Identifying heterotic combinations for yield and quality traits in Bread Wheat (*Triticum aestivum* L.)

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Abstract
An experiment was conducted to estimate the nature and magnitude of heterosis for grain yield, its components and quality traits in a diallel cross of eight genetically diverse wheat genotypes excluding reciprocals. Highly significant differences were observed among the genotypes for all the traits studied. Significant heterobeltiosis, average heterosis and standard heterosis was observed in the cross BL 3065 x DBW 16 with a value 39.64, 54.59 and 54.30, respectively over the check variety, UP 2554 and it was adjudged best heterotic cross combination for grain yield per plant. The cross UP 2596 x NAPHAL exhibited significant positive standard heterosis for number of tillers per plant and spikelets per spike over the check. The cross UP 2754 x NAPHAL exhibited highest and significant positive heterosis over better parent and mid parent for grains protein content. These crosses can be used in developing high yielding cultivar with good quality traits.

Key words: Heterosis, Diallel, Bread Wheat, Yield, Quality

Introduction

Wheat (*Triticum aestivum* L.) is a predominant cereal crop of the world and constitutes important source of carbohydrate and protein. India ranks second among wheat producing nations with 13.43% global wheat production (USDA, 2014). Wheat is the leading source of vegetable protein in human food, having higher protein content than either maize (corn) or rice, the other major cereals, to assume increasingly greater importance as a source of protein for much of the world's increasing population. Quality traits are becoming progressively more important in wheat breeding programs due to requirement of higher standards imposed by bakers, millers and consumers. Increased urbanization and associated changes in dietary habits have resulted in an increasing demand for wheat with specific quality attributes. Wheat is also used as multiple food and non-food raw material in some industries such as stiffening or surface coating agent in paper industry, as an adhesive in the manufacturing of corrugated boxes, as fermentation substrate, in the production of vitamins, antibodies, etc.

The exploitation of heterosis in wheat (*Triticum aestivum* L.) can be accomplished through the development and identification of high Performance of vigorous parental lines and their subsequent evaluation for combining ability in cross combinations to identify hybrids with high heterotic effects. The grain yield is the primary trait targeted for improvement of wheat productivity in both favourable and unfavourable environments from its present level. In self pollinated crops evidences are available to confirm the potential use of heterosis (Haq and Laila, 1991). Selections of potent parents represent the major step in the development of new high-yielding cultivars, and the efficient identification of superior hybrid combinations is a fundamental issue in wheat breeding programs (Gowda *et al*., 2010). Keeping in view this study was taken up to estimate the heterobeltiosis, average heterosis and standard heterosis of some representative genotypes and their crosses.

Materials and Methods

The present study was conducted at the N. E. Borlaug Crop Research Centre of G. B. Pant University of Agriculture and Technology, Pantnagar located in Udham Singh Nagar (Uttarakhand). The experimental material of the study consisted of eight wheat parental genotypes i.e. PBW 550, DBW 17, Raj 4105, BL 3065, UP 2754, DBW 16, UP 2696, NAPHAL and their 28 F_{1s}. The F_{1s} were made by crossing all the eight parents in half diallel fashion during *Rabi* 2008-09. These crosses were then evaluated along with the parents and check, UP 2554 during 2009-10. The experiment was laid out in a Randomized Block Design (RBD) with three replications. Each plot consisted of two rows of two meter long with a row to row distance of 23 cm. The plant to plant distance was maintained at 10 cm by dibbling the seeds manually. Eight morphological characters namely, days to 75% heading, days to maturity, plant height, number of effective tillers per plant, spike length, number of spikelets per ear, 1000 grain weight, seed yield per plant, and four quality traits, protein content, starch content, wet gluten and zeleny value were studied.

Estimation of heterosis

Heterosis, expressed as per cent increase or decrease in the performance of F_1 hybrid over the mid-parent (average or relative heterosis), better parent (heterobeltiosis) and check parent (standard or economic heterosis) was computed for each character using the following formula:

Relative Heterosis = $\overline{F_1}$ - $\overline{BP}$ / $\overline{MP}$ x 100

Heterobeltiosis = $\overline{F_1}$ - $\overline{BP}$ / $\overline{BP}$ x 100

Standard Heterosis = $\overline{F_1}$ - $\overline{CP}$ / $\overline{CP}$ x 100

Where,

$\overline{F_1}$ = Mean performance of F_1 hybrid

$\overline{P_1}$ = Mean performance of parent one

$\overline{P_2}$ = Mean performance of parent two

$\overline{BP}$ = Mean performance of better parent

$\overline{CP}$ = Mean performance of check parent

$\overline{MP}$ = Mean mid-parental value i.e. (P1+P2)/2

The differences in the magnitudes of relative heterosis, heterosis over male and female parents were tested as per the method proposed by Panse and Sukhatme (1961) and Fonesca and Patterson (1968).

Results and Discussion

Exploitation of heterosis in cultivated plants is one of the most important accomplishments of the science of genetics in agriculture. Although production of hybrids may be the best to exploit the heterosis in F_{1S} but in case of wheat development of successful hybrid for commercial cultivation is yet to become reality in India due to constraints like non-availibilty of stable male sterile lines, effective and high yielding restorers, free pollen dispersal, seed setting and high seed rate. It is therefore, necessary to see heterotic combinations in the first filial generation (F_1) in respect of yield, its components and quality attributes. Singh *et al*. (2004) stated that the superiority of hybrids particularly over high parent is more useful for commercial exploitation of heterosis and also indicated the parental combinations capable of producing the highest level of transgressive segregants.

In the present study the analysis of variance revealed significant variation due to parents for all the characters studied indicating that parents having good amount of genetic variability (Table 1). The variance due to hybrids was also significant for all the characters studied suggesting the generation of good amount of variability among the hybrids and also the possibilities of identifying the superior hybrids from the study. The mean values for all the twelve traits of F_1 hybrids were compared with the values of better parent, mid parent and the standard check were found to be significant for most of the characters which suggest that the hybrids differ considerably from the parents and there exist substantial heterosis for most of the characters studied.

Heterobeltiosis, average heterosis and standard heterosis were estimated with the check UP 2554 and results are presented in Table 2. Heterobeltiosis for days to 75% heading ranged from -17.61 (PBW 550 x NAPHAL) to 2.30 (UP 2754 x UP 2696). The cross PBW 550 x NAPHAL emerged as a better cross than others with a negative heterosis of -17.61, showing significant earliness than the better parent. Negative heterosis for days taken to heading is desirable if these have significant correlation with grain yield per plant for selecting higher yielding and short duration plants. Relative heterosis ranged from -11.27 (DBW 17 x NAPHAL) to 3.09 (UP 2754 x UP 2696). Highest negative standard heterosis was exhibited by DBW 17 x Raj 4105 (-10.51) which showed earliness over the standard check UP 2554. The importance of negative heterosis for days to 75% heading has been highlighted by Gawande and Dhumale (2002), Ashutosh *et al*. (2011) and Devi *et al*. (2013).

Heterobeltiosis for days to maturity ranged from -12.83 (DBW 17 x NAPHAL) to 2.22 (PBW 550 x DBW 17). Relative heterosis ranged from -6.86 (DBW 17 x NAPHAL) to 2.36 (PBW 550 x DBW 17) and the standard heterosis over the check UP 2554 ranged from -4.76 (DBW 17 x Raj 4105) to

0.00 (UP 2754 x NAPHAL).The cross DBW 17 x NAPHAL showed maximum negative heterobeltiosis (-6.86) and relative heterosis (-12.83). DBW 17 x Raj 4105 showed significant negative standard heterosis (-4.76) over the check UP 2554, indicating dominance for early maturity duration in these crosses. The importance of negative heterosis for this trait has been highlighted by Nanda *et al*. (1974) and Singh *et al*. (2013).
Short statured cultivars of wheat became much more popular after the commencement of green revolution in 1960s which drew the attention and attempts of plant breeders to breed for reduced plant height. Moreover the negative estimates of heterosis and heterobeltiosis for plant height are preferred over their mid and better parent in wheat breeding because dwarfness is a desirable character. In this contest the cross PBW 550 x Raj 4105 was observed with maximum (-25.47) amount of negative heterosis over the check UP 2554. However, maximum significant negative heterobeltiosis was observed in the cross UP 2754 x NAPHAL (-22.31) while UP 2696 x NAPHAL showed sufficient negative mid parent heterosis (16.91. Negative heterosis for plant height has also been reported by Yadav and Murty (1976), Randhawa and Minhas (1977), Beche *et al.* (2013) and Singh *et al*. (2013).

Number of productive tillers per plant is one of the most important yield traits, which contributes towards productivity and should be taken into consideration during selection. Heterobeltiosis for productive tillers per plant ranged from -43.75 (PBW 550 x NAPHAL) to 117.82 (DBW 16 x UP 2696) while, relative heterosis ranged from -26.87 (DBW 17 x UP 2696) to 125.64 (DBW 16 x UP 2696).The cross DBW 16 x UP 2696 emerged as the best cross for productive tiller number with highest expression of heterobeltiosis (117.82), significant positive mid parent heterosis (125.64) and economic heterosis (37.50) over the check UP 2554. This cross may prove to be the best source for tillers number per plant. The same hybrid may be advanced and utilized for single plant selection. Similar findings were also reported by Nanda *et al.* (1974), Chowdhry *et al*. (1996) and Singh *et al*. (2013).

Spike length is an important yield component, which contributes towards productivity thus positive heterosis for spike length is desirable. In the present study, the cross DBW 16 x NAPHAL showed the highest positive heterosis over better parent (53.71). Appreciable amount of heterotic response over the better parent was observed in the cross DBW 16 x NAPHAL (43.82). For standard heterosis, the best cross combination was UP 2754 x NAPHAL (30.25), which exhibited the highest significant positive heterosis over the standard check, UP 2554. The results for spike length are in agreement with Ribadia (2007), Dagustu (2008), Ashutosh *et al*. (2011) and Devi *et al*. (2013).
In the present study, the highest magnitude of positive heterotic response for number of spikelets per spike in terms of heterobeltiosis and relative heterosis was recorded in the cross PBW 550 x NAPHAL with the heterotic values of 16.14 and 19.82, respectively. The estimates of standard heterosis was found significantly highest in the cross combination UP 2696 x NAPHAL (17.06). Heterosis for this trait is in general agreement with the findings of Baloch *et al*. (2001) and Devi *et al*. (2013). Exploitation of this trait may contribute to increase the grain yield in wheat breeding programmes.

The test weight is another very important trait contributing towards yield *per se*. The cross Raj 4105 x NAPHAL exhibited the highest magnitude of positive heterosis over both the better parent and the mid parent with estimated values of 14.11 and 26.09 while the cross BL 3065 x UP 2754 showed highest positive standard heterosis over the standard checks with a value of 34.76. Positive heterosis for test weight was earlier reported by Prasad *et al.* (1998), Ashutosh *et al.* (2011) and Singh *et al*. (2012).

Exploitation of heterosis for increased yield was largely attributed to cross-pollinated crops. Freeman (1919) very early reported the presence of heterotic effects in self pollinated crops like wheat. In case of grain yield per plant, the cross BL 3065 x DBW 16 showed the highest significant positive heterosis over better parent, mid parent and check UP 2554 with a value 39.64, 54.59 and 54.30, respectively. Others promising crosses which recorded significantly higher values are BL 3065 x UP 2754, UP 2754 x NAPHAL UP 2754 x NAPHAL, PBW 550 x Raj 4105 and UP 2754 x NAPHAL. In some crosses where heterosis was observed, over dominance might be involved and it may be concluded that effective selection of desirable recombinants from this material is possible. The results reporting positive heterosis for grain yield per plant are in complete agreement with Borghi and Perenzin (1994), Ribadia *et al*. (2007) and Devi *et al*. (2013).

Protein content is one of the important desirable qualitative traits of wheat, which not only helps averting malnutrition but also very much desired for good bread and chapati making quality. The estimate for grain protein content for heterobeltiosis, mid parent heterosis and standard heterosis over check UP 2554 ranged from -12.67

to 16.95, -19.25 to 17.46 and -17.13 to 16.02, respectively. Maximum positive heterosis for this character for both heterobeltiosis and mid parent heterosis was recorded in the cross UP 2754 x UP 2696 with the values of 16.95 and 17.46, respectively. Significant standard heterosis over the check, UP 2554 was observed in crosse DBW 16 x NAPHAL (16.02) followed by UP 2754 x NAPHAL (14.92). The findings corroborate with the results reported by Kumar and Maloo (2011) Desale and Mehra (2013) and Singh *et al.* (2014). Heterobeltiosis, average heterosis and standard heterosis was also recorded significant effects for starch content in present investigation.

Gluten is an important qualitative trait of wheat for bread making quality. The cross DBW x NAPHAL looked to be promising with was highest positive estimates of better parent heterosis, mid parent heterosis and standard heterosis over the check, UP 2554 for wet gluten with a value of 21.89, 24.79 10.56, respectively. While, in case of zeleny value the same cross DBW x NAPHAL exhibit highest significant value for heterobeltiosis, mid parent heterosis and standard heterosis i.e. 45.94, 49.35 and 36.65, respectively. This cross could be utilized to generate transgressive segregants for quality traits. These results are in agreement with Mahmood *et al*. (2006) and Saxena and Rawat (2011).

The findings of the present investigation reveal the presence of good amount of genetic variability among the parents and hence there exists ample possibility for the exploitation of heterosis for grain yield and quality traits. The cross BL 3065 x DBW 16 was recognized as the best heterotic cross for grain yield and it exhibited highly significant positive heterosis over the standard check UP 2554 (Table 3). Therefore, this cross can be further evaluated and used in hybrid breeding programme to boost up the grain yield. Moreover, the cross UP 2754 x NAPHAL exhibited highest and significant positive heterosis over the standard check for protein content while the cross DBW 16 x NAPHAL showed best positive heterosis over better parent, mid parent and standard check for wet gluten content. Besides, results of present study also reveal ample scope for finding transgressive segregants involving some of these parents in developing high yielding wheat genotypes with good quality attributes.

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Table 1: Analysis of variance for different characters

Source of variation	d.f.	Days 75% flowering	Days to maturity	Plant height	Spike length (cm)	No. of spikelet/ spike	Test wt. (g)	Yield/plant (g)	Protein content (%)	Starch content	Wet Gluten	Zeleny value
Replicates	2	15.86	28.03	24.07	0.12	0.39	3.58	36.92	0.24	8.71	0.25	0.21
Treatments	35	31.93**	24.67**	176.01**	8.06**	4.01**	36.42**	102.37**	3.06**	3.77**	17.60**	99.38**
Parents	7	85.18**	95.47**	258.34**	11.22**	3.59**	41.25**	55.81*	1.08**	3.33**	3.82**	46.85**
Hybrids	27	15.75**	6.06**	134.27**	3.74**	2.75**	36.45**	79.12**	3.68**	3.98**	21.77**	113.47**
Parent Vs. Hybrids	1	96.01**	31.72**	726.81**	102.62**	41.01**	1.65	1055.98**	0.26**	1.27*	1.49**	86.91**
Error	70	1.58	2.13	8.68	0.33	0.51	1.32	21.97	0.01	0.28	0.02	0.16
Total	107	11.77	9.99	63.70	2.85	1.65	12.85	48.55	1.02	1.58	5.78	32.61

*, ** Significant at 5% and 1% level, respectively.

Table 2: Estimation of heterosis over better parents, mid parents and standard check for different characters under study

Cross combination	Days to 75% heading			Days to maturity			Plant height (cm)			Tillers per plant		
	Hetero-beltiosis	Mid parent heterosis	Standard heterosis UP 2554	Hetero-beltiosis	Mid parent heterosis	Standard heterosis UP 2554	Hetero-beltiosis	Mid parent heterosis	Standard heterosis UP 2554	Hetero-beltiosis	Mid parent heterosis	Standard heterosis UP 2554
PBW 550/ DBW17	-0.37	2.70*	-3.62**	2.22*	2.36**	-2.38*	-12.22**	-11.64**	-23.87**	-0.63	1.49	-0.63
PBW 550/ Raj4105	1.57	2.37*	-6.16**	0.54	1.51	-2.12*	-19.97**	-16.60**	-25.47**	24.37	51.91**	24.37
PBW 550/ BL3065	-0.39	0.79	-7.25**	0.55	1.24	-2.65**	-12.20**	-2.60	-6.40**	-14.38	5.38	-14.38
PBW 550/ UP2754	-2.68*	-0.78	-7.97**	-1.60	0.14	-2.65**	-1.33	1.18	-11.13**	-8.13	0.80	-8.13
PBW 550/ DBW16	-3.68**	0.19	-5.07**	-1.87	-0.14	-2.91**	-5.90*	-3.93	-16.00**	10.63	39.37**	10.63
PBW 550/ UP2696	1.56	2.76*	-5.43**	0.00	1.10	-2.38*	-10.22**	-3.34	-10.40**	-36.25**	-21.84	-36.25**
PBW 550/ NAPHAL	-17.61**	-10.14**	-10.14**	-10.90**	-4.91**	-2.65**	-21.95**	-12.18**	-14.07**	-43.75**	-22.64	-43.75**
DBW17/ Raj4105	-7.49**	-5.36**	-10.51**	-2.17*	-1.10	-4.76**	-12.56**	-9.45**	-18.57**	-23.04	-7.57	-26.25*
DBW17/ BL3065	-5.99**	-4.20**	-9.06**	0.55	1.38	-2.65**	-17.73**	-9.28**	-12.30**	-31.52*	-17.11	-34.38**
DBW17/ UP2754	-4.49**	-3.41**	-7.61**	-0.53	1.36	-1.59	-4.81	-3.02	-14.27**	-30.22*	-24.91*	-33.13**
DBW17/ DBW16	-1.84	-0.93	-3.26**	-2.41*	-0.54	-3.44**	-10.08**	-8.79**	-19.73**	-8.04	14.02	-11.87
DBW17/ UP2696	-4.49**	-2.67*	-7.61**	-0.81	0.41	-3.17**	-7.41**	-0.93	-7.60**	-39.35**	-26.87	-41.88**
DBW17/ NAPHAL	-16.28**	-11.27**	-8.70**	-12.83**	-6.86**	-4.76**	-22.43**	-13.23**	-14.60**	-38.04**	-15.93	-40.63**
Raj4105/ BL3065	0.39	0.78	-6.52**	-1.63	-1.36	-4.23**	-9.76**	-3.67	-3.80	43.14*	44.55**	-8.75
Raj4105/ UP2754	-2.68*	-1.55	-7.97**	-1.60	-0.81	-2.65**	-6.23*	-4.66	-12.67**	-14.94	-4.14	-30.00*
Raj4105/ DBW16	-7.72**	-4.74**	-9.06**	-2.14*	-1.35	-3.17**	-5.73*	-3.73	-12.20**	41.18*	46.94**	-10.00
Raj4105/ UP2696	0.39	0.78	-6.52**	0.81	0.95	-1.59	-5.68*	-2.42	-5.87*	14.71	15.27	-26.88
Raj4105/ NAPHAL	-15.61**	-8.63**	-7.97**	-10.17**	-4.99**	-1.85	-20.77**	-14.15**	-12.77**	32.35	54.58**	-15.63
BL3065/ UP2754	-2.30	-1.54	-7.61**	-1.34	-0.27	-2.38*	-3.94	4.14	2.40	5.57	20.00	-13.13
BL3065/ DBW16	-4.04**	-1.32	-5.43**	-0.53	0.54	-1.59	-13.07**	-5.38	-7.33**	63.00**	68.04**	1.87
BL3065/ UP2696	-0.39	-0.39	-7.25**	0.54	0.95	-1.85	-4.63	-1.49	1.67	85.15**	86.07**	16.88
BL3065/ NAPHAL	-15.28**	-8.60**	-7.61**	-10.17**	-4.75**	-1.85	-8.69**	-7.21**	0.53	29.00	49.42*	-19.38
UP2754/ DBW16	-1.84	0.19	-3.26**	0.27	0.27	-0.79	-1.04	-0.59	-10.87**	8.61	26.74	-10.62
UP2754/ UP2696	2.30	3.09**	-3.26**	0.27	0.94	-0.79	-11.62**	-7.09**	-11.80**	56.46**	77.08**	28.75*
UP2754/ NAPHAL	-8.97**	-2.49*	-0.72	-8.47**	-3.94**	0.00	-22.31**	-14.54**	-14.47**	16.96	50.73**	-3.75
DBW16/ UP2696	-2.57*	0.19	-3.99**	-0.27	0.40	-1.32	-8.08**	-2.96	-8.27**	117.82**	125.64**	37.50**
DBW16/ NAPHAL	-9.97**	-5.41**	-1.81	-10.17**	-5.72**	-1.85	-16.02**	-7.24**	-7.53**	44.68*	63.20**	-15.00
UP2696/ NAPHAL	-15.61**	-8.96**	-7.97**	-9.44**	-4.35**	-1.06	-20.80**	-16.91**	-12.80**	26.73	47.41*	-20.00

Table 2: contd...

Cross combination	Spike length (cm)			Spikelet/spike			Test wt. (g)			Yield per plant (g)		
	Hetero-beltiosis	Mid parent heterosis	Standard heterosis UP 2554	Hetero-beltiosis	Mid parent heterosis	Standard heterosis UP 2554	Hetero-beltiosis	Mid parent heterosis	Standard heterosis UP 2554	Hetero-beltiosis	Mid parent heterosis	Standard heterosis UP 2554
PBW 550/ DBW17	9.91*	14.91**	12.96**	8.52**	12.20**	12.97**	-20.84**	-19.95**	-3.96	14.05	14.69	21.33
PBW 550/ Raj4105	3.90	18.29**	6.79	4.79	7.91**	8.19**	-11.67**	-9.82**	4.77	25.62*	25.84**	32.14**
PBW 550/ BL3065	3.12	10.46**	22.22**	9.86**	11.57**	10.24	-10.66**	-4.99*	5.97	-9.28	-1.78	-4.58
PBW 550/ UP2754	5.32	11.71**	22.22**	1.24	7.57**	11.60**	-5.65*	-3.31	17.59**	16.78	20.86*	31.74**
PBW 550/ DBW16	12.91**	26.81**	16.05**	5.10	6.74*	5.46	-7.91**	-4.74*	9.23**	10.56	13.29	22.17
PBW 550/ UP2696	12.35**	13.52**	17.90**	2.94	6.60*	7.51*	-1.63	-0.39	19.64**	8.29	14.69	28.23*
PBW 550/ NAPHAL	20.72**	42.81**	24.07**	16.14**	19.82**	12.97**	-18.83**	-8.63**	-3.73	17.49	32.10**	23.59*
DBW17/ Raj4105	6.91	16.91**	0.31	4.59	5.02	8.87**	-12.21**	-9.38**	6.52*	19.54	20.43*	27.17*
DBW17/ BL3065	-1.04	10.47**	17.28**	3.93	5.84*	8.19**	-19.93**	-13.94**	-2.85	-3.77	4.73	2.38
DBW17/ UP2754	-1.06	9.41*	14.81**	-0.62	2.23	9.56**	-5.60*	-4.33*	17.65**	4.60	7.67	18.00
DBW17/ DBW16	7.57	15.96**	0.93	6.56	8.51**	10.92**	-13.66**	-9.71**	4.76	-1.78	0.08	8.53
DBW17/ UP2696	7.65	13.66**	12.96**	6.86	7.04**	11.60**	-15.07**	-14.97**	3.30	-10.74	-5.96	5.70
DBW17/ NAPHAL	26.32**	43.82**	18.52**	9.18**	16.33**	13.65**	10.16**	25.24**	33.66**	6.86	20.74*	13.68
Raj4105/ BL3065	-9.90**	8.81*	6.79	7.44*	8.97**	10.92**	-0.54	3.69	13.13**	8.50	17.28	13.73
Raj4105/ UP2754	-12.23**	5.10	1.85	0.00	3.28	10.24**	-10.27**	-6.17**	11.83**	8.87	12.86	22.82*
Raj4105/ DBW16	24.62**	26.56**	0.00	6.78*	8.30**	10.24**	5.16*	6.58**	19.61**	14.60	17.62	26.64*
Raj4105/ UP2696	5.88	21.62**	11.11**	3.59	4.19	8.19**	-2.77**	0.49	18.26**	19.93*	27.23**	42.02**
Raj4105/ NAPHAL	32.54**	38.59**	3.09	1.49	7.72**	4.78	14.11**	26.09**	29.79**	25.32*	40.69**	31.36**
BL3065/ UP2754	6.77	7.89*	26.54**	-3.56	0.97	6.31*	8.12**	17.65**	34.76**	36.38**	52.39**	53.86**
BL3065/ DBW16	5.21	25.47**	24.69**	-1.36	-1.36	-1.02	10.11**	13.32**	21.92**	39.64**	54.59**	54.30**
BL3065/ UP2696	10.42**	17.13**	30.86**	-8.17**	-6.33*	-4.10	-6.24**	0.88	14.03**	28.67**	46.83**	52.37**
BL3065/ NAPHAL	10.94**	38.76**	31.48**	-1.53	3.12	-1.19	1.53	7.90**	6.06*	22.57	27.73*	9.24
UP2754/ DBW16	13.30**	33.96**	31.48**	-2.48	2.11	7.51**	-16.68**	-11.76**	3.84	10.10	11.24	24.21*
UP2754/ UP2696	11.97**	17.60**	29.94**	4.95	7.79**	15.70**	-11.89**	-10.82**	9.81**	6.76	9.34	26.42*
UP2754/ NAPHAL	12.23**	39.27**	30.25**	3.72	13.46**	14.33**	-6.60**	7.41**	16.40**	23.04*	42.56**	38.81**
DBW16/ UP2696	18.24**	34.00**	24.07**	4.25	6.33*	8.87**	-1.76	2.85	19.49**	2.28	5.82	21.12
DBW16/ NAPHAL	57.31**	66.94**	26.23**	11.90**	17.19**	12.29**	2.06	11.42**	13.00**	14.23	31.19**	26.22*
UP2696/ NAPHAL	14.71**	36.84**	20.37**	12.09**	19.62**	17.06**	-12.44**	-0.35	6.50*	5.59	24.83**	25.04*

Table 2: contd...

Cross combination	Protein content %			Starch contents			Wet gluten			Zeleny value		
	Hetero-beltiosis	Mid parent heterosis	Standard heterosis UP 2554	Hetero-beltiosis	Mid parent heterosis	Standard heterosis UP 2554	Hetero-beltiosis	Mid parent heterosis	Standard heterosis UP 2554	Hetero-beltiosis	Mid parent heterosis	Standard heterosis UP 2554
PBW 550/ DBW17	-3.33**	-2.52**	-3.87**	-2.44**	-1.36*	-0.60	-2.54**	1.61**	-6.86**	8.23**	10.55**	2.72**
PBW 550/ Raj4105	2.19**	3.89**	3.31**	0.75	1.92**	0.40	-1.77**	-1.50**	-6.12**	-8.17**	-0.08	3.99**
PBW 550/ BL3065	-7.91**	-4.54**	-9.94**	-0.20	-0.07	-0.55	-8.51**	-3.78**	-12.57**	-17.26**	-10.67**	-21.48**
PBW 550/ UP2754	-7.63**	-6.84**	-9.67**	-1.30	-0.38	-1.64	-5.52v	-2.62**	-9.71**	-10.73**	-4.77**	-15.28**
PBW 550/ DBW16	-7.34**	-4.23**	-9.39**	-0.15	0.78	-0.50	-8.95**	-4.41**	-12.99**	-6.44**	-3.28**	-11.21**
PBW 550/ UP2696	11.30**	12.73**	8.84**	-3.29**	-2.29**	-3.63**	9.72**	12.27**	4.86**	25.67**	31.86**	19.27**
PBW 550/ NAPHAL	-12.27**	-8.82**	-7.18**	-0.95	0.08	-1.29	-7.96v	-5.56**	-12.04**	-8.05**	-7.09**	-12.73**
DBW17/ Raj4105	-11.75**	-11.02**	-10.77**	-1.02	1.22*	0.84	-14.33v	-10.92**	-18.59**	-27.21**	-19.25**	-17.57**
DBW17/ BL3065	-7.78**	-3.63**	-8.29**	-1.22	0.00	0.65	-3.37**	-2.49**	-15.21**	-11.30**	-6.13**	-19.35**
DBW17/ UP2754	-5.56**	-3.95**	-6.08**	-0.59	1.44*	1.29	0.47	1.66**	-9.71**	3.64**	8.35**	-5.77**
DBW17/ DBW16	-12.50**	-8.83**	-12.98**	-0.59	1.44*	1.29	-8.30**	-7.64**	-19.54**	-8.12**	-6.99**	-16.47**
DBW17/ UP2696	-16.39**	-14.61**	-16.85**	-1.27	0.85	0.60	-13.89**	-12.21**	-21.44**	-16.53**	-14.20**	-24.11**
DBW17/ NAPHAL	-21.67**	-19.25**	-17.13**	-1.41*	0.70	0.45	3.61**	5.33**	-6.02**	10.59**	11.82**	2.80**
Raj4105/ BL3065	-16.94**	-12.52**	-16.02**	0.95	1.99**	0.35	-17.22**	-13.17**	-21.33**	-30.58**	-19.02**	-21.39**
Raj4105/ UP2754	-7.10**	-4.76**	-6.08**	1.98**	2.21**	-0.25	-10.00**	-7.48**	-14.47**	-17.77**	-5.10**	-6.88**
Raj4105/ DBW16	-13.11**	-8.75**	-12.15**	2.18**	2.42**	-0.05	-14.00**	-9.95**	-18.27**	-23.16**	-13.83**	-12.99**
Raj4105/ UP2696	-2.73**	0.14	-1.66**	0.87	0.99	-1.54*	-7.33**	-5.44**	-11.93**	-15.89**	-4.39**	-4.75**
Raj4105/ NAPHAL	-7.83**	-5.74**	-2.49**	1.42*	1.55**	-0.99	-5.78**	-3.58**	-10.45**	-14.17**	-5.72**	-2.80**
BL3065/ UP2754	2.87**	5.76**	-1.10	-1.55*	-0.76	-2.14**	4.35**	6.54**	-6.23**	15.24**	16.73**	-4.33**
BL3065/ DBW16	0.30	0.61	-8.29**	0.25	1.06	-0.35	0.37	0.55	-13.20**	8.61**	13.61**	-3.65**
BL3065/ UP2696	12.17**	14.84**	6.91**	-2.70**	-1.82**	-3.28**	13.19**	16.43**	3.27**	31.39**	35.40**	12.99**
BL3065/ NAPHAL	-4.70**	2.53**	0.83	2.25**	3.18**	1.64*	1.28**	3.88**	-8.13**	-2.19*	4.59**	-9.08**
UP2754/ DBW16	0.86	3.39**	-3.04**	1.57*	1.57*	-0.65	4.00**	5.99**	-6.55**	3.44**	6.87**	-8.23**
UP2754/ UP2696	16.95**	17.46**	12.43**	-1.78**	-1.68**	-3.92**	15.28**	16.15**	5.17**	52.52**	55.20**	31.15**
UP2754/ NAPHAL	8.62**	13.82**	14.92**	-0.56	-0.46	-2.73**	14.90**	15.44**	4.22**	31.96**	39.41**	22.67**
DBW16/ UP2696	6.96**	9.17**	1.93*	-1.63*	-1.53**	-3.78**	10.07**	13.01**	0.42	20.96**	22.84**	7.30**
DBW16/ NAPHAL	9.66**	17.65**	16.02**	-1.73*	-1.63**	-3.87**	21.89**	24.79**	10.56**	45.94**	49.35**	35.65**
UP2696/ NAPHAL	-12.27**	-7.69**	-7.18**	-0.41	-0.41	-2.78**	-3.82**	-3.54**	-12.25**	-2.47**	1.33	-9.34**

Table 3: Promising heterotic crosses for various characters and numbers of desired hybrids

S. No.	Character	Relative heterosis	Heterobeltosis	Standard heterosis (Check UP 2554)	No. of desired hybrids
1	Days to 75% flowering	DBW17 x NAPHAL (-11.27)	PBW550 x NAPHAL (-17.61)	DBW17 x Raj4105 (-10.51)	26
2	Days to maturity	DBW17 x NAPHAL (-6.86)	DBW17 x NAPHAL (-12.83)	DBW17 x Raj4105 (-4.76)	16
3	Plant height (cm)	UP2696 x NAPHAL (-16.91)	UP2574 x NAPHAL (22.31)	PBW550 x Raj4105 (25.74)	24
4	Tillers per plant	UP2696 x NAPHAL (125.64))	UP2696 x NAPHAL (117.82)	UP2696 x NAPHAL (37.50)	2
5	Spike length (cm)	DBW16 x NAPHAL (66.94)	DBW16 x NAPHAL (57.31)	UP2754 x NAPHAL (30.25)	21
6	Spikelet/spike	PBW550 x NAPHAL (19.82)	PBW550 x NAPHAL (16.14)	UP2696 x NAPHAL (17.06)	22
7	Test weight (g)	Raj4105 x NAPHAL (26.09)	Raj4105 x NAPHAL (14.11)	BL3065 x UP2754 (34.76)	20
8	Yield per plant (g)	BL3065 x DBW16 (54.59)	BL3065 x DBW16 (39.64)	BL3065 x DBW16 (54.30)	16
9	Protein content (%)	UP2754 x UP2696 (17.46)	UP2754 x UP2696 (16.95)	UP2754 x NAPHAL (14.92)	6
10	Starch content	BL3065 x NAPHAL (3.18)	BL3065 x NAPHAL (2.25)	BL3065 x NAPHAL (1.64)	1
11	Wet gluten	DBW16 x NAPHAL (24.79)	DBW16 x NAPHAL (21.89)	DBW16 x NAPHAL (10.56)	4
12	Zeleny value	UP2754 x UP2696 (55.20)	UP2754 x UP2696 (52.52)	DBW16 x NAPHAL (35.65)	8