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Heterosis estimates for yield and yield components in rice (*Oryza sativa* L.) using line × tester analysis

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Abstract
Present investigation was undertaken to study heterosis through line × tester design of experimental hybrids for yield and its component at Norman E. Borlaug Crop Research Centre. Pantnagar, Uttarakhand, India. Ten lines were crossed with three testers and the resulting 30 hybrids along with their parents were evaluated for heterosis (heterobeltiosis, relative heterosis and standard heterosis) in a replicated trial using randomized block design for various yield contributing charachters namely days to 50% flowering, days to maturity, grain length, grain width, 1000 grain weight and grain yield per plant. Standard heterosis was estimated by using Pant dhan 24 as a check parent. Cross combinations namely PR113×HKR47 (-4.273) and UPR-3905-22-2-2-1×HKR 47 (-5.512) showed significant negative standard heterosis for days to 50% flowering and days to maturity respectively. highle significant and maximum standard heterosis was showed by cross combinations UPR3037-2-2-1-3×PD 24 (5.138), UPR3037-2-2-1-3×PD 24 (13.515), UPR3037-2-2-1-3×HKR47 (7.811) and UPRI 2015-2×PD 24 (18.728) for grain length, grain width, 1000 grain weight and grain yield per plant respectively.

Keywords: Heterobeltiosis, relative heterosis, standard heterosis, check parent

Introduction
Rice accounts for more than 40% of food grain production in India and is the world's most important food crop after wheat and maize. The area under rice cultivation in India was 43.5 million hectares with a production of 104.32 million tonnes during 2016-2017 (Directorate of economics and statistics Report, 2016-17). Genus Oryza constitute of 24 species out of which 2 are cultivated viz. *O. sativa* and *O. glaberrima.* There are three sub species of O.sativa namely Indica (tropical rice grown in India, long and weak stem, irresponsive to high input condition, low productivity), Japonica (temperate and sub-tropical regions of japan, short stature, sturdy stem, responsive to high input condition, high productivity), Javanica (Indonesia, wild form of rice). Rice can provide on an average 75% calories with 55% protein in their daily diet (Bhuiyan *et al*. 2002) [1]. The world population is expected to reach 8 billion by 2030 and rice production must be increased by 50% in order to meet the growing demand (Khush and Brar, 2002) [2]. This increase in production can be achieved only through developing heterotic hybrids that are superior to their parents for various yield related characters. In the present investigation we studied three types of heterosis viz. average heterosis (superiority of F1 over mid parental value), heterobeltosis (superiority of F1 over better parent) and standard heterosis (superiority of F1 over best commercial variety) among which standard heterosis is of utmost importance for plant breeder. Generally positive heterosis is desirable but negative heterosis is also desirable in some cases like days to 50% flowering and days to maturity

Material and Methods
The present study was conducted at Norman E. Borlaug Crop Research Centre, Pantnagar, Uttarakhand, India. The basic experimental material comprised of thirteen rice genotypes. Out of these ten parents were chosen as lines namely PR113, Pant Sugandh Dhan 17, UPR 3912-21-2-1, UPR 3654-5-1-2, UPRI 2015-2, UPR 3037-2-2-1-3, UPR 3905-22-2-2-1, UPR 2760-10-1-2, UPR 2015-5 and Pant Dhan 26 and three were chosen as testers *viz.* HKR 47, Pant Dhan 24 and NDR 359. Thirty crosses were generated using Line × tester mating design during kharif 2015-16. The experimental material consisted of 43 genotypes i.e., 10 lines, 3 testers, 30 F_1's. The experimental material was evaluated in a Randomized Block Design (RBD) with three replications.

The seeds of all 43 genotypes were sown in the poly house at Norman E. Borloug Crop Research Centre. twenty one days old seedling were transplanted in the main field in a single row of 3m length and spacing of 30 cm was kept between two entries with plant to plant spacing of 15cm. Observations were recorded on the whole plot basis in respect of days to 50 per cent flowering, Days to Maturity whereas Observation for Grain length, Grain width, 1000 grain weight and grain yield per plant were recorded on the basis of five randomly selected competitive plants from the F_1 crosses, lines and the testers. Heterosis for each character in each cross was computed by the following formulae as given below:

a) Relative heterosis = $\frac{F1-MP}{MP} \times 100$

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

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

Where,
$\overline{F}_{1i}$= Mean value of F_1 for i^{th} character
$\overline{BP}_i$= Mean value of better parent of the cross for i^{th} character
$\overline{SP}_i$= Mean value of standard parent (SP)/check variety/hybrid for i^{th} trait

The significance of heterosis was worked out with‘t’ test (Fisher and Yates, 1943) [3] at error degree of freedom of ANOVA table for RBD.

Results

Heterosis was estimated by comparing the mean value for all the six characters of F_1 hybrids with better parental value (heterobeltiosis), mid parental value (relative heterosis) and standard check i.e. Pant Dhan 24 (standard heterosis) expressed as percentage increase or decrease. Mean squares from analysis of variance of six indicated traits of rice are presented in Table 1. The table depicted significant differences among rice genotypes for all the characters studied.

Table 1: Analysis of variance for combining ability for various characters in rice

Source of variation	d.f.	Days to 50% flowering	Days to maturity	Grain length	Grain width	1000 grain weight	Grain yield per plant
Replication	2	3.222	1.331	0.0018	0.0009	1.552	168.838
Treatment	42	4.517*	8.845**	0.649**	0.035**	5.137**	4308.326**
Crosses	29	5.277*	7.774**	0.381**	0.039**	3.753**	5114.868**
Lines	9	4.584	14.359**	0.312	0.047	4.311	9686.185**
Tester	2	8.220	1.762	0.069	0.002	3.420	5317.200
Line×tester	18	5.296*	5.149	0.451**	0.039**	3.512**	2806.728**
Error	84	2.828	3.015	0.0015	0.0006	1.288	30.041

*,** Significance at 5% and 1% level of significane, respectively

Results on average heterosis for different character is given in table 2. The range for relative heterosis for days to 50% flowering varied from -4.046 to 4.142 five hybrids exhibited significant negative heterosis namely UPR3037-2-2-1-3×HKR47 (-4.046), PR113×HKR47 (-3.529), PD 26×HKR47 (-3.448), UPRI 2015-2× NDR 359 (-2.890) and UPR 3654-5-1-2× NDR 359 (-2.857). Average heterosis for days to maturity ranged from -4.280 to 4.000 five hybrids namely PR113×NDR 359 (-4.280), Pant Sugandh Dhan 17×NDR 359 (-2.767), UPR 2760-10-1-2×PD 24 (-2.362), UPRI 2015-5×HKR47 (-2.326) and PR113×PD 24 (-1.961) exhibited significant relative heterosis over their mid parental values.Values of average heterosis for grain length ranged from -2.439 to 5.138 eight cross combinations namely UPR3037-2-2-1-3×PD 24 (5.138), UPR 2760-10-1-2×HKR 47 (2.586), UPR 3654-5-1-2×HKR47 (2.499), UPRI 2015-5×NDR 359 (2.137), UPR 2760-10-1-2×NDR 359 (1.863), UPR3912-21-2-1×HKR47 (1.802), UPRI 2015-2×HKR47 (1.717), UPR3037-2-2-1-3×NDR 359 (1.768) exhibited significant positive heterosis over mid parental values. Values for average heterosis for grain width ranged from -2.439 to 5.138 eight cross combinations namely UPR3037-2-2-1-3×PD 24 (5.138), UPR 2760-10-1-2×HKR 47 (2.586), UPR 3654-5-1-2×HKR47 (2.449), UPRI 2015-5×NDR 359 (2.137), UPR 2760-10-1-2×NDR 359 (1.863), UPR3912-21-2-1×HKR47 (1.802), UPR3037-2-2-1-3×NDR 359 (1.768) and UPRI 2015-2×HKR47 (1.717) exhibited significant positive heterosis over the mid parental values. Average heterosis for 1000 grain weight ranged from -9.014 to 9.166. Four cross combinations namely UPRI 2015-5×HKR47 (9.166), Pant Sugandh Dhan 17×NDR 359 (8.742), Pant Sugandh Dhan 17×PD 24 (8.670) and UPR-3905-22-2-2-1×PD 24 (8.653) exhibited significant positive heterosis over the mid parental values. For grain yield per plant range of average heterosis varied from -15.225 to 15.387. Fourteen cross combinations namely UPRI 2015-2× NDR 359 (15.387), UPR3037-2-2-1-3×HKR47 (14.589), Pant Sugandh Dhan 17×PD 24 (10.419), UPRI 2015-5×PD 24 (9.520), UPR 2760-10-1-2×HKR 47 (9.062), UPR3037-2-2-1-3×PD 24 (8.226), UPRI 2015-5×HKR47 (8.105), UPR 2760-10-1-2×PD 24 (7.917), UPR3037-2-2-1-3×NDR 359 (7.407), PD 26×PD 24 (7.008), UPR3912-21-2-1×HKR47 (6.495), UPR3912-21-2-1×PD 24 (5.390) and UPRI 2015-2×PD 24 (4.813) exhibited significant positive heterosis over the mid parental value. Results on heterobeltiosis for different character is given in table 3. Heterobeltiosis for days to 50% flowering ranged from -4.545 to 4.878. Among the thirty F_1s studied twelve F_1s showed negative heterosis out of which only three cross combinations exhibited significant negative heterosis over their respective earlier parent namely UPR 3654-5-1-2× NDR 359 (-4.494), PD 26×HKR47 (-4.545) and UPRI 2015-5×PD 24 (-2.299). The range of heterobeltiosis for days to maturity is from -3.906 to 4.839. Thirteen F_1s showed negative heterobeltiosis out of which five hybrids namely PR113×NDR 359 (-3.906), Pant Sugandh Dhan 17×NDR 359 (-3.150), UPR 2760-10-1-2×PD 24 (-3.125) and UPR 3654-5-1-2×PD 24 (-3.077), UPR3037-2-2-1-3×HKR47 (-2.344) exhibited significant negative heterosis over their respective earlier parent. Heterobeltiosis for grain length ranged from -1.316 to 1.333. Two hybrids namely PD 26×HKR47 (1.333) and UPRI 2015-2×HKR47 (0.962) exhibited significant positive heterosis over the better parent. For grain width Heterobeltiosis ranged from -2.655 to 6.400. Seven cross combinations showed significant heterosis namely UPR3037-2-2-1-3×PD 24 (6.400), UPR 2760-10-1-2×HKR 47 (3.030), UPR 3654-5-1-2×HKR47 (2.449), UPRI 2015-5×NDR 359 (2.137), UPR 2760-10-1-2×NDR 359 (2.075), UPR3037-2-2-1-3×NDR 359 (1.969) and UPRI 2015-2×HKR47 (1.717) exhibited significant positive heterosis over the better parent. The values of heterobeltiosis for thousand grain weight ranged from -12.083 to 8.742. Among the thirty F_1s studied four crosses showed significant positive heterosis over the better parent namely Pant Sugandh Dhan 17×NDR 359 (8.742), UPRI 2015-5×HKR47 (8.671), Pant Sugandh Dhan 17×PD 24 (7.903) and UPR-3905-22-2-2-1×PD 24 (7.843). Heterobeltiosis for grain yield per plant ranged from -16.797 to 19.240. Among the thirty F_1s studied eight hybrids namely UPR3037-2-2-1-3×HKR47 (19.240), UPRI 2015-5×PD 24 (12.894), UPR 2760-10-1-2×HKR 47 (11.589), UPRI 2015-2× NDR 359 (10.717), UPR-3905-22-2-2-1×PD 24 (10.034), UPR3037-2-2-1-3×NDR 359 (9.851), UPR3912-21-2-1×HKR47 (8.810) and UPRI 2015-2×PD 24 (6.107) exhibited significant positive heterosis over the better parent. Results on standard heterosis for different characters is given table 4. For days to 50% flowering standard heterosis over the check parent Pant Dhan 24 ranged from -4.273 to 5.067. Thirteen cross combinations showed negative standard heterosis out of which only two hybrids namely PR113×HKR47 (-4.273) and UPR 3654-5-1-2×PD 24 (-4.273) showed significant negative standard heterosis. Standard heterosis for days to maturity ranged from -5.512 to 2.362. Twenty cross combinations showed negative standard heterosis out of which seven hybrids namely UPR-3905-22-2-2-1×HKR 47 (-5.512), UPRI 2015-2×PD 24 (-3.150), Pant Sugandh Dhan 17×NDR 359 (-3.150), PR113×NDR 359 (-3.150), UPR 2760-10-1-2×PD 24 (-2.362), UPR3912-21-2-1×NDR 359 (-2.362) and Pant Sugandh Dhan 17× HKR47 (-2.362) exhibited significant negative standard heterosis. Standard heterosis for grain length ranged from -10.383 to 13.515. Twenty-three F_1s showed significant heterosis out of which fifteen hybrids namely UPR3037-2-2-1-3×PD 24 (13.515), UPR3037-2-2-1-3×NDR 359 (10.528), UPR 3654-5-1-2×HKR47 (7.114), UPR-3905-22-2-2-1×NDR 359 (5.407), UPR 2760-10-1-2×NDR 359 (4.980), UPRI 2015-2× NDR 359 (4.553), PR113×NDR 359 (4.553), UPRI 2015-5×PD 24 (4.553), UPR3037-2-2-1-3×HKR47 (4.127), PD 26×HKR47 (4.127), PD 26× NDR 359 (4.127), UPR 2760-10-1-2×PD 24 (3.700), PD 26×PD 24 (2.846), UPR 3654-5-1-2×NDR 359 (2.846) and UPRI 2015-5×NDR 359 (1.993) exhibited significant positive heterosis over the check parent Pant Dhan 24. Range of standard heterosis over the check parent Pant Dhan 24 for grain width ranged from -10.383 to 13.515. Twenty-two cross combinations exhibited significant heterosis out of which fourteen hybrids namely UPR3037-2-2-1-3×PD 24 (13.515), UPR3037-2-2-1-3×NDR 359 (10.528), UPR 3654-5-1-2×HKR47 (7.114), UPR-3905-22-2-2-1×NDR 359 (5.407), UPR 2760-10-1-2×NDR 359 (4.980), UPRI 2015-5×PD 24 (4.553), PR113×NDR 359 (4.553), UPRI 2015-2× NDR 359 (4.553), PD 26× NDR 359 (4.127), UPR3037-2-2-1-3×HKR47 (4.127), UPR 2760-10-1-2×PD 24 (3.700), PD 26×PD 24 (2.846), UPR 3654-5-1-2× NDR 359 (2.846) and UPRI 2015-5×NDR 359 (1.993) exhibited significant positive heterosis over the check parent. For 1000 grain weight standard heterosis ranged from -13.431 to 7.811. Among the thirty F_1s studied three hybrids namely UPR3037-2-2-1-3×HKR47 (7.811), UPR-3905-22-2-2-1×PD 24 (7.576) and PR113×PD 24 (7.302) exhibited significant positive heterosis over the standard check parent. Standard heterosis over the check parent Pant Dhan 24 ranged from -69.600 to 18.7258. Only two hybrids namely UPRI 2015-2×PD 24 (18.728) and UPRI 2015-5×NDR 359 (11.101) exhibited significant positive heterosis over the check parent.

Table 2: Estimation of average heterosis for different character

SI No.	Crosses	Daya to 50% flowering	Days to maturity	Grain length	Grain width	1000 grain weight	Grain yield per plant
1	UPR-3905-22-2-2-1×HKR 47	-0.578	-1.235	-2.439**	-2.439**	0.799	-3.421
2	Pant Sugandh Dhan 17× HKR47	-0.585	1.639	-2.098 *	-2.098*	6.309	-12.406*
3	PR113×HKR47	-3.529**	0.402	-1.709 *	-1.709*	3.995	-15.225*
4	UPR3037-2-2-1-3×HKR47	-4.046**	-1.575	0.412	0.412	0.036	14.589*
5	UPRI 2015-5×HKR47	2.353	-2.326*	1.293	1.293	9.166**	8.105*
6	UPR3912-21-2-1×HKR47	2.381	-1.575	1.802 *	1.802*	-7.055*	6.495*
7	UPR 3654-5-1-2×HKR47	-1.149	0.000	2.449**	2.449**	-7.904*	-0.556
8	UPRI 2015-2×HKR47	0.578	0.000	1.717 *	1.717*	-6.975*	-7.497*
9	UPR 2760-10-1-2×HKR 47	-2.273	-0.794	2.586**	2.586**	-7.406*	9.062*
10	PD 26×HKR47	-3.448*	-1.176	-1.014	-1.014	4.353	-1.548
11	UPR-3905-22-2-2-1×PD 24	0.000	0.794	-1.053	-1.053	8.653**	14.324*
12	Pant Sugandh Dhan 17×PD 24	-1.734	-1.176	-0.467	-0.467	8.670**	10.419*
13	PR113×PD 24	3.571*	-1.961*	-0.634	-0.634	-5.609*	-0.094
14	UPR3037-2-2-1-3×PD 24	3.529*	3.586**	5.138**	5.138**	-4.330	8.226*
15	UPRI 2015-5×PD 24	-0.585	1.575	1.240	1.240	-6.975*	9.520*
16	UPR3912-21-2-1×PD 24	-0.571	-1.563	-1.339	-1.339	-5.261	5.390*
17	UPR 3654-5-1-2×PD 24	-1.796	4.000**	-0.640	-0.640	-9.014**	0.088
18	UPRI 2015-2×PD 24	4.142**	-0.806	-1.525 *	-1.525*	-1.352	4.813*
19	UPR 2760-10-1-2×PD 24	0.000	-2.362*	-1.420 *	-1.420*	-4.901	7.917*
20	PD 26×PD 24	-0.599	-1.575	-0.823	-0.823	5.094	7.008*
21	UPR-3905-22-2-2-1×NDR 359	0.000	0.000	1.022	1.022	-0.511	-0.059
22	Pant Sugandh Dhan 17×NDR 359	1.124	-2.767**	0.000	0.000	8.742**	-6.502*
23	PR113×NDR 359	-1.176	-4.280**	0.204	0.204	-7.800*	-8.585*
24	UPR3037-2-2-1-3×NDR 359	0.000	1.205	1.768 *	1.768*	-7.251*	7.407*
25	UPRI 2015-5×NDR 359	1.176	0.392	2.137**	2.137**	-3.889	-0.378
26	UPR3912-21-2-1× NDR 359	-0.571	-1.587	-1.271	-1.271	5.515	0.416
27	UPR 3654-5-1-2× NDR 359	-2.857*	0.000	1.048	1.048	-3.971	-4.594*
28	UPRI 2015-2× NDR 359	-2.890*	2.419*	0.616	0.616	-0.193	15.387*
29	UPR 2760-10-1-2×NDR 359	-1.163	2.400*	1.863 *	1.863*	1.968	-12.287
30	PD 26× NDR 359	1.149	2.362*	0 .205	0.205	2.594	-5.587*

Table 3: Estimation of heterobeltiosis for different character

SI No.	Crosses	Daya to 50% flowering	Days to maturity	Grain length	Grain width	1000 grain weight	Grain yield per plant
1	UPR-3905-22-2-2-1×HKR 47	1.176	0.000	-0.857*	-2.655**	1.764	-12.832
2	Pant Sugandh Dhan 17× HKR47	0.000	1.639	-0.477	-1.408	5.653	-8.406
3	PR113×HKR47	-2.381	0.806	-0.212	-1.288	2.782	-8.403
4	UPR3037-2-2-1-3×HKR47	-2.353	-2.344 *	0.000	-0.408	3.843	19.240**
5	UPRI 2015-5×HKR47	4.819**	-1.563	-1.316**	0.427	8.671*	5.082
6	UPR3912-21-2-1×HKR47	4.878**	-0.794	-0.429	1.345	-6.987*	8.810**
7	UPR 3654-5-1-2×HKR47	0.000	0.000	-0.109	2.449**	-7.885*	-6.891
8	UPRI 2015-2×HKR47	-1.136	-0.787	0.962**	1.717*	-7.045*	-9.982*
9	UPR 2760-10-1-2×HKR 47	-2.27	-0.794	0.000	3.030**	-7.017	11.589**
10	PD 26×HKR47	-4.545**	-0.787	1.333**	0.000	3.118	-10.094*
11	UPR-3905-22-2-2-1×PD 24	2.410	0.794	0.217	0.000	7.843*	10.034**
12	Pant Sugandh Dhan 17×PD 24	0.000	-0.787	0.000	0.948	7.903*	6.396
13	PR113×PD 24	4.819**	0.000	0.000	0.427	-12.083**	-5.961
14	UPR3037-2-2-1-3×PD 24	2.326	3.175**	-0.213	6..400**	-4.259	5.348
15	UPRI 2015-5×PD 24	-2.299*	1.575	-0.106	0.410	-4.850	12.894**
16	UPR3912-21-2-1×PD 24	-1.124	-3.077**	-0.107	-1.778*	-8.421*	3.037
17	UPR 3654-5-1-2×PD 24	0.000	4.000**	0.325	-0.427	-6.279	3.37
18	UPRI 2015-2×PD 24	4.762**	0.000	-0.219	-2.165*	-1.818	6.107*
19	UPR 2760-10-1-2×PD 24	0.000	-3.125**	0.429	-2.410**	-5.389	5.523
20	PD 26×PD 24	-1.190	-1.575	-0.107	0.000	6.429	5.120
21	UPR-3905-22-2-2-1×NDR 359	0.000	0.000	0.106	1.230	0.900	-5.416
22	Pant Sugandh Dhan 17×NDR 359	1.124	-3.150**	0.000	0.000	8.742*	-8.220*
23	PR113×NDR 359	-1.176	-3.906**	0.106	0.000	-7.817*	-5.403
24	UPR3037-2-2-1-3×NDR 359	-1.136	2.439*	0.000	1.969*	-7.337*	9.851*
25	UPRI 2015-5×NDR 359	2.381	-0.775	0.000	2.137*	-3.889	-3.382
26	UPR3912-21-2-1× NDR 359	0.000	0.000	0.000	-1.688*	4.339	-6.581
27	UPR 3654-5-1-2× NDR 359	-4.494**	0.000	0.000	1.261	-3.259	-5.789
28	UPRI 2015-2× NDR 359	-1.176	1.600	0.000	0.823	-0.577	10.717**
29	UPR 2760-10-1-2×NDR 359	0.000	2.400*	0.000	2.075*	1.718	-16.797**
30	PD 26× NDR 359	2.326	4.839**	0.219	0.000	2.002	-6.848*

Table 4: Estimation of standard heterosis for different character

SI No.	Crosses	Daya to 50% flowering	Days to maturity	Grain length	Grain width	1000 grain weight	Grain yield per plant
1	UPR-3905-22-2-2-1×HKR 47	-0.397	-5.512**	-6.115**	-6.115**	6.090	-66.050**
2	Pant Sugandh Dhan 17× HKR47	-0.770	-2.362 *	-10.383**	-10.383**	3.821	-61.846**
3	PR113×HKR47	-4.273**	-1.575	-1.848 *	-1.848*	-1.734	-68.037**
4	UPR3037-2-2-1-3×HKR47	-3.105	-1.575	4.127**	4.127**	7.811*	-53.782**
5	UPRI 2015-5×HKR47	1.564	-0.787	0.286	0.286	2.960	-28.350**
6	UPR3912-21-2-1×HKR47	0.397	-1.575	-3.555**	-3.555**	-0.013	-10.139**
7	UPR 3654-5-1-2×HKR47	0.397	-0.787	7.114**	7.114**	-12.257**	-43.604**
8	UPRI 2015-2×HKR47	1.564	-0.787	1.139	1.139	-4.003	-35.862**
9	UPR 2760-10-1-2×HKR 47	0.397	0.000	1.566	1.566	-13.431**	-35.190**
10	PD 26×HKR47	-1.938	-0.787	4.127**	4.127	2.217	-64.063**
11	UPR-3905-22-2-2-1×PD 24	-0.770	0.000	0.286	0.286	7.576*	-58.610**
12	Pant Sugandh Dhan 17×PD 24	-0.770	-0.787	-9.103**	-9.103**	4.681	-42.150**
13	PR113×PD 24	1.564	-1.575	0.286	0.286	7.302*	-39.115**
14	UPR3037-2-2-1-3×PD 24	2.732	2.362*	13.515**	13.515**	1.122	-32.809**
15	UPRI 2015-5×PD 24	-0.770	1.575	4.553**	4.553**	-7.915*	-41.647**
16	UPR3912-21-2-1×PD 24	2.732	-0.787	-5.689**	-5.689**	-1.734	0.087
17	UPR 3654-5-1-2×PD 24	-4.273**	2.362*	-0.568	-0.568	-3.651	3.032
18	UPRI 2015-2×PD 24	2.732	-3.150**	-3.555**	-3.555**	5.620	18.728**
19	UPR 2760-10-1-2×PD 24	0.770	-2.362*	3.700**	3.700**	0.965	-25.224**
20	PD 26×PD 24	-3.105	-1.575	2.846**	2.846**	4.916	-21.510**
21	UPR-3905-22-2-2-1×NDR 359	1.564	0.787	5.407**	5.407**	-0.913	-38.740**
22	Pant Sugandh Dhan 17×NDR 359	5.067**	-3.150**	-9.103**	-9.103**	4.134	-22.207**
23	PR113×NDR 359	-1.938	-3.150**	4.553**	4.553**	-2.20	-48.923**
24	UPR3037-2-2-1-3×NDR 359	1.564	-0.787	10.528**	10.528**	-2.673	-27.175**
25	UPRI 2015-5×NDR 359	0.397	0.787	1.993 *	1.993*	1.513	11.101**
26	UPR3912-21-2-1× NDR 359	1.564	-2.362*	-0.568	-0.568	2.530	-49.523**
27	UPR 3654-5-1-2× NDR 359	-0.770	-1.575	2.846**	2.846**	2.178	2.341
28	UPRI 2015-2× NDR 359	-1.938	0.000	4.553**	4.553**	1.122	-62.918**
29	UPR 2760-10-1-2×NDR 359	0.770	0.787	4.980**	4.980**	-2.712	-69.600
30	PD 26× NDR 359	2.732	2.362*	4.127**	4.127**	3.664	-0.446

Discussion

Negative heterosis for days to 50% flowering and days to maturity is desirable in multi-crop rotation systems which involve growing of several crops on same piece of land. In general short duration varieties have higher per day productivity. For days to 50% flowering UPR 3654-5-1-2× NDR 359 (-4.494), PD 26×HKR47 (-4.545) showed highest negative heterosis over better parent followed by UPRI 2015-5×PD 24 (-2.299). UPR 3037-2-2-1-3×HKR47 (-4.046) showed highest negative heterosis over mid parental value followed by PD 26×HKR47 (-3.529) and UPRI 2015-5×PD 24 (-3.448). PR113×HKR47 (-4.273) and UPR 3654-5-1-2×PD 24 (-4.273) exhibit highest negative heterosis over standard check parent. For days to maturity PR113×NDR 359 (-3.906) exhibited highest negative heterosis over better parent followed by Pant Sugandh Dhan 17×NDR 359 (-3.150) and UPR 2760-10-1-2×PD 24 (-3.125). PR113×NDR 359 (-4.280) showed highest negative heterosis over mid parental value followed by Pant Sugandh Dhan 17×NDR 359 (-2.767) and UPR 2760-10-1-2×PD 24 (-2.362) .UPR-3905-22-2-2-1×HKR 47 (-(5.512) exhibit highest negative heterosis over standard check parent followed by UPRI 2015-2×PD 24 (-3.150) and Pant Sugandh Dhan 17×NDR 359 (-3.150). Pant Sugandh Dhan 17×NDR 359, PR113×NDR 359, UPR 2760-10-1-2×PD 24 exhibited significant negative heterobeltiosis and average heterosis. These three hybrids also exhibit significant negative economic heterosis. The results are in accordance with the findings reported by Dwivedi *et al*. (1998) [4]. The desirable features of grain length and grain width depends on the preference of the population residing in the area for which the variety is to be developed. hence, both negative and positive heterosis can be utilized for these two characters. For grain length crosses PD 26×HKR47 (1.33) exhibited highest significant positive heterosis over the better parent followed by UPRI 2015-2×HKR4 (0.962).UPRI 2015-5×HKR47 (-1.316) and UPR-3905-22-2-2-1×HKR 47 (-0.0857) showed significant negative heterobeltiosis. UPR3037-2-2-1-3×PD 24 (5.138) exhibited highest positive heterosis over mid parent followed by UPR 2760-10-1-2×HKR 47 (2.586) and UPR 3654-5-1-2×HKR47 (2.499).UPR-3905-22-2-2-1×HKR 47 (-2.439) showed highest significant negative average heterosis. UPR3037-2-2-1-3×PD 24 (13.515) exhibited highest significant positive heterosis over the standard check followed by UPR3037-2-2-1-3×NDR 359 (10.528) and UPR 3654-5-1-2×HKR47 (7.114). Pant Sugandh Dhan 17× HKR47 (-10.383) exhibited highest significant negative standard heterosis. For grain width UPR3037-2-2-1-3×PD 24 (6.400) hybrid exhibited highest significant positive heterosis over the better parent followed by UPR 2760-10-1-2×HKR 47 (3.030) and UPR 3654-5-1-2×HKR47 (2.445). The cross UPR-3905-22-2-2-1×HKR 47 (-2.655) showed significant negative heterobeltiosis. UPR3037-2-2-1-3×PD 24 (5.138) exhibited highest significant positive heterosis over mid parent followed by UPR 2760-10-1-2×HKR 47 (2.586) and UPR 3654-5-1-2×HKR47 (2.449). UPR-3905-22-2-2-1×HKR 47 (-2.439) showed highest negative heterosis mid parent. UPR3037-2-2-1-3×PD 24 (13.515) exhibited highest significant positive heterosis over the standard check followed by UPR3037-2-2-1-3×NDR 359 (10.528), UPR 3654-5-1-2×HKR47 (7.114). Pant Sugandh Dhan 17× HKR47 (-10.383) exhibited highest significant negative standard heterosis. Positive heterosis is desirable for 1000 grain weight. Pant Sugandh Dhan 17×NDR 359 (8.742) exhibited highest significant positive heterosis over the better parent followed by UPRI 2015-5×HKR47 (8.671) and Pant Sugandh Dhan 17×PD 24 (7.903). UPRI 2015-5×HKR47 (9.166) exhibited highest significant positive relative heterosis followed by Pant Sugandh Dhan 17×NDR 359 (8.742) and Pant Sugandh Dhan 17×PD 24 (8.670). UPR3037-2-2-1-3×HKR47 (7.811) exhibited highest significant positive heterosis over the standard check followed by UPR-3905-22-2-2-1×PD 24 (7.576) and PR113×PD 24 (7.302). Similar findings were reported by Singh *et al.* (2007) [5]. Positive heterosis is desirable for grain yield per plant. UPR3037-2-2-1-3×HKR47 (19.240) exhibited highest significant positive heterosis over the better parent followed by UPRI 2015-5×PD 24 (12.894), UPR 2760-10-1-2×HKR 47 (11.589) and UPRI 2015-2× NDR 359 (10.717). UPRI 2015-2× NDR 359 (15.387) exhibited highest significant positive relative heterosis followed by UPR3037-2-2-1-3×HKR47 (14.589) and Pant Sugandh Dhan 17×PD 24 (14.324). UPRI 2015-2×PD 24 (18.728) and UPRI 2015-5×NDR 359 (11.101) exhibited significant heterosis over the check parent. UPRI 2015-2×PD 24 exhibited significant positive heterobeltiosis and average heterosis. It also exhibited significant economic heterosis. Similar results were obtain by Abdel *et al.* (2016) [6], Deshmukh *et al.* (2016) [7], Rahimi *et al.* (2010) [8], Gnanasekaran *et al*. (2006) [9], Pandey *et al*. (1995) [10]

Table 5: Summary depicting Promising heterotic crosses for different characters in rice genotypes

SI no.	Characters	Heterobeltiosis	Relative heterosis	Standard heterosis
1	Days to 50% flowering	PD 26×HKR47, UPR 3654-5-1-2× NDR 359 and UPRI 2015-5×PD 24	UPR3037-2-2-1-3×HKR47, PR113×HKR47, PD 26×HKR47	PR113×HKR47 and UPR 3654-5-1-2×PD 24
2	Days to maturity	PR113×NDR 359, Pant Sugandh Dhan 17×NDR 359, UPR 2760-10-1-2×PD 24	PR113×NDR 359, Pant Sugandh Dhan 17×NDR 359, UPR 2760-10-1-2×PD 24	UPR-3905-22-2-2-1×HKR 47 (-5.512), UPRI 2015-2×PD 24 (-3.150), Pant Sugandh Dhan 17×NDR 359 (-3.150)
3	Grain length (cm)	PD 26×HKR47 and UPRI 2015-2×HKR47	UPR3037-2-2-1-3×PD 24, UPR 2760-10-1-2×HKR 47, UPR 3654-5-1-2×HKR47	UPR 3037-2-2-1-3×PD 24, UPR 3037-2-2-1-3×NDR 359
4	Grain width (cm)	UPR 3037-2-2-1-3×PD 24, UPR 2760-10-1-2×HKR 47	UPR 3037-2-2-1-3×PD 24, UPR 2760-10-1-2×HKR 47, UPR 3654-5-1-2×HKR47	UPR 3037-2-2-1-3×PD 24, UPR 3037-2-2-1-3×NDR 359, UPR 3654-5-1-2×HKR47
5	1000 grain weight (gm)	Pant Sugandh Dhan 17×NDR 359, UPRI 2015-5×HKR47	UPRI 2015-5×HKR47, Pant Sugandh Dhan 17×NDR 359	UPR 3037-2-2-1-3×HKR47, UPR-3905-22-2-2-1×PD 24
6	Grain yield per plant (gm)	UPR 3037-2-2-1-3×HKR47, UPRI 2015-5×PD 24, UPR 2760-10-1-2×HKR 47	UPRI 2015-2× NDR 359, UPR3037-2-2-1-3×HKR47, Pant Sugandh Dhan 17×PD 24	UPRI 2015-2×PD 24 and UPRI 2015-5×NDR 359

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