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Dhanraj Meena
Department of Genetics and Plant Breeding, College of Agriculture G.B. Pant University of Agriculture and Technology, Pantnagar, Uttarakhand, India

Mukesh Kumar Karnwal
Department of Genetics and Plant Breeding, College of Agriculture G.B. Pant University of Agriculture and Technology, Pantnagar, Uttarakhand, India

Himanshu Chaudhary
Department of Genetics and Plant Breeding, College of Agriculture G.B. Pant University of Agriculture and Technology, Pantnagar, Uttarakhand, India

Sakshi Kashyap
Department of Genetics and Plant Breeding, College of Agriculture G.B. Pant University of Agriculture and Technology, Pantnagar, Uttarakhand, India

Neha Sachan
Department of Genetics and Plant Breeding, College of Agriculture G.B. Pant University of Agriculture and Technology, Pantnagar, Uttarakhand, India

Corresponding Author:
Dhanraj Meena
Department of Genetics and Plant Breeding, College of Agriculture G.B. Pant University of Agriculture and Technology, Pantnagar, Uttarakhand, India

Study of heterosis for yield and quality traits in rice (*Oryza sativa* L.) using line x tester mating system

Dhanraj Meena, Mukesh Kumar Karnwal, Himanshu Chaudhary, Sakshi Kashyap and Neha Sachan

Abstract

Heterotic performance of fifty one F_1s and their 20 parents were evaluated in randomized complete block design with three replications. Significant differences were observed among parents, hybrids and hybrids versus parents for most of the yield and yield related characters**.** On the basis of SCA effects, crosses UPRI 2008-6 × Pant Dhan 23, UPRI 2012-10 × Pant Dhan 26, *Kharif* 2011-SNo-1423 × Pant Dhan 26, *Kharif* 2015-SNo-1414 × Pant Dhan 4, Pant Dhan 18 × Pant Dhan 23 showed significant standard heterosis for various traits. These crosses can be included in future breeding programme to achieve better heterotic output for grain yield and most of the quality traits.

For grain yield per plant, *Kharif* 2015-SNo-1414×Pant Dhan 4 (16.608) exhibited highly significant positive standard heterosis over Govind (339.177) and Pant Dhan 4 (145.226) having Good × Poor gca effect of parents followed by *Kharif* 2011-SNo-1423×Pant Dhan 26 (13.348) with significant standard heterosis over Govind (316.463) and Pant Dhan 4 (132.543) having Good × Good gca effects of parents. Both the crosses exhibited high F_1 mean (72.170) and (68.437), respectively.

Keywords: Lines, testers, Line × Tester analysis, heterosis and rice (*Oryza sativa* L.)

Introduction

Rice (*Oryza sativa* L.) is the most popular cereal grains and is the staple food of about half of the world's population. More than 90% of rice is consumed in Asia. Therefore, rice plays an important role in ensuring food security and contributing to poverty and malnutrition alleviation in Asia and the world. Rice is the world's second most important cereal crop following only corn. The major objectives of rice breeding programme are to improve rice production and productivity to fulfill the growing mouth. Breeding for insect pest resistance, lodging resistance, wider adaptability to different environmental conditions are other breeding objectives ultimately leading to higher production. Heterosis breeding evolved as one of the most reliable way to break the yield plateau and achieve quantum jump in rice production worldwide. It has been found through several studies that inter sub-specific hybrid (indica × japonica) show high heterosis for grain yield than inter-varietal hybrids, therefore more emphasis is laid down on exploitation of inter sub-specific heterosis in rice because heterosis breeding become the backbone of modern plant breeding.

Heterosis (term coined by Shull, 1914) [16] is quantitatively defined as an upward deviation of the mid parent, based on the average of the value of two parents. Heterosis refers as superiority of F_1 hybrid to its either parent in most of the characters such as hybrid vigour, fitness, adaptability and other morphological characters. An offspring exhibits heterosis if its traits are enhanced as a result of mixing the genetic contributions of its parents. These effects can be due to Mendelian or non-Mendelian inheritance. Early discovery of heterosis in rice done by Jones (1926) [4]. Presence of heterosis and SCA effects for yield and its related traits in rice are reported by Roy and Mandel, (2001) [12]. Selection of appropriate parents by studying their heterosis still remains best option for increasing the breeding efficiency in identifying heterotic hybrids. By estimating the degree of heterosis, clues on desirable parents and heterotic hybrids in economic important yield traits may be found. Accordingly, the present investigation is undertaken to get an idea of nature and magnitude of heterosis to find out best heterotic hybrids for yield and quality traits in rice. Rice cultivation is well-suited to countries and regions with low labor costs and high rainfall, as it is labor-intensive to cultivate and requires ample water (Bora *et al*., 2020) [2].

Materials and Methods

- The experimental material consisted of twenty parents including 17 lines, 3 testers and two checks to generate fifty one hybrids for the evaluation of various quantitative and qualitative characters in rice by using line x tester mating design (Kempthorne, 1957) [5]. The crosses (51) along with their parents (20) and standard checks (2) were evaluated in a Randomized Complete Block Design (RCBD) with 3 replications at Norman E. Borlaug Crop Research Centre, Pantnagar, Uttarakhand during *Kharif* 2017.
- Twenty one days old seedling were transplanted in the main field in a single row of 2 m length and spacing of 30 cm was kept between two entries with plant to plant spacing of 15 cm. Observations were recorded on the whole plot basis for days to 50% flowering and days to maturity, However, plant height (cm), number of tillers per plant, panicle length (cm), number of filled grains per panicle, spikelet fertility (%), grain length (mm), grain width (mm), 1000 grain weight (g), kernel length (mm), kernel breadth (mm), kernel length/breadth ratio, hulling recovery (%), milling recovery (%), harvest index (%), alkali digestion value and grain yield per plant (g) were recorded on the basis of five randomly selected plants from the F_1 crosses, lines and the testers separately. The mean value for these plants were calculated and used for statistical analysis. Heterosis was estimated as the per cent change in F1 over better parent (Heterobeltiosis) and standard check (Standard heterosis) by method suggested by Turner (1953) [20]. The significance of different types of heterosis was carried out by adopting ‘t test’ as suggested by Nadarajan and Gunasekaran (2005) [9] as given below:

$$\text{Heterobeltiosis (\%)} = \frac{\overline{\text{F}}_{1\text{i}} - \overline{\text{BP}}_{\text{i}}}{\overline{\text{BP}}_{\text{i}}} \times 100$$

$$\text{Standard heterosis (\%)} = \frac{\overline{\text{F}}_{1\text{i}} - \overline{\text{SP}}_{\text{i}}}{\overline{\text{SP}}_{\text{i}}} \times 100$$

Where, BP- Better parent, SP- Standard parent

Results and Discussion

Analysis of variance indicated that variances due to treatments (parents+crosses) were highly significant for all the characters studied. The variance due to parents (lines, testers) and hybrids were highly significant for most of the characters (Table 1). Line × tester showed significant difference (p<0.01) for all the character under study except grain length, grain width, kernel length and breadth, L/B ratio and harvest index also reported by Latha *et al.* (2013) [7]. The significant differences between lines × testers interaction indicates that sca attributed heavily in the expression of these traits and demonstrates the importance of dominance or non-additive variances for all the traits studied (Thakare *et al.*, 2013) [18].

Table 1: Analysis of variance for line x tester analysis for various characters in rice genotypes

Source of variation	d.f.	Days to 50% flowering	Days to maturity	Plant height (cm)	Number of tillers per plant	Panicle length (cm)	Number of grains per panicle	Spikelet fertility (%)	1000 grain weight (g)	Grain length (mm)
Replication	2	1.967	6.412	110.869	4.725	8.052	32.450	65.164	12.768	0.078
Treatment	70	125.204**	98.611**	342.844**	74.617**	18.363**	7617.186**	804.451**	139.487**	0.688**
Crosses	50	93.991**	93.393**	373.255**	88.635**	20.758**	7622.535**	554.216**	116.474**	0.472
Lines	16	131.293**	107.753**	766.800**	123.638**	24.987**	16416.738**	877.925**	167.927**	0.949
Tester	2	180.810**	98.843**	195.930**	181.431**	10.261**	22757.376**	116.407**	4.347*	0.463
Line × Tester	32	69.915**	85.871**	187.563**	65.334**	19.301**	2279.506**	419.724**	97.756**	0.235
Error	100	5.667	6.805	20.007	15.565	6.922	9.013	2.567	24.519	0.033

Table 1: (Contd.)

Source of variation	d.f.	Grain width (mm)	Kernel length (mm)	Kernel breadth (mm)	L/B ratio	Harvest index	Hulling recovery (%)	Milling recovery (%)	Alkali digestion value	Grain yield per plant (g)
Replication	2	0.005	0.026	0.044	0.111	0.001	0.869	5.909	6.516	13.535
Treatment	70	0.982**	0.604**	0.442**	0.842**	0.240**	143.40**	139.05**	2.088**	610.086**
Crosses	50	0.078	0.568	0.043	0.050	0.021	112.910**	117.414**	1.799**	551.585**
Lines	16	0.080	0.895	0.073	0.110	0.033	206.552**	232.507**	3.429**	720.464**
Tester	2	0.013	0.364	0.007	0.028	0.011	100.497**	40.003**	2.693**	2,239.899**
Line × tester	32	0.081	0.418	0.031	0.022	0.015	66.865**	64.705**	0.929**	361.625**
Error	100	0.004	0.013	0.015	0.023	0.000	1.663	1.963	0.876	4.339

**Significant at 1% level, *Significant at 5% level

Commercial exploitation of hybrid vigour is feasible only if the vigour is in excess of prevailing better parent and standard parent (commercial check). As we know, the primary objective in plant breeding is to get higher grain yield per plant, therefore, emphasis was given in the present study for heterosis over better parent (heterobeltiosis) and standard parent/check (standard heterosis). Standard heterosis is desirable for the breeder point of view.

Quantitative traits- For grain yield per plant, heterobeltiosis ranged from -43.740 to 174.581 and standard heterosis ranged from 5.175 to 373.216. The cross combinations *Kharif*2015-SNo-1414 × Pant Dhan 4 (174.581) exhibited highest significant positive heterosis over better parent and the crosses *viz.*, Pant Dhan 22 × Pant Dhan 26 (373.216), *Kharif*2015-SNo-1414 × Pant Dhan 4 (339.177) exhibited highest significant positive standard heterosis over the commercial check Govind and Pant Dhan 22 × Pant Dhan 26 (164.233) over standard parent Pant Dhan 4 (Table 2). Similar findings were reported by Virmani *et al.* (1982) [22], Priyanka *et al.* (2017) [11], Bhatti *et al.* (2015) [1] and Premkumar *et al.* (2017) [10] for grain yield per plant.

Early flowering and early maturity is always desirable traits in heterosis breeding programme. Maximum desirable heterosis for days to 50% flowering was observed in crosses NDR3012 × Pant Dhan 4, 23 & 26 (-17.544), JGL1172-7 × Pant Dhan 4 (-12.844) over better parent (Table 2). None of the crosses showed significant negative standard heterosis over standard parents. The results were support by earlier reports of Mirarab *et al.* (2011) and Priyanka *et al.* (2017) [8, 11].

Shorter plant type is an important trait in hybrid breeding. For the plant height, heterobeltiosis varied from -30.809 (Pant Dhan 10 × Pant Dhan 26) to 34.921 (NDR3012 × Pant Dhan 4) and out of 51 crosses, only six cross combinations namely Pant Dhan 10 × Pant Dhan 26 (-16.993), *Kharif*2015-SNo-1414 × Pant Dhan 26 (-13.399), Pant Dhan 10 × Pant Dhan 4, BBL180-5-1-4-1 × Pant Dhan 4(-7.516), BBL180-5-1-4-1 × Pant Dhan 23 (-5.556) and Pant Dhan 10 × Pant Dhan 23 (-5.229) showed significant negative standard heterosis over the check parent Pant Dhan 4 for this character (Table 2). Significant and negative heterosis for plant height was reported by Waza *et al.* (2016) and Priyanka *et al.* (2017) [23, 11].

For number of tillers per plant, heterobeltiosis ranged from -60.870 to 63.380. 11 crosses out of 51 and cross named UPRI2008-8 × Pant Dhan 26 (63.380) showed highest significant positive heterosis over better parent. In respect to standard heterosis over the standard parent Govind varied from -19.514 to 182.920 and over Pant Dhan 4 ranged from -69.318 to 31.820. Out of 51 crosses, 36 cross combinations showed significant positive standard heterosis over the commercial checks for number of tillers per plant (Table 2).

Table 2: Estimation of heterosis for various quantitative and qualitative traits in rice genotypes (HB-heterobeltiosis, SH-over standard parent (Govind) and over standard parent (Pant Dhan 4)

Crosses	Days to 50% flowering			Days to maturity			Plant height (cm)			Number of tillers per plant		
	HB	SH (Govind)	SH (PD 4)	HB	SH (Govind)	SH (PD 4)	HB	SH (Govind)	SH (PD 4)	HB	SH (Govind)	SH (PD 4)
L1 X T1	1.439	23.684**	8.461**	-1.081	6.250*	-4.762	-1.238	29.344**	9.477**	-2.941	60.972*	-24.999**
L1 X T2	-0.351	24.561**	9.230**	-3.655	15.312**	3.361	-1.828	28.572**	8.824**	3.03	65.850**	-22.726**
L1 X T3	9.028**	37.719**	20.769**	6.720**	24.062**	11.204**	1.062	43.244**	21.242**	4.545	68.289**	-21.590**
L2 X T1	6.885**	42.982**	25.384**	2.519	27.187**	14.006**	8.224**	27.028**	7.516*	-5.556	65.850**	-22.726**
L2 X T2	-8.852**	21.930**	6.923**	-12.343**	8.750*	-2.521	4.934	23.166**	4.248	-9.722	58.533*	-26.136**
L2 X T3	-1.639	31.578**	15.384**	-6.045**	16.562**	4.482*	-4.113	35.908**	15.033**	-12.5	53.655*	-28.408**
L3 X T1	-6.312**	23.684**	8.460**	-6.736**	12.500**	0.84	-2.682	9.267*	-7.516	-10.294	48.777**	-30.681**
L3 X T2	-10.299**	18.421	3.845	-8.549**	10.312**	-1.12	-1.701	11.583**	-5.556	22.222*	87.800**	-12.499**
L3 X T3	9.635**	44.736**	26.922**	5.959**	27.812**	14.566**	-5.203*	34.363**	13.725**	52.381**	134.141**	9.092**
L4 X T1	-3.846	20.614	5.769*	2.778	15.625**	3.641*	-3.378	15.946**	-1.863	-6.25	82.922**	-14.772**
L4 X T2	8.392**	35.964**	19.229**	4.178	24.687**	11.765**	-1.544	18.147**	0	-36.250**	24.387	-42.045**
L4 X T3	-1.389	24.561**	9.230**	-4.57	10.937**	-0.56	-2.751	37.838**	16.667**	-16.25	63.411**	-23.863**
L5 X T1	-11.491**	25.000**	9.614**	-6.394**	14.375**	2.521	4.454	25.869**	6.536*	8.451	87.800**	-12.499**
L5 X T2	-3.727	35.964**	19.229**	1.279	23.750**	10.924**	5.095*	26.641**	7.190*	-11.268	53.655*	-28.408**
L5 X T3	2.484	44.736**	26.922**	6.138**	29.687**	16.246**	-15.010**	20.464**	1.961	63.380**	182.920**	31.820**
L6 X T1	-9.034**	28.069**	12.303**	-1.781	20.625**	8.123**	-2.832	15.251**	-2.451	-6.818	99.995**	-6.817*
L6 X T2	-2.804	36.842**	19.999**	1.527	24.687**	11.765**	-0.716	17.761**	-0.327	-25.000*	60.972**	-24.999**
L6 X T3	2.804	44.736**	26.922**	6.107**	30.312**	16.807**	-3.841	36.294**	15.359**	5.682	126.824**	5.683*
L7 X T1	0.352	25.000**	9.614**	-1.63	13.125**	1.401	5.217*	40.155**	18.627**	1.389	78.044**	-17.045**
L7 X T2	-4.211*	19.736	4.999*	-2.089	17.187**	5.042**	5.507*	40.541**	18.954**	-12.5	53.655*	-28.408**
L7 X T3	-3.125	22.368**	7.307**	-2.151	13.750**	1.961	13.865**	61.391**	36.601**	1.389	78.044**	-17.045**
L8 X T1	-0.382	14.473	0.384	-2.778	9.375*	-1.961	-4.714	9.267*	-7.516	-30.435*	17.07	-45.454**
L8 X T2	-9.474**	13.157	-0.769	-5.483*	13.125**	1.401	-2.357	11.970**	-5.229	-11.594	48.777	-30.681**
L8 X T3	-0.694	25.438**	9.999**	-0.269	15.937**	3.922*	-30.809**	-1.93	-16.993	-60.870**	-34.148	-69.318**
L9 X T1	-5.960*	24.561**	9.230**	-1.535	20.312**	7.843**	-8.529**	20.078**	1.634	-15.493	46.338	-31.817**
L9 X T2	-0.662	31.578**	15.384**	-2.302	19.375**	7.003**	-1.765	28.958**	9.150**	-18.31	41.46	-34.090**
L9 X T3	1.325	34.210**	17.691**	-8.696**	11.562**	0	-8.744**	29.344**	9.477**	-59.155**	-29.27	-67.045**
L10 X T1	-0.353	23.684**	8.461**	-1.105	11.875**	0.28	-14.205**	16.603**	-1.307	33.824*	121.946**	3.410*
L10 X T2	-3.158	21.052*	6.153**	-7.833**	10.312**	-1.12	-11.932**	19.692**	1.307	31.481*	73.167**	-19.317**
L10 X T3	-3.819	21.490*	6.537**	-1.882	14.062**	2.241	-16.372**	18.533**	0.327	31.481*	73.167**	-19.317**
L11 X T1	-11.765**	25.00**	9.614**	-7.557**	14.687**	2.801	-0.667	15.058**	-2.614	20.588	99.995**	-6.817*
L11 X T2	-5.263*	34.210**	17.691**	0	24.062**	11.204**	9.333**	26.641**	7.190*	-32.653*	-19.514	-62.500**
L11 X T3	-11.765**	25.00**	9.614**	-5.038*	17.812**	5.602**	-27.813**	2.317	-13.399	49.020**	85.361**	-13.635**
L12 X T1	-9.121**	22.368**	7.307**	-3.646	15.625**	3.641*	7.855**	37.838**	16.667**	-2.941	60.972**	-24.999**
L12 X T2	-7.166**	25.00**	9.614**	-2.083	17.500**	5.322**	-9.063**	16.217**	-1.634	21.538*	92.678**	-10.226**
L12 X T3	-8.143**	23.684**	8.461**	0.26	20.312**	7.843**	-4.658	35.136**	14.379**	18.462	87.800**	-12.499**
L13 X T1	-8.974**	24.561**	9.230**	-4.798	17.812**	5.602**	-0.324	18.919**	0.654	-9.722	58.533*	-26.136**
L13 X T2	-11.538**	21.052*	6.153**	-6.818**	15.312**	3.361	-3.236	15.444**	-2.288	-18.056	43.899	-32.954**
L13 X T3	-12.500**	19.736	4.999*	-6.313**	15.937**	3.922*	-16.644**	18.147**	0	23.611*	117.068**	1.138*
L14 X T1	-12.000**	25.438**	9.999**	-6.127**	19.687**	7.283**	-14.402**	21.622**	2.941	2.941	70.728**	-20.454**
L14 X T2	-5.846*	34.210**	17.691**	-1.471	25.625**	12.605**	-10.136**	27.684**	8.072*	-14.754	26.826	-40.908**
L14 X T3	-12.615**	24.56**	9.230**	-7.598**	17.812**	5.602**	-10.326**	27.414**	7.843*	22.951*	82.922**	-14.772**
L15 X T1	-17.544**	23.684**	8.461**	-7.635**	17.187**	5.042**	34.921**	50.966**	27.778**	-17.647	36.582	-36.363**
L15 X T2	-17.544**	23.684**	8.461**	-7.635**	17.187**	5.042**	13.265**	28.572**	8.824**	-3.774	24.387	-42.045**
L15 X T3	-17.544**	23.684**	8.461**	-6.897**	18.125**	5.882**	-8.472**	29.730**	9.804**	-13.208	12.192	-47.727**
L16 X T1	-12.844**	25.00**	9.614**	-5.941*	18.750**	6.443**	1.108	40.927**	19.281**	-20.588	31.704	-38.636**
L16 X T2	-11.009**	27.631**	11.922**	-4.703	20.312**	7.843**	11.080**	54.827**	31.046**	-22.581*	17.07	-45.454**
L16 X T3	-10.092**	28.947**	13.076**	-3.465	21.875**	9.244**	-2.479	38.224**	16.993**	25.806*	90.239**	-11.363**

L17 X T1	-1.418	21.930**	6.923**	3.591	17.187**	5.042**	20.635**	46.719**	24.183**	16.901	102.434**	-5.681*
L17 X T2	-3.158	21.052*	6.153**	-3.916	15.000**	3.081	8.254**	31.661**	11.438**	-5.634	63.411**	-23.863**
L17 X T3	-1.042	25.00**	9.614**	1.613	18.125**	5.882**	-5.475	33.977**	13.399**	-2.817	68.289**	-21.590**

**Significant at 1% level, *Significant at 5% level

A hybrid with greater panicle length is desirable. For panicle length, six crosses registered significantly positive heterobeltiosis and thirty five crosses over the check parent Govind and only four cross combinations showed significant positive standard heterosis over the check parent Pant Dhan 4. The cross Pant Dhan 22 × Pant Dhan 23 exhibited highest significant positive standard heterosis over both standard checks for panicle length (Table 2). Similarity results were reported by Mirarab *et al.* (2011), Latha *et al.* (2013) [8, 7].

Number of grains per panicle and spikelet fertility directly associated with grain yield per plant. For number of grains per panicle, heterobeltiosis ranged from -37.190 to 68.427. As many as 28 crosses exhibited significant positive heterobeltiosis. Standard heterosis over the standard check Govind ranged from -1.600 to 172.444 and over Pant Dhan 4 ranged from -13.086 to 133.062. Almost all crosses showed highly significant positive standard heterosis over both the standard checks. These heterotic crosses *viz.*, UPRI2011-21 × Pant Dhan 26, Pant Dhan 22 × Pant Dhan 2, JGL1172-7 × Pant Dhan 23 exhibited highly significant positive heterosis for number of grains per panicle (Table 2). For spikelet fertility, five crosses, five cross and thirty five cross exhibited significant positive heterosis over better parent, standard heterosis over the check Govind and standard heterosis over the check Pant Dhan 4, respectively. The crosses *viz.*, Pant Dhan 10 × Pant Dhan 23, Pant Dhan 10 × Pant Dhan 26, Pant Dhan 24 × Pant Dhan 26, Pant Dhan 10 × Pant Dhan 4 and Pant Dhan 22 × Pant Dhan 26 exhibited highly significant positive heterosis for this character (Table 2). The findings were supported with the earlier reports of Tiwari *et al.* (2011), Showkat *et al.* (2016) [19, 15].

The heterobeltiosis for 1000 grain weight varied from -57.061 to 90.130. The cross combinations Pant Dhan 19 × Pant Dhan 23 (90.130) exhibited highest significant positive heterosis over the better parent. The standard heterosis over the check parent Govind ranged from -30.948 to 171.925 and over the check parent Pant Dhan 4 from -40.986 to 108.263. The cross combinations namely, Pant Dhan 19 × Pant Dhan 23, BBL180-5-1-4-1 × Pant Dhan 4, BBL180-5-1-4-1 × Pant Dhan 26 and UPRI2014-8 × Pant Dhan 26 showed significant positive heterosis over both the standard checks for this character (Table 2). These results coincide with the findings of Tiwari *et al.* (2011) [19], Kumar *et al.* (2017) [6], and Showkat *et al.* (2016) [15].

Qualitative traits- For kernel length, six crosses exhibited significant positive heterobeltiosis and thirty seven cross showed significant positive standard heterosis over the standard parent Govind and over the standard parent Pant Dhan 4 also. The cross combinations namely UPRI2012-19 × Pant Dhan 23 (20.556), Pant Dhan 10 × Pant Dhan 4 (16.393), UPRI2012-10 × Pant Dhan 23 (13.333), UPRI2012-19 × Pant Dhan 26 observed as highly heterotic hybrids for this character. A similar trend has been reported by Singh *et al.* (2011) and Borah *et al.* (2017) [17, 3].

The heterobeltiosis for kernel breadth ranged from -13.846 to 7.937. Eight cross combinations showed significant positive better parent heterosis and standard heterosis over Govind varied from -3.432 to 27.608. 19 cross combinations showed significant positive standard heterosis over the standard parent Govind and standard heterosis over the Pant Dhan 4 varied from -1.754 to 29.825. 22 crosses showed significant positive standard heterosis over the standard parent Pant Dhan 4 for this character (Table 2). Similar results coincide with the earlier reports of Tiwari *et al.* (2011) [19] and Singh *et al.* (2011) [17].

Long/medium slender grain type is most preferred so, positive significant standard heterosis is desirable. For Length/Breadth ratio, heterobeltiosis ranged from -22.152 to 10.885. The cross combinations namely UPRI2012-10 × Pant Dhan 23 (10.885) and Pant Dhan 10 × Pant Dhan 4 (9.213) exhibited highest significantly positive heterosis over better parent. The standard heterosis over the standard parent Govind for L/B ratio varied from -9.399 to 9.942 and over the check parent Pant Dhan 4 varied from 3.368 to 25.436. The heterotic crosses namely Pant Dhan 10 × Pant Dhan 4, UPRI2012-19 × Pant Dhan 23, Pant Dhan 18 × Pant Dhan 23, UPRI2012-19 × Pant Dhan 26, Pant Dhan 10 × Pant Dhan 26 and UPRI2012-10 × Pant Dhan 23 showed significant positive standard heterosis over both the standard checks (Table 2) for this character. The results found similar with the earlier report of Sanghera and Hussain (2012).

For alkali digestion value, the heterobeltiosis ranged from -8.334 to 66.667. Thirteen crosses showed significant positive heterobeltiosis. The standard heterosis over the standard parent Govind varied from -11.111 to 44.445 and over the check parent Pant Dhan 4 for -8.333 to 8.333 (Table 2). The crosses namely Pant Dhan 18 × Pant Dhan 26 and Pant Dhan 18 × Pant Dhan 4 found highly heterotic hybrids for this character as Venkatesan *et al.* (2008) [21].

For hulling recovery, the heterosis over better parent ranged from -23.789 to 7.763, over the standard parent Govind varied from -7.104 to 32.787 and over the check parent Pant Dhan 4 varied from -6.594 to 33.516. These cross combinations namely Pant Dhan 10 × Pant Dhan 26, Kharif2011-SNo-1423 × Pant Dhan 4, Pant Dhan 10 × Pant Dhan 4, Pant Dhan 24 × Pant Dhan 26, UPRI2014-8 × Pant Dhan 26 and Kharif2015-SNo-1414 × Pant Dhan 4 found best heterotic crosses with significant and positive heterosis for this character (Table 2). A similar trend has been reported by Saravanan *et al.* (2018) [14].

Table 2 (contd.): Estimation of heterosis for various quantitative and qualitative traits in rice genotypes (HB-heterobeltiosis, SH-over standard parent (Govind) and over standard parent (Pant Dhan 4)

Crosses	Panicle length (cm)			Number of grains per panicle			Spikelet fertility (%)			1000 grain weight (g)		
	HB	SH (Govind)	SH (PD 4)	HB	SH (Govind)	SH (PD 4)	HB	SH (Govind)	SH (PD 4)	HB	SH (Govind)	SH (PD 4)
L1 X T1	4.481	21.702**	2.308	30.695**	106.482**	76.635**	-6.643	-5.498	33.247**	-33.069	2.525	-16.361
L1 X T2	-14.675**	-0.963	-16.745	26.850**	100.407**	71.438**	-28.906	-29.237	-0.224	-33.795	-5.313	-22.127
L1 X T3	-3.146	18.405*	-0.463	68.427**	172.444**	133.062**	-11.748	-10.544	26.132**	-39.287	-2.365	-19.958
L2 X T1	-28.656**	-16.897	-30.139	0.543	30.540**	11.670**	-32.86	-32.037	-4.172	-46.165	-17.535	-31.118
L2 X T2	19.048**	37.361**	15.472*	11.274**	75.346**	50.000**	1.71	1.236	42.742**	-15.772	20.464	-3.164

L2 X T3	-1.124	20.877**	1.615	-10.379	44.969**	24.014**	-26.75	-25.751	4.691	-47.95	-16.295	-30.207
L3 X T1	-14.286**	3.021	-13.396	-10.275	44.942**	23.990**	-6.77	-5.627	33.066**	25.380**	92.058**	49.506**
L3 X T2	2.286	22.938**	3.348	-16.353	35.123**	15.591**	-7.248	-7.681	30.170**	0.094	43.155**	13.53
L3 X T3	3.371	26.372**	6.234	-1.878	58.720**	35.777**	-30.252	-29.301	-0.315	7.059	72.165**	34.872*
L4 X T1	-3.243	12.704	-5.255	-6.171	20.423**	3.016	-10.901	-9.808	27.171**	-9.443	38.717**	10.265
L4 X T2	-13.381**	-0.413	-16.283	-1.842	54.679**	32.320**	-23.004	-23.363	8.058**	-12.202	25.570**	0.593
L4 X T3	4.494	27.745**	7.389	26.258**	104.231**	74.710**	-16.04	-14.895	19.998**	-3.113	55.809**	22.839
L5 X T1	6.132	23.625**	3.925	29.750**	84.649**	57.958**	-1.143	0.069	41.097**	-6.213	43.665*	13.905
L5 X T2	3.345	18.817**	-0.117	13.201**	78.384**	52.598**	-8.393	-8.82	28.564**	-32.863	-3.98	-21.147
L5 X T3	-1.685	20.191**	1.038	13.213**	83.130**	56.659**	-51.591	-50.931	-30.812	-57.061	-30.948	-40.986
L6 X T1	-1.828	14.353	-3.869	-9.256	16.463**	-0.371	-17.917	-16.91	17.156**	-23.092	17.808	-5.117
L6 X T2	2.987	18.405*	-0.463	14.017**	79.669**	53.698**	-42.851	-43.117	-19.795	-33.345	-4.669	-21.653
L6 X T3	-1.124	20.877**	1.615	-13.749	39.517**	19.350**	-62.36	-61.846	-46.203	0.555	61.708**	27.178
L7 X T1	2.128	31.866**	10.853	26.097**	69.840**	45.290**	-40.051	-39.315	-14.435	-47.613	-19.753	-32.75
L7 X T2	8.511*	40.108**	17.782**	28.726**	102.848**	73.526**	-5.731	-6.171	32.299**	1.832	52.072**	20.09
L7 X T3	3.191	33.240**	12.008	61.033**	160.483**	122.830**	5.628**	7.069**	50.966**	-14.869	36.902**	8.93
L8 X T1	-4.481	11.262	-6.468	-14.465	9.778**	-6.091	0.931	7.096**	51.005**	6.064	62.470**	27.74
L8 X T2	-3.226	11.262	-6.468	-32.272	6.726**	-8.701	16.698**	23.826**	74.594**	-0.632	42.117*	12.766
L8 X T3	-18.539**	-0.413	-16.283	-37.19	1.6	-13.086	13.861**	20.816**	70.350**	-11.016	43.099*	13.489
L9 X T1	1.17	18.817*	-0.117	-15.554	8.381**	-7.286	-7.177	-6.038	32.486**	-6.783	42.790*	13.261
L9 X T2	1.754	19.504*	0.461	-2.358	53.865**	31.624**	-15.282	-15.677	18.895**	11.400*	59.326**	25.426
L9 X T3	-7.865	12.636	-5.313	-1.375	59.533**	36.473**	1.079	2.457	44.464**	-40.604	-4.483	-21.516
L10 X T1	-9.574*	16.757	-1.849	-17.011	21.074**	3.573*	-10.91	-9.817	27.158**	-18.543	25.987	0.899
L10 X T2	-1.064	27.745**	7.389	24.940**	96.881**	68.422**	-1.227	-1.688	38.620**	-24.299	17.084	-5.65
L10 X T3	-12.234*	13.323	-4.736	-13.749	39.517**	19.350**	8.819**	10.303**	55.527**	-22	25.436	0.494
L11 X T1	-8.608*	6.455	-10.509	-12.495	64.687**	40.881**	-20.495	-19.52	13.476**	-10.7	36.791	8.848
L11 X T2	-5.018	9.202	-8.2	-3.449	81.711**	55.445**	-50.784	-51.013	-30.929	-51.557	-30.717	-40.816
L11 X T3	0.562	22.938**	3.348	26.819**	138.676**	104.176**	-5.637	-4.35	34.866**	-18.549	30.985	4.577
L12 X T1	-6.48	14.971	-3.35	-17.309	61.703**	38.329**	-35.07	-34.274	-7.326	-30.722	6.12	-13.716
L12 X T2	-4.693	17.169*	-1.502	-9.875	76.241**	50.765**	-31.783	-32.101	-4.262	-31.5	-2.03	-19.712
L12 X T3	0	22.938**	3.348	-8.155	79.604**	53.642**	-32.179	-31.255	-3.069	-35.548	3.647	-15.535
L13 X T1	13.208**	31.866**	10.853	9.877**	49.661**	28.028**	-6.205	-5.055	33.873**	-39.296	-7.014	-23.378
L13 X T2	5.137	20.877**	1.615	3.115	62.490**	39.002**	6.044**	5.55	48.825**	-12.332	25.384	0.456
L13 X T3	-9.551*	10.575	-7.045	4.678*	69.325**	44.849**	-13.287	-12.104	23.932**	4.918	68.723**	32.339*
L14 X T1	10.849*	29.119**	8.544	4.280*	89.015**	61.693**	-35.888	-35.102	-8.494	2.019	56.274**	23.181
L14 X T2	-1.493	13.254	-4.793	-6.532	69.420**	44.930**	-14.28	-14.68	20.301**	-13.431	23.811	-0.701
L14 X T3	0	22.251**	2.77	23.253**	123.407**	91.113**	-50.76	-50.089	-29.626	-31.231	10.59	-10.428
L15 X T1	2.594	19.504*	0.461	28.825**	65.338**	41.438**	-39.829	-39.091	-14.119	2.566	57.111**	23.797
L15 X T2	10.514*	27.059**	6.812	12.702**	77.597**	51.925**	1.618	1.144	42.613**	8.31	54.906**	22.175
L15 X T3	12.360*	37.361**	15.472*	4.510*	69.053**	44.617**	-20.892	-19.813	13.063**	-10.97	43.173*	13.543
L16 X T1	5.376	34.614**	13.163*	19.411**	133.089**	99.396**	-24.278	-23.349	8.077**	-18.39	25.012	0.182
L16 X T2	-1.075	26.372**	6.234	31.207**	156.116**	119.095**	-25.344	-25.692	4.775	-21.179	12.73	-8.853
L16 X T3	0	27.745**	7.389	31.096**	155.899**	118.909**	-20.084	-18.994	14.218**	-28.373	15.186	-7.046
L17 X T1	4.53	23.625**	3.925	12.912**	44.915**	23.967**	-28.458	-27.581	2.111	-13.19	32.976	6.041
L17 X T2	3.368	22.251**	2.77	25.663**	98.020**	69.396**	-9.707	-10.128	26.719**	90.130**	171.925**	108.263**
L17 X T3	0.674	23.075**	3.463	20.087**	94.250**	66.171**	-6.892	-5.622	33.073**	-14.187	38	9.738

**Significant at 1% level, *Significant at 5% level

For milling recovery, seventeen cross, thirty nine and forty seven cross combinations showed significant positive heterosis over better parent, over the standard parent Govind and over the standard parent Pant Dhan 4, respectively (Table 2). These results coincide with the reports of Virmani *et al.* (1982) [22].

The heterosis over better parent for harvest index ranged from -43.796 to 32.929. Out of 51, twelve crosses showed significant positive heterobeltiosis. These crosses UPR3199-464-1-2 × Pant Dhan 4 and Pant Dhan 19 × Pant Dhan 4 found highly heterotic hybrids for this character. The standard heterosis over the standard parent Govind for harvest index ranged from -46.436 to 2.682 and over check parent Pant Dhan 4 ranged from -5.266 to 81.605. These cross combinations namely Pant Dhan 19 × Pant Dhan 4 and Pant Dhan 22 × Pant Dhan 23 and UPR3199-464-1-2 × Pant Dhan 4 observed as highly heterotic crosses over standard checks for this character (Table 2). Standard heterosis of positive nature was observed by Tiwari *et al.* (2011) [19] and Showkat *et al.* (2016) [15].

Table 2(contd.): Estimation of heterosis for various quantitative and qualitative traits in rice genotypes (HB-heterobeltiosis, SH-over standard parent (Govind) and over standard parent (Pant Dhan 4)

Crosses	Kernel length (mm)			Kernel breadth (mm)			Length/breadth ratio			Alkali digestion value		
	HB	SH (Govind)	SH (PD 4)	HB	SH (Govind)	SH (PD 4)	HB	SH (Govind)	SH (PD 4)	HB	SH (Govind)	SH (PD 4)
L1 X T1	-8.840**	-3.509	12.245	0.644	5.191	7.018	-8.876**	-8.268	4.659	-41.667**	-22.222	-41.667**
L1 X T2	-6.667**	-1.754	14.286*	-4.615*	6.915	8.772	-6.559*	-8.155	4.788	-25.000**	0	-25.000**
L1 X T3	-13.402**	-1.754	14.286*	-1.587	6.915	8.772	-12.121**	-8.155	4.788	-25.000**	0	-25.000**
L2 X T1	-5.525*	0	16.327**	0.079	5.191	7.018	-5.506*	-4.875	8.53	-11.111*	-11.111	-33.333**
L2 X T2	0.556	5.848**	23.129**	-6.154*	5.191	7.018	5.826*	0.667	14.854**	-33.333**	-33.333*	-50.000**
L2 X T3	-3.608*	9.357**	27.211**	1.587	10.364*	12.281*	-2.056	2.364*	16.789**	-33.333**	-33.333*	-50.000**
L3 X T1	-7.182**	-1.754	14.286*	-11.765**	3.466	5.263	-5.506*	-4.875	8.53	-8.333	22.222	-8.333*
L3 X T2	1.667	7.018**	24.490**	-7.353**	8.639	10.526*	5.060*	-1.369	12.531**	0	33.333*	0

L3 X T3	-8.247**	4.094*	21.088**	-11.765**	3.466	5.263	-3.68	0.667	14.854**	0	33.333*	0
L4 X T1	-2.762	2.924	19.728**	0.121	5.191	7.018	-3.146	-2.5	11.240*	0	-11.111	-33.333**
L4 X T2	13.333**	19.298**	38.776**	1.538	13.813**	15.789**	10.885**	4.852*	19.628**	-50.000**	-55.556**	-66.667**
L4 X T3	-5.670*	7.018**	24.490**	-1.587	6.915	8.772	-4.221	0.102	14.208**	-12.500*	-22.222	-41.667**
L5 X T1	-1.657	4.094*	21.088**	-1.639	3.466	5.263	0	0.667	14.854**	12.500*	0	-25.000**
L5 X T2	1.111	6.433**	23.810**	-4.615*	6.915	8.772	-0.565	-0.464	13.563**	12.500*	0	-25.000**
L5 X T3	-5.670*	7.018**	24.490**	0.079	8.639	10.526*	-5.628*	-1.369	12.531*	0	-22.222	-41.667**
L6 X T1	-2.762	2.924	19.728**	-1.639	3.466	5.263	-1.124	-0.464	13.563**	-20.000**	33.333*	0
L6 X T2	20.556**	26.901**	47.619**	4.615*	17.262**	19.298**	8.371**	8.359**	23.629**	-53.333**	-22.222	-41.667**
L6 X T3	9.278**	23.977**	44.218**	7.937**	17.262**	19.298**	1.407	5.983*	20.919**	-13.333*	44.444**	8.333*
L7 X T1	1.105	7.018**	24.490**	0.025	5.191	7.018	1.124	1.798	16.144**	0	-11.111	-33.333**
L7 X T2	3.443*	9.942**	27.891**	0.896	12.088**	14.035**	-2.147	-2.047	11.756*	12.500*	0	-25.000**
L7 X T3	-1.546	11.696**	29.932**	1.587	10.364**	12.281*	-3.247	1.12	15.370**	-25.000**	-33.333*	-50.000**
L8 X T1	16.393**	24.561**	44.898**	6.452*	13.813**	15.789**	9.213**	9.942**	25.436**	-50.000**	-55.556**	-66.667**
L8 X T2	0	7.018**	24.490**	-4.615*	6.915	8.772	0	0.102	14.208**	-37.500**	-44.444**	-58.333**
L8 X T3	8.763**	23.392**	43.537**	7.937**	17.262**	19.298**	0.758	5.305*	20.145**	14.286*	-11.111	-33.333**
L9 X T1	-11.111**	16.959**	36.054**	6.352*	15.537**	17.544**	-18.626**	1.798	16.144**	62.500**	44.444**	8.333*
L9 X T2	-1.333	29.825**	51.020**	7.692**	20.710**	22.807**	-13.924**	7.680*	22.855**	-12.500*	-22.222	-41.667**
L9 X T3	-23.556**	0.585	17.007**	-4.762*	3.466	5.263	-22.152**	-2.613	11.111*	66.667**	11.111	-16.667**
L10 X T1	1.105	7.018**	24.490**	1.639	6.915	8.772	-1.124	-0.464	13.563**	12.500*	0	-25.000**
L10 X T2	1.111	6.433**	23.810**	-4.615*	6.915	8.772	6.024*	-0.464	13.563**	-12.500*	-22.222	-41.667**
L10 X T3	-11.856**	0	16.327**	-9.524**	-1.707	0	-2.489	1.912	16.273**	0	-11.111	-33.333**
L11 X T1	1.657	7.602**	25.170**	3.279	8.639	10.526	-2.775	-0.916	13.047**	-37.500**	-44.444**	-58.333**
L11 X T2	-5.000*	0	16.327**	-13.846**	-3.432	-1.754	1.554	3.495	18.080**	-37.500**	-44.444**	-58.333**
L11 X T3	-8.763**	3.509	20.408**	-6.349*	1.742	3.509	-2.597	1.798	16.144**	33.333**	-11.111	-33.333**
L12 X T1	0	5.848**	23.129**	0.07	5.191	7.018	0	0.667	14.854**	0	33.333*	0
L12 X T2	0.556	5.848**	23.129**	-4.615*	6.915	8.772	0	-1.029	12.918**	-25.000**	0	-25.000**
L12 X T3	-5.155*	7.602**	25.170**	-1.587	6.915	8.772	-3.68	0.667	14.854**	0	33.333*	0
L13 X T1	-2.02	13.450**	31.973**	7.843**	15.537**	17.544**	-10.986**	-1.934	11.885*	-12.500*	-22.222	-41.667**
L13 X T2	-7.576**	7.018**	24.490**	-4.615*	6.915	8.772	-9.138**	0.102	14.208**	-12.500*	-22.222	-41.667**
L13 X T3	-4.040*	11.111**	29.252**	1.587	10.364*	12.281*	-8.624**	0.667	14.854**	16.667*	-22.222	-41.667**
L14 X T1	-0.546	6.433**	23.810**	2.763	20.710**	22.807**	-10.000**	-9.399	3.368	-25.000**	-33.333*	-50.000**
L14 X T2	-1.093	5.848**	23.129**	-5.714*	13.813**	15.789**	-1.205	-7.25	5.82	0	-11.111	-33.333**
L14 X T3	-11.340**	0.585	17.007**	-12.857**	5.191	7.018	-7.792*	-3.631	9.950*	0	-22.222	-41.667**
L15 X T1	-6.154*	7.018**	24.490**	-5.714*	13.813**	15.789**	-5.730*	-5.101	8.272	12.500*	0	-25.000**
L15 X T2	-1.026	12.865**	31.293**	1.429	22.435**	24.561**	-2.392	-7.703	5.304	-37.500**	-44.444**	-58.333**
L15 X T3	1.538	15.789**	34.694**	5.714*	27.608**	29.825**	-13.095**	-9.173	3.626	-33.333**	-55.556**	-66.667**
L16 X T1	-6.736*	5.263**	22.449**	0.024	5.191	7.018	-8.290*	0.102	14.208**	-12.500*	-22.222	-41.667**
L16 X T2	-9.845**	1.754	18.367**	-10.769**	0.017	1.754	-6.736*	1.798	16.144**	-12.500*	-22.222	-41.667**
L16 X T3	-1.031	12.281**	30.612**	-0.043	8.639	10.526*	-5.181*	3.495	18.080**	16.667*	-22.222	-41.667**
L17 X T1	-9.453**	6.433**	23.810**	-8.824**	6.915	8.772	-1.124	-0.464	13.563**	12.500*	0	-25.000**
L17 X T2	-6.965*	9.357**	27.211**	-4.412	12.088**	14.035**	-2.593	-2.273	11.498**	-25.000**	-33.333*	-50.000**
L17 X T3	-2.488	14.620**	33.333**	-3.14	12.088**	14.035**	-2.165	2.251	16.660**	28.571**	0	-25.000**

**Significant at 1% level, *significant at 5% level

Table 2(contd.): Estimation of heterosis for various quantitative and qualitative traits in rice genotypes (HB-heterobeltiosis, SH-over standard parent (Govind) and over standard parent (Pant Dhan 4)

Crosses	**Hulling recovery (%)**			**Milling recovery (%)**			**Harvest index**			**Grain yield per plant (g)**		
	HB	**SH (Govind)**	**SH (PD 4)**	**HB**	**SH (Govind)**	**SH (PD 4)**	**HB**	**SH (Govind)**	**SH (PD 4)**	**HB**	**SH (Govind)**	**SH (PD 4)**
L1 X T1	-3.084	20.219**	20.878**	-7.576*	11.585**	18.832**	-19.257**	-23.704**	34.938	46.998**	147.238**	38.052**
L1 X T2	-18.502**	1.093	1.648	-16.832**	2.438	9.092**	-11.777**	-16.627**	47.456	46.484**	146.374**	37.569**
L1 X T3	-13.242**	3.825*	4.395*	-16.146**	-1.83	4.546**	-34.058**	-37.719**	10.151	41.345**	203.326**	69.370**
L2 X T1	-19.824**	-0.546	-0.001	-16.667**	0.609	7.144**	6.459*	-12.396**	54.938	43.747**	141.905**	35.074**
L2 X T2	-7.048*	15.301**	15.933**	-9.406**	11.585**	18.832**	-4.144	-21.148**	39.459	53.665**	158.595**	44.393**
L2 X T3	-8.920**	6.011**	6.593**	-4.688*	11.585**	18.832**	1.122	-9.644**	59.805	26.498**	171.466**	51.580**
L3 X T1	-11.894**	9.290**	9.890**	-15.657**	1.829	8.442**	-15.563**	-19.534**	42.314	4.674	93.707**	8.162
L3 X T2	-7.048*	15.301**	15.933**	-4.950*	17.072**	24.676**	-6.309*	-10.697**	57.943	19.867**	121.824**	23.861**
L3 X T3	-16.90**	-3.279	-2.748	-20.833**	-7.318	-1.298	-43.796**	-46.436**	-5.266	42.675**	206.180**	70.964**
L4 X T1	-1.322	22.404**	23.076**	-0.5	21.341**	29.222**	-9.838*	-16.421**	47.819	-4.138	67.153**	-6.666
L4 X T2	-0.881	22.951**	23.626**	-3.960*	18.292**	25.975**	-33.676**	-38.526**	8.723	-39.683**	5.174	-41.273
L4 X T3	-12.670**	5.464**	6.043**	-18.000**	-0.001	6.494**	-11.297**	-17.744**	45.479	52.186**	226.592**	82.362**
L5 X T1	-22.467**	-3.825	-3.297	-23.232**	-7.318	-1.298	12.525**	-16.281**	48.067	52.983**	174.009**	53.000**
L5 X T2	-23.789**	-5.464	-4.946	-24.257**	-6.708	-0.649	-17.911**	-34.977**	15	47.537**	164.254**	47.554**
L5 X T3	-15.023**	-1.093	-0.55	-12.500**	2.438	9.092**	-31.576**	-38.852**	8.147	14.904**	146.585**	37.687**
L6 X T1	-2.643	20.765**	21.428**	-4.040*	15.853**	23.377**	-3.683	-22.647**	36.809	3.623	69.153**	-5.549
L6 X T2	2.643	27.322**	28.021**	-1.98	20.731**	28.572**	-3.745	-22.717**	36.684	53.053**	149.840**	39.505**
L6 X T3	-20.188**	-7.104	-6.594	-19.792**	-6.098	0.001	-23.163**	-31.353**	21.41	33.921**	187.395**	60.475**
L7 X T1	-18.502**	1.093	1.648	-17.172**	-0.001	6.494**	-13.315**	-19.378**	42.589	70.618**	177.476**	54.936**
L7 X T2	-6.167*	16.393**	17.032**	-4.950*	17.072**	24.676**	9.326*	1.704**	79.876**	119.013**	256.181**	98.883**
L7 X T3	1.408	18.033**	18.681**	1.042	18.292**	25.975**	-9.272*	-15.604**	49.264	120.510**	373.216**	164.233**
L8 X T1	6.167*	31.694**	32.417**	12.121**	35.365**	44.157**	-17.451**	-24.361**	33.777	39.014**	122.345**	24.152**
L8 X T2	1.762	26.230**	26.922**	5.446*	29.877**	38.313**	7.495*	-1.514***	74.184**	19.899**	83.527**	2.477

L8 X T3	7.763**	28.962**	29.670**	6.566*	28.658**	37.014**	-25.164**	-31.429**	21.277	-43.740**	20.734	-32.585
L9 X T1	-7.489**	14.754**	15.384**	-7.576*	11.585**	18.832**	-28.735**	-37.609**	10.346	-6.643	49.319**	-16.624
L9 X T2	-4.846*	18.033**	18.681**	6.931*	31.707**	40.261**	-17.344**	-27.664**	27.934	125.172**	244.667**	92.453**
L9 X T3	4.225*	21.311**	21.977**	2.604	20.121**	27.923**	-16.826**	-25.624**	31.543	60.196**	243.781**	91.959**
L10 X T1	-4.846*	18.033**	18.681**	1.515	22.560**	30.520**	-9.882*	-27.303**	28.573	51.130**	146.295**	37.525**
L10 X T2	-1.762	21.858**	22.527**	2.475	26.219**	34.416**	-11.436**	-28.566**	26.339	107.059**	237.440**	88.419**
L10 X T3	5.634*	22.951**	23.626**	6.250*	24.389**	32.468**	-16.209**	-25.133**	32.411	1.75	118.355**	21.924**
L11 X T1	3.524*	28.415**	29.120**	6.566*	28.658**	37.014**	-8.803*	-7.594**	63.431*	174.581**	339.177**	145.226**
L11 X T2	-3.084	20.219**	20.878**	-18.812**	-0.001	6.494**	-31.850**	-30.917**	22.181	44.734**	121.542**	23.704**
L11 X T3	1.408	18.033**	18.681**	0.521	17.682**	25.325**	-20.870**	-19.799**	41.844	97.023**	322.811**	136.088**
L12 X T1	-8.811**	13.115**	13.736**	-7.071*	12.194**	19.481**	32.929**	-1.083*	74.947**	93.083**	229.818**	84.162**
L12 X T2	-10.573**	10.929**	11.538**	-8.416*	12.804**	20.131**	16.835**	-7.449**	63.688*	86.713**	218.937**	78.087**
L12 X T3	-7.512*	7.650**	8.241**	-5.729*	10.365**	17.533**	8.357*	-3.173**	71.250**	94.030**	316.389**	132.502**
L13 X T1	-0.881	22.951**	23.626**	8.586*	31.097**	39.611**	21.145**	-9.825**	59.486	55.297**	148.388**	38.694**
L13 X T2	0.881	25.137**	25.823**	2.475	26.219**	34.416**	-15.316**	-32.962**	18.564	24.269**	90.2168**	6.212
L13 X T3	3.756*	20.765**	21.428**	5.729*	23.780**	31.819**	-16.601**	-25.499**	31.764	65.713**	255.621**	98.571**
L14 X T1	7.048*	32.787**	33.516**	-3.03	17.072**	24.676**	-10.976**	-33.744**	17.181	79.843**	187.648**	60.616**
L14 X T2	-14.537**	6.011**	6.593**	-14.851**	4.877*	11.689**	-19.873**	-36.556**	12.207	5.762	61.887**	-9.606
L14 X T3	0.469	16.940**	17.582**	4.167*	21.950**	29.871**	-30.679**	-38.035**	9.592	94.064**	316.462**	132.543**
L15 X T1	-6.167*	16.393**	17.032**	-7.576*	11.585**	18.832**	-11.852**	-34.411**	16.002	23.458**	97.464**	10.259
L15 X T2	-2.643	20.765**	21.428**	1.98	25.609**	33.767**	-15.759**	-33.278**	18.005	76.716**	170.496**	51.039**
L15 X T3	0	16.393**	17.032**	3.125	20.731**	28.572**	3.085	-7.840**	62.996*	17.17**	110.917**	17.771**
L16 X T1	-6.167*	16.393**	17.032**	-6.061*	13.414**	20.780**	14.343**	-14.887**	50.532	53.692**	145.822**	37.261**
L16 X T2	-5.727*	16.940**	17.582**	-6.436*	15.243**	22.728**	-11.835**	-30.195**	23.457	20.880**	85.0280**	3.315
L16 X T3	0	16.393**	17.032**	0.521	17.682**	25.325**	3.421	-7.594**	63.431*	40.122**	200.703**	67.906**
L17 X T1	-5.603*	19.672**	20.329**	7.576*	29.877**	38.313**	30.510**	2.682**	81.605*	78.674**	185.778**	59.572**
L17 X T2	-1.724	24.590**	25.274**	2.97	26.828**	35.066**	18.924**	-5.784**	66.631*	93.322**	199.340**	67.145**
L17 X T3	-1.724	24.590**	25.274**	1.581	24.389**	32.468**	6.562*	-4.762**	68.440*	79.834**	285.924**	115.491**

** Significant at 1% level, * significant at 5% level

Conclusion

As the findings from the present study on heterosis revealed that the higher and desirable magnitude of all quantitative and qualitative traits were not expressed in a single cross combinations, which was varied from cross to cross due to diverse genetic background of parents. Based on overall performance these crosses NDR3012 × Pant Dhan 4, Pant Dhan 10 × Pant Dhan 26, UPRI2008-8 × Pant Dhan 26, *Kharif* 2015-SNo-1414 × Pant Dhan 26 and Pant Dhan 19 × Pant Dhan 23 were identified as best heterotic crosses for quantitative traits and UPRI 2008-8 × Pant Dhan 23, Pant Dhan 19 × Pant Dhan 26, Pant Dhan 18 × Pant Dhan 23, *Kharif* 2011-SNo-1423 × Pant Dhan 4, Pant Dhan 10 × Pant Dhan 4 and NDR 3012 × Pant Dhan 26 were identified as best heterotic crosses for qualitative traits. For grain yield per plant, *Kharif* 2015-SNo-1414 × Pant Dhan 4 and *Kharif* 2011-SNo-1423 × Pant Dhan 26 were exhibited highly significant positive standard heterosis over Govind and Pant Dhan 4 therefore, would be expected to utilize in future breeding programme for high grain yield in rice.

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