showed increased or decreased vigor, yield and other attributes over the mid parent value or better parent value, whereas standard heterosis (F_1 performance over standard check variety) is more important than heterobeltiosis / better parental heterosis (heterosis over better parent) and average heterosis (heterosis over mid parent). The F_1 hybrids can be commercially exploited and/or used in subsequent generations to identify suitable cross combinations to release the best variety when homozygosity has been reached Positive heterosis is generally desired for yield, Zn content and negative heterosis for earliness (Nuruzzaman *et al*., 2002). The expression of heterosis varies with cross combinations as well as characters. Still, with an increase in the high yielding varieties with efficient zinc content it is necessary to study the heterotic effect of zinc with donors. With this basic information, the present study was conducted with 30 hybrids generated from Line x Tester mating design from crossing 6 lines with 5 pollen parents along with two checks.

MATERIALS AND METHODS

The experiment was conducted at Agricultural Research Farm, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi, India. during *Kharif*, 2019. The crossing was effected between the lines and testers in the Line x Tester mating design of Kempthorne (1957) to develop hybrids. The experimental material consisting of 30 F_1 hybrids generated by Line x Tester mating design from 6 lines and 5 testers during season *Kharif* 2018 along with two standard checks BPT-5204 (check used for yield) and DRR dhan-45 (check used for Zinc) in a Randomized Complete Block Design (RCBD) with three replications. The list of parents and the hybrids obtained by crossing the parents are presented in **Table 1**.

Table 1. List of Lines, Testers and their hybrids evaluated in the present study

S. No.	Entry	S. No.	Entry
	Lines	20	HUR-1304 × URG-30
1	NDR 359	21	RAJENRDA KANSTURI × URG-30
2	HUR 1309	22	VANDANA × URG-30
3	HUR 1304	23	HUR-3022 × URG-30
4	RAJENRDA KASTURI	24	NDR 359 × IR 91143-AC-293-1
5	VANDANA	25	HUR-1309 × IR 91143-AC-293-1
6	HUR-3022	26	VANDANA × IR 91143-AC-293-1
	Testers	27	HUR-3022 × IR 91143-AC-293-1
7	SATHI	28	NDR-359 × IR 91143-AC-290-1
8	URG-30	29	HUR 1309 × IR 91143-AC-290-1
9	IR 91143-AC-293-1	30	HUR-1304 × IR 91143-AC-290-1
10	IR 91143-AC-290-1	31	RAJENRDA KASTURI × IR 91143-AC-290-1
11	DUDHKANDER	32	HUR-3022 × IR 91143-AC-290-1
	Hybrids	33	NDR 369 × DUDHKANDER
12	NDR 359 × SATHI	34	HUR-1309 × DUDHKANDER
13	HUR-1309 × SATHI	35	HUR-1304 × DUDHKANDER
14	HUR-1304 × SATHI	36	RAJENRDA KASTURI × DUDHKANDER
15	RAJENRDA KASTURI × SATHI	37	VANADANA× DUDHKANDER
16	VANADANA × SATHI	38	HUR 3022 × DUDHKANDER
17	HUR-3022 ×SATHI		**Checks**
18	NDR 359 × URG-30	39	BPT-5204 (Check for grain yield)
19	HUR 1309 × URG-30	40	DRR DHAN-45 (Check for Zinc)

Twenty one day's old seedlings were transplanted in the main field with a spacing of 20 x 15 cm. All the recommended agronomic practices from transplanting to harvesting were followed correctly to raise a healthy crop. Morphological data were recorded for sixteen quantitative characters *viz.* days to 1st flowering, days to 50% flowering, days to maturity, plant height, the number of effective tillers per plant, panicle length, the number of grains per panicle, spikelet fertility percentage, 1000-grain weight, grain L/B ratio, kernel L/B ratio, grain yield per plant, grain yield per plot, biomass, harvest index and grain Zn content. For most of the traits data was recorded on five randomly selected plants in each plot in every replication whereas, the data for days to 1st flowering, days to 50% flowering, days to maturity, grain yield per plot, biomass and harvest index were collected on a plot basis. Zinc content was estimated using Brown rice grain with energy dispersive X-ray fluorescence spectrophotometer (ED - XRF) instrument at IRRI-SAH, Hyderabad, India. Heterosis was estimated from mean values obtained from each replication according to Fehr (1987) and t-test was performed.

RESULTS AND DISCUSSION

Analysis of variance presented in **Table 2**, exhibited significant differences among different lines for various characters under study, days to 1st flowering, days to 50% flowering, days to maturity, plant height, effective tillers per plant, panicle length, the number of grains per panicle, spikelet fertility %, 1000-grain weight, grain L/B ratio, kernel L/B ratio, grain yield per plant, grain yield per plot, biomass, harvest index and grain Zn content and similar result for variances among testers. The variances among crosses were highly significant for all crosses except plant height. This showed that there is sufficient variability in the material included in the study and can be exploited. These findings confirm with the reports of Bisne *et al.* (2009)**,** Karthikeyan *et al.* (2010), Saidaiah *et al.* (2011) who reported significant variability for different yield and yield contributing attributes in genotypes of rice.

Heterosis is the F_1's superiority, which shows increased or decreased performance over better parent value (heterobeltiosis) and standard heterosis (standard check variety). The results obtained from the experimental

Table 2. Analysis of variance for different characters in rice

Source of variation	Df	Days to 1st flowering	Days to 50% flowering	Days to maturity	Plant height	Number of effective tillers	Panicle length	Number of grains per panicle	Spikelet fertility
Replicates	2	71.892**	14.128**	6.274	26.945	6.223**	2.515	57.544	6.318**
Parents	10	212.933**	197.006**	168.455**	384.774**	11.447**	13.143**	10326.14**	97.232**
Lines	5	181.789**	138.8**	125.256**	496.936**	8.999**	11.338**	10531.9**	83.176**
Testers	4	191.48**	214.933**	224.767**	330.299**	14.759**	15.392**	3665.315**	82.343**
Lines *vs* Testers	1	454.789**	416.327**	159.201**	41.865	10.441**	13.176**	35940.63**	227.073**
Parents *vs* Hybrids	1	2.958	13.711	83.093**	1936.787**	48.426**	34.581**	1613.948**	1391.501**
Hybrids	29	135.054**	92.666**	75.355**	434.212**	14.522**	18.907**	1568.659**	557.063**
Error	80	7.030	4.920	5.770	13.332	1.008	1.270	95.716	6.569

Source of variation	Df	1000-grain weight	Grain L/ B ratio	Grain yield per plant	Yield per plot	Biomass	Harvest index	Grain Zn content
Replicates	2	0.376	0.066	1.615	3270.958	12.330	0.000	0.832
Parents	10	77.304**	1.598**	217.752 **	440946.800 **	1650.738 **	0.002 **	124.442 **
Lines	5	134.703**	1.879**	330.325 **	668908.100 **	2405.717 **	0.002 **	10.785 **
Testers	4	20.194**	1.187**	126.558 **	256280.600 **	1051.523 **	0.002 **	17.196 **
Lines vs Testers	1	18.749**	1.839**	19.657 **	39805.060 **	272.701 **	0.004 **	1121.712 **
Parents vs Hybrids	1	167.176**	0.012	177.834 **	360113.600 **	1117.429 **	0.000	197.999 **
Hybrids	29	28.965**	1.389**	119.882 **	242761.200 **	856.284 **	0.001 **	62.375 **
Error	80	0.psp484	0.032	2.127	4307.353	11.654	0.000	1.488

** Significant at 1% level of probability, df = Degrees of freedom

Table 3. Percentage heterosis of F_1 crosses over better parent for various characters in rice

Crosses	Days to 50% flowering	Days to maturity	Plant height	Number. of effective tillers	Panicle length	Number of grains per panicle	Spikelet fertility	1000-grain weight	Grain L/B ratio	Kernel L/B ratio	Yield per plant	Biomass	Zn Content
NDR359 x Sathi	-16.22 **	-14.39 **	-0.34	12.04	-11.87 **	-58.89 **	-47.46 **	-3.35	-5.54	-3.35	-37.39 **	-44.00 **	-32.27 **
NDR359 x URG-30	-9.61 **	-9.83 **	8.89 **	-6.12	-3.77	-20.71 **	-15.80 **	-9.92 **	-10.18 *	-4.57	0.87	-10.92 *	-15.64 **
NDR359 x IR 91143 AC 293-1	-2.70	-6.47 **	6.56 *	-2.67	0.34	-32.98 **	1.45	-6.32 **	-4.58	-1.78	17.89 **	17.38 **	-23.26 **
NDR359 x IR 91143 AC 290-1	0.00	-2.16	0.40	8.00	4.22	-14.58 *	1.36	-1.12	0.77	-2.07	-8.66	-19.99 **	-16.13 **
NDR359 x Dudhkander	-10.81 **	-10.31 **	3.71	29.33 **	7.30 *	-34.51 **	-11.76 **	3.75	-7.65	1.36	-15.65 *	-24.00 **	-2.48
HUR-1309 x Sathi	-2.28	0.26	4.50	-8.33	-5.16	-37.85 **	-51.63 **	-7.45 **	-8.05 **	-7.76 **	-77.99 **	-80.69 **	-6.86
HUR-1309 x URG-30	-5.54 **	-2.60	12.66 **	8.16	1.24	-8.78	-19.66 **	-5.22 *	-33.26 **	-30.54 **	-41.63 **	-45.19 **	-28.26 **
HUR-1309 x IR 91143 AC 293-1	0.33	-1.55	-1.72	22.54 *	-0.86	-11.44	3.70	6.95 **	-5.23	-11.76 **	-59.33 **	-59.02 **	5.02
HUR-1309 x IR 91143 AC 290-1	-3.74 *	-3.98 **	18.19 **	15.28	7.73 *	-12.72	-9.39 **	-11.21 **	-4.82	-7.89 **	-16.27 **	-16.33 **	-34.06 **
HUR-1309 x Dudhkander	-1.95	0.26	-1.03	19.67	5.13	-11.08	-9.20 **	2.73	-9.80 **	-3.71 *	-59.33 **	-59.67 **	-24.95 **
HUR-1304 x Sathi	-6.25 **	0.79	9.06 **	0.00	10.56 **	-37.32 **	-9.03 **	18.49 **	-8.33 *	-11.96 **	21.43 *	24.60 **	0.25
HUR-1304 x URG-30	-0.33	1.05	-12.21 **	-38.78 **	4.20	-45.20 **	-13.25 **	8.08 **	-23.45 **	-24.20 **	35.82 **	30.55 **	-15.21 **
HUR-1304 x IR 91143 AC 293-1	-3.92 *	-0.65	7.30 *	18.31	5.85	-41.26 **	2.04	7.46 **	-15.55 **	-17.16 **	-28.46 **	-24.45 **	-10.21 **
HUR-1304 x IR 91143 AC 290-1	-4.98 **	-3.23 *	3.02	-19.44	3.75	-5.02	-3.66	-4.56 *	-1.76	2.06	-36.22 **	-38.00 **	-29.00 **
HUR-1304 x Dudhkander	4.93 **	3.42 *	-30.00 **	-3.08	-12.05 **	-15.51 *	-10.73 **	-1.20	-22.23 **	-7.39 **	119.40 **	108.36 **	-24.02 **
Rajendra kasturi x Sathi	0.30	6.81 **	-3.68	-34.26 **	-3.26	-73.78 **	-51.40 **	34.38 **	6.35	9.41 **	-60.59 **	-66.97 **	-7.62 *
Rajendra kasturi x URG-30	-6.06 **	1.57	12.76 **	2.94	2.39	-50.09 **	-15.50 **	-1.49	-11.06 *	-7.80 *	72.33 **	76.99 **	-5.50
Rajendra kasturi x IR 91143 AC 293-1	-2.88	3.11 *	4.54	-13.73	-4.59	-61.93 **	-23.34 **	4.76	-4.21	1.30	-26.84 **	-23.72 **	-8.61 *
Rajendra kasturi x IR 91143 AC 290-1	-2.73	-0.25	3.21	-36.27 **	-1.31	-40.53 **	2.08	-17.40 **	40.57 **	30.91 **	6.30	0.14	-0.84
Rajendra kasturi x Dudhkander	-2.73	1.05	4.27	-2.94	14.67 **	-48.46 **	-9.46 **	11.68 **	-13.83 **	-18.52 **	52.94 **	52.84 **	-21.43 **
Vandana x Sathi	-2.53	-0.84	-11.79 **	-9.26	-19.65 **	17.00	-9.45 **	-10.88 **	-14.48 **	-12.16 **	91.43 **	107.14 **	22.62 **
Vandana x URG-30	3.41	3.49 *	-6.29 *	-7.14	-1.89	3.95	-4.20	-28.68 **	-12.82 **	-11.44 **	10.64	8.51	-47.68 **
Vandana x IR 91143 AC 293-1	-3.27	-0.52	0.12	-2.82	-3.95	1.12	-2.91	-14.05 **	-12.86 **	-7.58 **	2.44	7.19	10.49 **
Vandana x IR 91143 AC 290-1	-6.70 **	-4.23 **	-3.09	11.11	-12.04 **	-31.67 **	-1.75	-21.37 **	-13.82 **	-17.03 **	-29.92 **	-31.38 **	-12.52 **
Vandana x Dudhkander	-0.36	-1.12	9.55 **	51.52 **	1.09	1.66	-32.19 **	-6.74 **	-8.50 *	-0.06	-12.90	0.10	-9.21 **
HUR-3022 x Sathi	0.32	3.98 *	16.51 **	18.52 **	4.66	3.19	-2.84	23.25 **	3.14	-0.01	112.86 **	123.94 **	38.37 **
HUR-3022 x URG-30	-14.92 **	-9.28 **	0.66	30.61 **	-1.93	-32.63 **	-26.94 **	0.02	-19.06 **	-18.82 **	117.95 **	146.36 **	-29.88 **
HUR-3022 x IR 91143 AC 293-1	-3.81 *	-0.52	9.35 **	-5.63	2.30	7.04	11.90 **	17.97 **	-2.24	-2.81	-16.26 **	-19.19 **	-0.80
HUR-3022 x IR 91143 AC 290-1	-2.80	-6.97 **	3.83	15.28	-5.98	-26.95 **	1.47	-3.22	-5.48	-0.69	-25.98 **	-28.75 **	-4.91
HUR-3022 x Dudhkander	-1.27	3.18 *	11.29 **	91.94 **	12.21 **	16.44 *	-6.92 **	26.28 **	-22.24 **	-13.20 **	214.03 **	225.12 **	-12.84 **

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

findings for yield, yield-related traits and grain Zinc content was computed over better parents (heterobeltiosis) and presented in **Table 3** and for standard heterosis over both checks (BPT-5204 and DRR dhan-45) is presented in **Table 4a** and **Table 4b.**

The major breakthrough is on the development of short duration varieties for north India which having high intensity, crop rotation areas and where the majority rice growing area is under assured irrigation. Negative heterosis for days to 1st flowering is desirable. Among 30 hybrids, thirteen hybrids exhibited significant negative heterosis over the better parent. The highest significant negative heterosis was recorded over better parents by cross NDR-359 x Sathi. For standard heterosis over both BPT-5204 and DRR dhan-45, all 30 hybrids showed significant negative heterosis. The highest significant negative heterosis over both BPT-5204 and DRR dhan-45 was recorded by cross HUR-3022 x URG-30. T. Similar findings reported by Eradasappa *et al*. (2007), Venkatesan *et al*. (2008) and Sahu *et al.* (2017).

Negative heterosis in a positive direction for earliness is preferred with respect to days to 50% flowering among 30 hybrids, thirteen hybrids showed significant negative heterosis over the better parent. The highest significant negative heterosis for heterobeltiosis by cross NDR-359 x Sathi. For standard heterosis over BPT-5204 and DRR dhan-45 all hybrids showed significant negative heterosis. The highest negative significant heterosis over both BPT-5204 and DRR dhan-45 was recorded by cross HUR-3022 x URG-30. Similar findings were reported by Eradasappa *et al*. (2007), Venkatesan *et al*. (2008), Chougule *et al.* (2012), Bhati *et al.*(2015) and Sahu *et al.* (2017). Nine hybrids showed significant negative heterobeltiosis for days to maturity. The highest significant negative heterosis over better parent was recorded by cross NDR-359 x Sathi. The standard heterosis over BPT-5204 and DRR dhan-45, all hybrids showed significant negative heterosis. The highest negative significant heterosis over both BPT-5204 and DRR dhan-45 was exhibited by cross HUR-3022 x URG-30. Similar results were reported by Eradasappa *et al*. (2007), Venkatesan *et al*. (2008), Chougule *et al.* (2012), Bhati *et al.* (2015) and Sahu *et al.* (2017).

Short height is preferred over tall varieties in breeding. Dwarf varieties are desirable against lodging whereas tall varieties are desirable for straw purposes. So, the selection for plant height can be significant in either of the direction based on the objective of the breeder. Where dwarf variety is preferred, heterosis in the negative direction is useful, among 30 hybrids, four hybrids showed significant negative heterosis over the better parent. The highest significant negative heterosis over better parent was recorded by cross HUR-1304 x Dudhkander. Standard negative heterosis over BPT-5204, by one cross and three crosses over DRR dhan-45. The highest negative significant heterosis over DRR dhan-45 was recorded by cross HUR-1304 x Dudhkander over both BPT-5204 and DRR dhan-45. These results are in conformity with the results of Khoyumthem *et al*. (2005) and Vanisree *et al.* (2011).

The number of effective tillers directly have influence the yield component. A total of six hybrids exhibited significant positive for heterobeltiosis. The highest significant positive heterosis over better parent was recorded by cross HUR-3022 x URG-30. Standard heterosis over BPT-5204, twenty hybrids showed significant positive heterosis and over DRR dhan- 45, none with significant positive heterosis. The highest positive heterosis over DRR dhan-45 was recorded by cross HUR-3022 x Sathi and HU-3022 x URG-30. These results are in conformity with reports by Khoyumthem *et al*. (2005), Soni *et al*. (2005) and Vanisree *et al.* (2011) and Ambikabathy *et al.* (2019). Twelve hybrids exhibited significant positive performance over better parents for plant height. The highest significance positive heterosis over better parent by cross Rajendra kasturi x Dudhkander. Standard heterosis over BPT-5204, twenty five hybrids showed significant positive heterosis and fifteen showed significant positive heterosis over DRR dhan-45. The highest positive significant heterosis over both BPT-5204 and DRR dhan-45 was recorded by cross HUR-1309 x IR 91143AC 290-1. Khoyumthem *et al.* (2005), Soni *et al*. (2005) and Pandya and Tripathi (2006), Ambikabathy *et al.* (2019) and Sundaram *et al.* (2019) reported similar findings.

The cross Vandana x Sathi showed the highest significant positive over better parent for the number of grains per panicle. Standard heterosis over BPT-5204, one hybrid showed significant positive heterosis and none showed significant positive heterosis over DRR dhan-45. The highest positive heterosis over BPT-5204 was recorded by cross Rajendra kasturi x IR 91143 AC 290-1 and over DRR dhan-45 was recorded by cross Rajendra kasturi x IR 91143 AC 290-1.

Among 30 hybrids, one hybrid showed significant positive heterobeltiosis for spiklet fertilty. The highest significant positive heterosis over better parent was recorded by cross HUR- 3022 x IR 91143 290-1. Standard heterosis over BPT-5204, eight hybrids showed significant positive heterosis and none showed significant positive heterosis over DRR dhan-45. The highest positive heterosis over BPT-5204 was recorded by cross NDR-359 x IR 91143 AC 293-1. Heterosis in a positive direction was also reported by Soni *et al*. (2005).

With respect to 1000-grain weight among 30 hybrids, nine hybrids exhibited significant positive heterosis over the better parent. The cross Rajendra kasturi x Sathi exhibited the highest significant positive over the better parent. Standard heterosis over BPT-5204, all hybrids showed significant positive heterosis and twenty nine over DRR

Table 4a. Percentage heterosis of F_1 crosses over standard checks for various characters in rice

Crosses	Days to 50% flowering		Days to maturity		Plant height		Number of effective tillers		Panicle length		Number of grains per panicle		Spikelet fertility	
	BPT-5204	DRR dhan-45	BPT-5204	DRR dhan-45	BPT-5204	DRR dhan-45	BPT-5204	DRR dhan-45	BPT-5204	DRR dhan-45	BPT-5204	DRR dhan-45	BPT-5204	DRR dhan-45
NDR359 x Sathi	-25.60 **	-23.77 **	-21.02 **	-18.49 **	28.65 **	24.30 **	83.33 **	3.42	12.89 **	1.73	-59.13 **	-59.00 **	-40.19 **	-44.35 **
NDR359 x URG-30	-19.73 **	-17.76 **	-16.81 **	-14.16 **	32.82 **	28.33 **	39.39 **	-21.37 **	23.26 **	11.08 **	-21.17 **	-20.93 **	-4.35	-11.00 **
NDR359 x IR 91143 AC 293-1	-13.60 **	-11.48 **	-13.72 **	-10.96 **	29.98 **	25.58 **	10.61	-37.61 **	28.52 **	15.83 **	-33.37 **	-33.16 **	12.35 **	4.53
NDR359 x IR 91143 AC 290-1	-11.20 **	-9.02 **	-9.73 **	-6.85 **	22.47 **	18.32 **	22.73 *	-30.77 **	33.49 **	20.30 **	-15.07 **	-14.81 *	12.25 **	4.44
NDR359 x Dudhkander	-20.80 **	-18.85 **	-17.26 **	-14.61 **	48.13 **	43.12 **	46.97 **	-17.09 **	37.44 **	23.86 **	-34.89 **	-34.68 **	-2.28	-9.08 **
HUR-1309 x Sathi	-20.00 **	-18.03 **	-14.82 **	-12.10 **	34.89 **	30.33 **	50.00 **	-15.38 *	22.79 **	10.66 **	-45.53 **	-45.36 **	-44.94 **	-48.77 **
HUR-1309 x URG-30	-22.67 **	-20.77 **	-17.26 **	-14.61 **	33.93 **	29.40 **	60.61 **	-9.40	31.07 **	18.12 **	-20.05 **	-19.80 **	-8.74 **	-15.09 **
HUR-1309 x IR 91143 AC 293-1	-17.87 **	-15.85 **	-15.93 **	-13.24 **	16.83 **	12.88 **	31.82 **	-25.64 **	28.34 **	15.66 **	-22.38 **	-22.14 **	11.37 **	3.61
HUR-1309 x IR 91143 AC 290-1	-17.60 **	-15.57 **	-14.60 **	-11.87 **	40.50 **	35.75 **	25.76 *	-29.06 **	39.47 **	25.69 **	-23.50 **	-23.27 **	-2.69	-9.46 **
HUR-1309 x Dudhkander	-19.73 **	-17.76 **	-14.82 **	-12.10 **	41.37 **	36.59 **	10.61	-37.61 **	36.10 **	22.65 **	-22.07 **	-21.82 **	-1.75	-8.59 **
HUR-1304 x Sathi	-24.00 **	-22.13 **	-15.27 **	-12.56 **	40.77 **	36.01 **	63.64 **	-7.69	26.82 **	14.29 **	-49.30 **	-49.14 **	3.57	-3.64
HUR-1304 x URG-30	-19.20 **	-17.21 **	-15.04 **	-12.33 **	3.84	0.33	-9.09	-48.72 **	19.52 **	7.71	-55.67 **	-55.53 **	-1.45	-8.31 **
HUR-1304 x IR 91143 AC 293-1	-21.60 **	-19.67 **	-15.15 **	-12.44 **	22.31 **	18.17 **	27.27 *	-28.21 **	23.17 **	11.00 **	-52.49 **	-52.34 **	1.06	-5.98 *
HUR-1304 x IR 91143 AC 290-1	-18.67 **	-16.67 **	-13.94 **	-11.19 **	16.99 **	13.03 **	-12.12	-50.43 **	27.33 **	14.75 **	-20.59 **	-20.34 **	2.06	-5.05 *
HUR-1304 x Dudhkander	-14.93 **	-12.84 **	-13.05 **	-10.27 **	-0.01	-3.39	-4.55	-46.15 **	3.81	-6.45	-31.66 **	-31.45 **	-3.41	-10.13 **
Rajendra kasturi x Sathi	-11.73 **	-9.56 **	-9.73 **	-6.85 **	27.92 **	23.59 **	7.58	-39.32 **	7.87	-2.79	-55.05 **	-54.91 **	-44.67 **	-48.52 **
Rajendra kasturi x URG-30	-17.33 **	-15.30 **	-14.16 **	-11.42 **	49.76 **	44.69 **	59.09 **	-10.26	14.17 **	2.89	-14.45 *	-14.19 *	-4.01	-10.69 **
Rajendra kasturi x IR 91143 AC 293-1	-14.53 **	-12.43 **	-11.95 **	-9.13 **	38.84 **	34.14 **	33.33 **	-24.79 **	11.02 *	0.05	-34.75 **	-34.55 **	-24.34 **	-29.60 **
Rajendra kasturi x IR 91143 AC 290-1	-14.40 **	-12.30 **	-11.28 **	-8.45 **	37.07 **	32.43 **	-1.52	-44.44 **	21.12 **	9.16 *	1.94	2.26	8.14 **	0.61
Rajendra kasturi x Dudhkander	-14.40 **	-12.30 **	-14.60 **	-11.87 **	48.94 **	43.91 **	50.00 **	-15.38 *	35.34 **	21.97 **	-11.66 *	-11.38 *	-2.04	-8.86 **
Vandana x Sathi	-28.00 **	-26.23 **	-21.68 **	-19.18 **	25.31 **	21.07 **	48.48 **	-16.24 *	-14.71 **	-23.13 **	-42.50 **	-42.32 **	3.09	-4.08
Vandana x URG-30	-19.20 **	-17.21 **	-14.60 **	-11.87 **	33.11 **	28.61 **	37.88 **	-22.22 **	4.14	-6.14	-48.91 **	-48.75 **	8.83 **	1.25
Vandana x IR 91143 AC 293-1	-21.07 **	-19.13 **	-15.04 **	-12.33 **	42.22 **	37.41 **	4.55	-41.03 **	11.76 *	0.72	-36.83 **	-36.63 **	-0.66	-7.57 **
Vandana x IR 91143 AC 290-1	-20.13 **	-18.17 **	-14.82 **	-12.10 **	37.66 **	33.01 **	21.21	-31.62 **	7.95	-2.71	-42.87 **	-42.69 **	4.08	-3.16
Vandana x Dudhkander	-26.40 **	-24.59 **	-21.90 **	-19.41 **	56.48 **	51.18 **	51.52 **	-14.53 *	19.31 **	7.52	-50.04 **	-49.88 **	-26.62 **	-31.73 **
HUR-3022 x Sathi	-15.73 **	-13.66 **	-13.27 **	-10.50 **	50.39 **	45.30 **	93.94 **	9.40	19.65 **	7.83	-21.99 **	-21.75 **	10.61 **	2.91
HUR-3022 x URG-30	-28.53 **	-26.78 **	-24.34 **	-21.92 **	19.06 **	15.04 **	93.94 **	9.40	12.11 **	1.04	-49.07 **	-48.91 **	-17.00 **	-22.78 **
HUR-3022 x IR 91143 AC 293-1	-19.20 **	-17.21 **	-15.04 **	-12.33 **	24.65 **	20.43 **	1.52	-42.74 **	19.04 **	7.28	-19.08 **	-18.82 **	10.44 **	2.75
HUR-3022 x IR 91143 AC 290-1	-16.80 **	-14.75 **	-17.26 **	-14.61 **	17.91 **	13.92 **	25.76 *	-29.06 **	15.39 **	3.99	-38.93 **	-38.74 **	7.49 **	0.01
HUR-3022 x Dudhkander	-17.07 **	-15.03 **	-13.94 **	-11.19 **	58.96 **	53.59 **	80.30 **	1.71	32.43 **	19.35 **	-11.97 *	-11.69 *	0.72	-6.30 **

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

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Table 4b. Percentage heterosis of F_1 crosses over standard checks for various characters in rice

Crosses	1000-grain weight		Grain L/B Ratio		Kernel L/B Ratio		Yield per plant		Biomass		Harvest index		Grain Zinc content	
	BPT-5204	DRR dhan-45	BPT-5204	DRR dhan-45	BPT-5204	DRR dhan-45	BPT-5204	DRR dhan-45	BPT-5204	DRR dhan-45	BPT-5204	DRR dhan-45	BPT-5204	DRR dhan-45
NDR359 x Sathi	84.50 **	49.68 **	5.84	29.66 **	-7.23 **	37.60 **	16.13	-48.20 **	10.36	-51.57 **	5.77	6.51 *	-17.08 **	-21.56 **
NDR359 x URG-30	71.95 **	39.50 **	-11.53 **	8.38	-26.62 **	8.84 **	87.10 **	-16.55 **	75.54 **	-22.97 **	7.64 *	8.39 *	21.66 **	15.08 **
NDR359 x IR 91143 AC 293-1	78.83 **	45.08 **	-6.03	15.12 **	-21.64 **	16.23 **	133.87 **	4.32	133.44 **	2.44	0.73	1.43	4.70	-0.96
NDR359 x IR 91143 AC 290-1	88.76 **	53.13 **	-0.03	22.47 **	-15.56 **	25.25 **	87.10 **	-16.55 **	74.77 **	-23.31 **	7.71 *	8.46 *	8.43	2.58
NDR359 x Dudhkander	98.05 **	60.67 **	-9.04 *	11.43 *	-22.06 **	15.60 **	56.45 **	-30.22 **	49.76 **	-34.29 **	5.07	5.80	46.55 **	38.63 **
HUR-1309 x Sathi	65.55 **	34.31 **	26.66 **	55.17 **	5.39 *	56.32 **	-25.81 *	-66.91 **	-32.91 **	-70.56 **	11.19 **	11.96 **	14.03 **	7.87
HUR-1309 x URG-30	69.54 **	37.54 **	-8.07 *	12.62 **	-20.64 **	17.71 **	96.77 **	-12.23 *	90.43 **	-16.44 **	3.97	4.69	3.45	-2.13
HUR-1309 x IR 91143 AC 293-1	91.32 **	55.21 **	30.54 **	59.92 **	0.81	49.53 **	37.10 **	-38.85 **	42.38 **	-37.52 **	-3.20	-2.53	43.28 **	35.54 **
HUR-1309 x IR 91143 AC 290-1	58.82 **	28.85 **	31.10 **	60.61 **	5.23 *	56.09 **	182.26 **	25.90 **	190.69 **	27.56 **	-2.39	-1.71	-14.75 **	-19.35 **
HUR-1309 x Dudhkander	83.76 **	49.08 **	24.25 **	52.21 **	10.01 **	63.18 **	37.10 **	-38.85 **	40.12 **	-38.51 **	-1.53	-0.85	12.79 **	6.70
HUR-1304 x Sathi	69.35 **	37.39 **	2.70	25.82 **	-15.50 **	25.34 **	37.10 **	-38.85 **	46.74 **	-35.61 **	-6.50 *	-5.85	22.74 **	16.11 **
HUR-1304 x URG-30	46.78 **	19.08 **	-14.87 **	4.29	-28.73 **	5.72	46.77 **	-34.53 **	53.74 **	-32.54 **	-3.98	-3.31	22.28 **	15.67 **
HUR-1304 x IR 91143 AC 293-1	58.07 **	28.23 **	-6.08	15.05 **	-22.11 **	15.53 **	41.94 **	-36.69 **	50.24 **	-34.07 **	-5.24	-4.58	22.51 **	15.89 **
HUR-1304 x IR 91143 AC 290-1	55.36 **	26.04 **	9.25 *	33.84 **	-4.04	42.34 **	30.65 *	-41.73 **	35.43 **	-40.57 **	-2.97	-2.29	-8.21	-13.17 **
HUR-1304 x Dudhkander	46.95 **	19.21 **	-13.52 **	5.95	-12.93 **	29.16 **	137.10 **	5.76	145.39 **	7.68	-2.81	-2.14	14.19 **	8.02
Rajendra kasturi x Sathi	92.05 **	55.80 **	19.15 **	45.96 **	5.01 *	55.76 **	-45.97 **	-75.90 **	-52.29 **	-79.06 **	13.91 **	14.70 **	13.10 **	6.99
Rajendra kasturi x URG-30	16.15 **	-5.77	-33.86 **	-18.98 **	-43.37 **	-16.01 **	136.26 **	5.38	155.67 **	12.19 **	-7.07 *	-6.43	36.28 **	28.92 **
Rajendra kasturi x IR 91143 AC 293-1	54.10 **	25.02 **	-7.36	13.49 **	-19.18 **	19.88 **	45.15 **	-35.26 **	51.69 **	-33.44 **	3.42	4.13	24.69 **	17.95 **
Rajendra kasturi x IR 91143 AC 290-1	34.47 **	9.09 **	39.45 **	70.84 **	12.88 **	67.43 **	117.74 **	-2.88	118.74 **	-4.02	0.10	0.79	28.19 **	21.27 **
Rajendra kasturi x Dudhkander	66.10 **	34.75 **	-25.46 **	-8.68	-38.17 **	-8.28 **	109.68 **	-6.47	120.79 **	-3.12	-4.55	-3.89	18.08 **	11.70 *
Vandana x Sathi	71.81 **	39.38 **	-4.18	17.38 **	-15.69 **	25.06 **	116.13 **	-3.60	126.90 **	-0.44	-4.06	-3.40	50.12 **	42.02 **
Vandana x URG-30	37.49 **	11.54 **	-14.49 **	4.76	-30.63 **	2.89	-16.13	-62.59 **	-13.42	-62.01 **	-2.51	-1.84	-24.55 **	-28.62 **
Vandana x IR 91143 AC 293-1	65.70 **	34.43 **	-14.53 **	4.70	-26.27 **	9.36 **	103.23 **	-9.35	113.18 **	-6.46	-4.11	-3.44	50.75 **	42.60 **
Vandana x IR 91143 AC 290-1	51.59 **	22.98 **	-14.51 **	4.73	-28.45 **	6.13	43.55 **	-35.97 **	49.88 **	-34.23 **	-3.31	-2.64	13.10 **	6.99
Vandana x Dudhkander	79.80 **	45.86 **	-10.25 **	9.95 *	-21.72 **	16.11 **	-12.90	-61.15 **	-5.04	-58.33 **	-8.09 *	-7.45 *	36.43 **	29.07 **
HUR-3022 x Sathi	76.15 **	42.90 **	15.56 **	41.57 **	-4.03	42.35 **	140.32 **	7.19	145.30 **	7.64	-1.56	-0.88	69.42 **	60.26 **
HUR-3022 x URG-30	37.47 **	11.52 **	-11.36 **	8.59	-24.48 **	12.01 **	37.10 **	-38.85 **	39.23 **	-38.91 **	-1.03	-0.34	1.12	-4.34
HUR-3022 x IR 91143 AC 293-1	73.53 **	40.78 **	7.06	31.15 **	-9.60 **	34.10 **	66.13 **	-25.90 **	60.71 **	-29.48 **	4.08	4.80	35.35 **	28.04 **
HUR-3022 x IR 91143 AC 290-1	57.54 **	27.81 **	3.51	26.81 **	-7.62 **	37.02 **	51.61 **	-32.37 **	55.62 **	-31.71 **	-2.11	-1.43	22.93 **	16.29 **
HUR-3022 x Dudhkander	87.81 **	52.37 **	-14.85 **	4.32	-19.26 **	19.76 **	214.03 **	40.07 **	208.41 **	35.33 **	2.36	3.07	30.99 **	23.91 **

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

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dhan-45. The highest positive heterosis over both BPT-5204 and DRR dhan-45 was recorded by cross NDR-359 X Dudhkander. Similar results of positive heterosis for 1000-grain weight are in conformity with findings of Rashid *et al.* (2007) and Devi *et al.* (2018). Rajendra kasturi x IR 91143 AC 290-1 identified with the highest significant positive heterosis over better parent for Grain L/B and Kernel L/B. Standard heterosis over BPT-5204, seven hybrids showed significant positive heterosis and twenty hybrids over DRR dhan-45. The highest positive heterosis over both BPT-5204 and DRR dhan-45 was recorded by cross Rajendra kasturi x IR 91143 AC 290-1. Similar findings of positive heterosis for L/B ratio were also reported by Gnanasekaran *et al.* (2006), Venkatesan *et al.* (2008) and Dalvi and Patel (2009).

Grain yield per plant and grain yield per plot is the most complex trait under influence of cumulative genes, from among 30 hybrids, ten hybrids showed significant positive heterosis over the better parent. The highest significant positive better parent heterosis was recorded by cross HUR-3022 x Dudhkander. Standard heterosis over BPT-5204, twenty five hybrids showed significant positive heterosis and two hybrids over DRR dhan-45. The highest positive heterosis over both BPT-5204 and DRR dhan-45 was recorded by cross HUR-3022 x Dudhkander. Similar findings were reported by Soni *et al*. (2005), Khoyumthem *et al.* (2005), Venkatesan *el al.* (2008), Dalvi and Patel (2009), Vanisree *et al.* (2011), Bhati *et al.* (2015) Devi *et al.* (2018), Ambikabathy *et al.* (2019) and Sundaram *et al.* (2019).

The highest significant positive heterosis over better parent was recorded by cross HUR-3022 x Dudhkander for biomass. Standard heterosis over BPT-5204, twenty five hybrids showed significant positive heterosis and three hybrids over DRR dhan-45. The highest positive heterosis over both BPT-5204 and DRR dhan-45 was recorded by cross HUR-3022 x Dudhkander. Similar results have been reported by Venkatesan *et al.* (2008), Dalvi and Patel (2009) and Vanisree *et al.* (2011). Harvest index indirectly influences the yield component by diversion of photosynthates to economical and non-economical parts. Among 30 hybrids, three hybrids showed significant positive heterosis over the better parent. The highest significant positive heterosis over better parent was recorded by cross NDR-359 x IR 91143 AC 290-1. Standard heterosis over BPT-5204, four hybrids showed significant positive heterosis and five hybrids over DRR dhan-45. The highest positive heterosis over both BPT-5204 and DRR dhan-45 was recorded by cross Rajendra kasturi x Sathi. Similar results are in conformity with Pandya and Tripathi (2006). For grain Zn among 30 hybrids, three crosses showed significant positive heterosis over the better parent. The highest significant positive heterosis over better parent recorded by cross HUR-3022 x Sathi. Standard heterosis over BPT- 5204, twenty two hybrids showed significant positive heterosis and seventeen hybrids over DRR dhan-45. The highest positive heterosis over both BPT-5204 and DRR dhan-45 was recorded by cross HUR-3022 x Sathi.

A best performing cross combinations should perform better than the locally available checks for yield attributes and grain Zn content. In present findings HUR-3022 x Dudhkander, HUR-1304 x Dudhkander and HUR-3022 x URG-30 were found to be the most promising hybrids for yield. HUR-3022 x Dudhkander exhibited standard heterosis of 214.03 and 40.07 per cent over checks BPT-5204 and DRR Dhan-45 for grain yield per plant respectively. The hybrid HUR-3022 x Sathi exhibited the highest positive economic heterosis of 69.42 and 60.26 per cent over BPT-5204 and DRR dhan-45 for grain Zn, respectively and these combinations have to be tested on a larger scale for commercial utilization.

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