Available online at www.ijpab.com

DOI: http://dx.doi.org/10.18782/2320-7051.6684

ISSN: 2320 – 7051

Int. J. Pure App. Biosci. **6 (4):** 107-115 (2018)

International Journal of Pure & Applied Bioscience

Research Article

OPEN ACCESS

Identification of Heterotic Combinations for Grain Yield and Quality Traits in Bread Wheat (*Triticum aestivum* L.)

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Received: 2.07.2018 | Revised: 12.08.2018 | Accepted: 19.08.2018

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 HI 1588 x MP 4080 with a value 39.64, 54.59 and 54.30, respectively over the check variety, GW 496 and it was adjudged best heterotic cross combination for grain yield per plant. The cross HD 2392 x GW 273 exhibited significant positive standard heterosis for number of tillers per plant and spikelets per spike over the check. The cross UP 2669 x GW 273 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[25]. 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.

Cite this article: Patel, H.N., Identification of Heterotic Combinations for Grain Yield and Quality Traits in Bread Wheat (*Triticum aestivum* L.), *Int. J. Pure App. Biosci.* **6(4):** 107-115 (2018). doi: http://dx.doi.org/10.18782/2320-7051.6684

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[12]. 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[11]. Keeping in view this study was taken up to estimate the heterobeltiosis, average heterosis and standard heterosis of some representative genotypes and their crosses.

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MATERIAL AND METHODS

The present study was conducted at the Agricultural Research Station of S. D. Agricutural University, Ladol, Ta-vijapur located in Gujarat. The experimental material of the study consisted of eight wheat parental genotypes i.e. PBW 612, GW 418, Raj 4229, HI 1588, UP 2669, MP 4080, HD 2392, GW 273 and their 28 F_{1s}. The F_{1s} were made by crossing all the eight parents in half diallel fashion during *Rabi* 2012-13. These crosses were then evaluated along with the parents and check, GW 496 during 2013-14. 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:

$$\text{Relative heterosis (\%)} = \frac{\overline{F1} - \overline{MP}}{\overline{MP}} \times 100$$

$$\text{Heterobeltiosis (\%)} = \frac{\overline{F1} - \overline{BP}}{\overline{BP}} \times 100$$

$$\text{Standard heterosis (\%)} = \frac{\overline{F1} - \overline{SC}}{\overline{SC}} \times 100$$

Where,

F_1= Mean performance of F_1 hybrid

P_1= Mean performance of parent one

P_2= Mean performance of parent two

BP = Mean performance of better parent

CP= Mean performance of check parent

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[16] and Fonesca and Patterson[8].

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*.[21] 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 GW 496 and results are presented in Table 2. Heterobeltiosis for days to 75% heading ranged from -17.61 (PBW 612 x GW 273) to 2.30 (UP 2669 x HD 2392). The cross PBW 612 x GW 273 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(GW 418 x GW 273) to 3.09 (UP 2669 x HD 2392). Highest negative standard heterosis was exhibited by GW 418 x Raj 4229(-10.51) which showed earliness over the standard check GW 496. The importance of negative heterosis for days to 75% heading has been highlighted by Gawande and Dhumale, Ashutosh *et al*.[1] and Devi *et al*.[7]. Heterobeltiosis for days to maturity ranged from -12.83 (GW 418 x GW 273) to 2.22 (PBW 612 x GW 418). Relative heterosis ranged from-6.86(GW 418 x GW 273) to 2.36 (PBW 612 x GW 418) and the standard heterosis over the check GW 496 ranged from -4.76 (GW 418 x Raj 4229) to 0.00 (UP 2669 x GW 273).

The cross GW 418 x GW 273 showed maximum negative heterobeltiosis (-6.86) and relative heterosis (-12.83). GW 418 x Raj 4229 showed significant negative standard heterosis (-4.76) over the check GW 496, indicating dominance for early maturity duration in these crosses. The importance of negative heterosis for this trait has been highlighted by Nanda *et al*.[15] and Singh *et al*.[23].

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 612 x Raj 4229 was observed with maximum (-25.47) amount of negative heterosis over the check GW 496.

However, maximum significant negative heterobeltiosis was observed in the cross UP 2669 x GW 273 (-22.31) while HD 2392 x GW 273 showed sufficient negative mid parent heterosis (16.91. Negative heterosis for plant height has also been reported by Yadav and Murty[26], Randhawa and Minhas[18], Beche *et al.*[2] and Singh *et al*.[23].

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 612 x GW 273) to 117.82 (MP 4080 x HD 2392) while, relative heterosis ranged from -26.87 (GW 418 x HD 2392) to 125.64 (MP 4080 x HD 2392).The cross MP 4080 x HD 2392 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 GW 496. 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.*[15], Chowdhry *et al*.[4] and Singh *et al*. showed the highest positive heterosis over better parent (53.71). Appreciable amount of heterotic response over the better parent was observed in the cross MP 4080 x GW 273 (43.82). For standard heterosis, the best cross combination was UP 2669 x GW 273 (30.25), which exhibited the highest significant positive heterosis over the standard check, GW 496. The results for spike length are in agreement with Ribadia[19], Dagustu[5], Ashutosh *et al*.[1] and Devi *et al*.[7].

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 612 x GW 273 with the heterotic values of 16.14 and 19.82, respectively. The estimates of standard heterosis was found significantly highest in the cross combination HD 2392 x GW 273 (17.06). Heterosis for this trait is in general agreement with the findings of Baloch *et al*. and Devi *et al*.[7]. 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 4229 x GW 273 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 HI 1588 x UP 2669 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.*[17], Ashutosh *et al.*[1] and Singh *et al*.[22].

Exploitation of heterosis for increased yield was largely attributed to cross-pollinated crops. Freeman[9] very early reported the presence of heterotic effects in self pollinated crops like wheat. In case of grain yield per plant, the cross HI 1588 x MP 4080 showed the highest significant positive heterosis over better parent, mid parent and check GW 496 with a value 39.64, 54.59 and 54.30, respectively. Others promising crosses which recorded significantly higher values are HI 1588 x UP 2669, UP 2669 x GW 273, PBW 612 x Raj 4229 and HD 2392 x GW 273. 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[3], Ribadia *et al*.[19] and Devi *et al*.[7].

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 GW 496 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 2669 x

HD 2392 with the values of 16.95 and 17.46, respectively. Significant standard heterosis over the check, GW 496 was observed in crosse MP 4080 x GW 273 (16.02) followed by UP 2669 x GW 273 (14.92). The findings corroborate with the results reported by Kumar and Maloo[13] Desale and Mehra[6] and Singh *et al.*[24].

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 MP 4080 x GW 273 looked to be promising with was highest positive estimates of better parent heterosis, mid parent heterosis and standard heterosis over the check, GW 496 for wet gluten with a value of 21.89, 24.79 10.56, respectively. While, in case of zeleny value the same cross MP 4080 x GW 273 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.*[14] and Saxena and Rawat[20].

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 HI 1588 x MP 4080 was recognized as the best heterotic cross for grain yield and it exhibited highly significant positive heterosis over the standard check GW 496 (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 2669 x GW 273 exhibited highest and significant positive heterosis over the standard check for protein content while the cross MP 4080 x GW 273 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.

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 GW 496	Hetero-beltiosis	Mid parent heterosis	Standard heterosis GW 496	Hetero-beltiosis	Mid parent heterosis	Standard heterosis GW 496	Hetero-beltiosis	Mid parent heterosis	Standard heterosis GW 496
PBW 612/ GW 418	-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 612/ Raj4229	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 612/ HI 1588	-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 612/ UP2669	-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 612/ MP 4080	-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 612/ HD 2392	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 612/ GW 273	-17.61**	-10.14**	-10.14**	-10.90**	-4.91**	-2.65**	-21.95**	-12.18**	-14.07**	-43.75**	-22.64	-43.75**
GW 418/ Raj 4229	-7.49**	-5.36**	-10.51**	-2.17*	-1.10	-4.76**	-12.56**	-9.45**	-18.57**	-23.04	-7.57	-26.25*
GW 418/ HI 588	-5.99**	-4.20**	-9.06**	0.55	1.38	-2.65**	-17.73**	-9.28**	-12.30**	-31.52*	-17.11	-34.38**
GW 418/ UP2669	-4.49**	-3.41**	-7.61**	-0.53	1.36	-1.59	-4.81	-3.02	-14.27**	-30.22*	-24.91*	-33.13**
GW 418/ MP 4080	-1.84	-0.93	-3.26**	-2.41*	-0.54	-3.44**	-10.08**	-8.79**	-19.73**	-8.04	14.02	-11.87
GW 418/ HD 2392	-4.49**	-2.67*	-7.61**	-0.81	0.41	-3.17**	-7.41**	-0.93	-7.60**	-39.35**	-26.87	-41.88**
GW 418/ GW 273	-16.28**	-11.27**	-8.70**	-12.83**	-6.86**	-4.76**	-22.43**	-13.23**	-14.60**	-38.04**	-15.93	-40.63**
Raj 4229/ HI 1588	0.39	0.78	-6.52**	-1.63	-1.36	-4.23**	-9.76**	-3.67	-3.80	43.14*	44.55**	-8.75
Raj 4229/ UP2669	-2.68*	-1.55	-7.97**	-1.60	-0.81	-2.65**	-6.23*	-4.66	-12.67**	-14.94	-4.14	-30.00*
Raj 4229/ MP 4080	-7.72**	-4.74**	-9.06**	-2.14*	-1.35	-3.17**	-5.73*	-3.73	-12.20**	41.18*	46.94**	-10.00
Raj 4229/ HD 2392	0.39	0.78	-6.52**	0.81	0.95	-1.59	-5.68*	-2.42	-5.87*	14.71	15.27	-26.88
Raj 4229/ GW 273	-15.61**	-8.63**	-7.97**	-10.17**	-4.99**	-1.85	-20.77**	-14.15**	-12.77**	32.35	54.58**	-15.63
HI 1588/ UP2669	-2.30	-1.54	-7.61**	-1.34	-0.27	-2.38*	-3.94	4.14	2.40	5.57	20.00	-13.13
HI 1588/ MP 4080	-4.04**	-1.32	-5.43**	-0.53	0.54	-1.59	-13.07**	-5.38	-7.33**	63.00**	68.04**	1.87
HI 1588/ HD 2392	-0.39	-0.39	-7.25**	0.54	0.95	-1.85	-4.63	-1.49	1.67	85.15**	86.07**	16.88
HI 1588/ GW 273	-15.28**	-8.60**	-7.61**	-10.17**	-4.75**	-1.85	-8.69**	-7.21**	0.53	29.00	49.42*	-19.38
UP 2669/ MP 4080	-1.84	0.19	-3.26**	0.27	0.27	-0.79	-1.04	-0.59	-10.87**	8.61	26.74	-10.62
UP 2669/ HD 2392	2.30	3.09**	-3.26**	0.27	0.94	-0.79	-11.62**	-7.09**	-11.80**	56.46**	77.08**	28.75*
UP 2669/ GW 273	-8.97**	-2.49*	-0.72	-8.47**	-3.94**	0.00	-22.31**	-14.54**	-14.47**	16.96	50.73**	-3.75
MP 4080/ HD 2392	-2.57*	0.19	-3.99**	-0.27	0.40	-1.32	-8.08**	-2.96	-8.27**	117.82**	125.64**	37.50**
MP 4080/ GW 273	-9.97**	-5.41**	-1.81	-10.17**	-5.72**	-1.85	-16.02**	-7.24**	-7.53**	44.68*	63.20**	-15.00
HD 2392/ GW 273	-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 GW 496	Hetero-beltiosis	Mid parent heterosis	Standard heterosis GW 496	Hetero-beltiosis	Mid parent heterosis	Standard heterosis GW 496	Hetero-beltiosis	Mid parent heterosis	Standard heterosis GW 496
PBW 612/ GW 418	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 612/ Raj4229	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 612/ HI 1588	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 612/ UP2669	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 612/ MP 4080	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 612/ HD 2392	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 612/ GW 273	20.72**	42.81**	24.07**	16.14**	19.82**	12.97**	-18.83**	-8.63**	-3.73	17.49	32.10**	23.59*
GW 418/ Raj 4229	6.91	16.91**	0.31	4.59	5.02	8.87**	-12.21**	-9.38**	6.52*	19.54	20.43*	27.17*
GW 418/ HI 588	-1.04	10.47**	17.28**	3.93	5.84*	8.19**	-19.93**	-13.94**	-2.85	-3.77	4.73	2.38
GW 418/ UP2669	-1.06	9.41*	14.81**	-0.62	2.23	9.56**	-5.60*	-4.33*	17.65**	4.60	7.67	18.00
GW 418/ MP 4080	7.57	15.96**	0.93	6.56	8.51**	10.92**	-13.66**	-9.71**	4.76	-1.78	0.08	8.53
GW 418/ HD 2392	7.65	13.66**	12.96**	6.86	7.04**	11.60**	-15.07**	-14.97**	3.30	-10.74	-5.96	5.70
GW 418/ GW 273	26.32**	43.82**	18.52**	9.18**	16.33**	13.65**	10.16**	25.24**	33.66**	6.86	20.74*	13.68

Raj 4229/ HI 1588	-9.90**	8.81*	6.79	7.44*	8.97**	10.92**	-0.54	3.69	13.13**	8.50	17.28	13.73
Raj 4229/ UP2669	-12.23**	5.10	1.85	0.00	3.28	10.24**	-10.27**	-6.17**	11.83**	8.87	12.86	22.82*
Raj 4229/ MP 4080	24.62**	26.56**	0.00	6.78*	8.30**	10.24**	5.16*	6.58**	19.61**	14.60	17.62	26.64*
Raj 4229/ HD 2392	5.88	21.62**	11.11**	3.59	4.19	8.19**	-2.77**	0.49	18.26**	19.93*	27.23**	42.02**
Raj 4229/ GW 273	32.54**	38.59**	3.09	1.49	7.72**	4.78	14.11**	26.09**	29.79**	25.32*	40.69**	31.36**
HI 1588/ UP2669	6.77	7.89*	26.54**	-3.56	0.97	6.31*	8.12**	17.65**	34.76**	36.38**	52.39**	53.86**
HI 1588/ MP 4080	5.21	25.47**	24.69**	-1.36	-1.36	-1.02	10.11**	13.32**	21.92**	39.64**	54.59**	54.30**
HI 1588/ HD 2392	10.42**	17.13**	30.86**	-8.17**	-6.33*	-4.10	-6.24**	0.88	14.03**	28.67**	46.83**	52.37**
HI 1588/ GW 273	10.94**	38.76**	31.48**	-1.53	3.12	-1.19	1.53	7.90**	6.06*	22.57	27.73*	9.24
UP 2669/ MP 4080	13.30**	33.96**	31.48**	-2.48	2.11	7.51**	-16.68**	-11.76**	3.84	10.10	11.24	24.21*
UP 2669/ HD 2392	11.97**	17.60**	29.94**	4.95	7.79**	15.70**	-11.89**	-10.82**	9.81**	6.76	9.34	26.42*
UP 2669/ GW 273	12.23**	39.27**	30.25**	3.72	13.46**	14.33**	-6.60**	7.41**	16.40**	23.04*	42.56**	38.81**
MP 4080/ HD 2392	18.24**	34.00**	24.07**	4.25	6.33*	8.87**	-1.76	2.85	19.49**	2.28	5.82	21.12
MP 4080/ GW 273	57.31**	66.94**	26.23**	11.90**	17.19**	12.29**	2.06	11.42**	13.00**	14.23	31.19**	26.22*
HD 2392/ GW 273	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 GW 496	Hetero-beltiosis	Mid parent heterosis	Standard heterosis GW 496	Hetero-beltiosis	Mid parent heterosis	Standard heterosis GW 496	Hetero-beltiosis	Mid parent heterosis	Standard heterosis GW 496
PBW 612/ GW 418	-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 612/ Raj4229	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 612/ HI 1588	-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 612/ UP2669	-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 612/ MP 4080	-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 612/ HD 2392	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 612/ GW 273	-12.27**	-8.82**	-7.18**	-0.95	0.08	-1.29	-7.96v	-5.56**	-12.04**	-8.05**	-7.09**	-12.73**
GW 418/ Raj 4229	-11.75**	-11.02**	-10.77**	-1.02	1.22*	0.84	-14.33v	-10.92**	-18.59**	-27.21**	-19.25**	-17.57**
GW 418/ HI 588	-7.78**	-3.63**	-8.29**	-1.22	0.00	0.65	-3.37**	-2.49**	-15.21**	-11.30**	-6.13**	-19.35**
GW 418/ UP2669	-5.56**	-3.95**	-6.08**	-0.59	1.44*	1.29	0.47	1.66**	-9.71**	3.64**	8.35**	-5.77**
GW 418/ MP 4080	-12.50**	-8.83**	-12.98**	-0.59	1.44*	1.29	-8.30**	-7.64**	-19.54**	-8.12**	-6.99**	-16.47**
GW 418/ HD 2392	-16.39**	-14.61**	-16.85**	-1.27	0.85	0.60	-13.89**	-12.21**	-21.44**	-16.53**	-14.20**	-24.11**
GW 418/ GW 273	-21.67**	-19.25**	-17.13**	-1.41*	0.70	0.45	3.61**	5.33**	-6.02**	10.59**	11.82**	2.80**
Raj 4229/ HI 1588	-16.94**	-12.52**	-16.02**	0.95	1.99**	0.35	-17.22**	-13.17**	-21.33**	-30.58**	-19.02**	-21.39**
Raj 4229/ UP2669	-7.10**	-4.76**	-6.08**	1.98**	2.21**	-0.25	-10.00**	-7.48**	-14.47**	-17.77**	-5.10**	-6.88**
Raj 4229/ MP 4080	-13.11**	-8.75**	-12.15**	2.18**	2.42**	-0.05	-14.00**	-9.95**	-18.27**	-23.16**	-13.83**	-12.99**
Raj 4229/ HD 2392	-2.73**	0.14	-1.66**	0.87	0.99	-1.54*	-7.33**	-5.44**	-11.93**	-15.89**	-4.39**	-4.75**
Raj 4229/ GW 273	-7.83**	-5.74**	-2.49**	1.42*	1.55**	-0.99	-5.78**	-3.58**	-10.45**	-14.17**	-5.72**	-2.80**
HI 1588/ UP2669	2.87**	5.76**	-1.10	-1.55*	-0.76	-2.14**	4.35**	6.54**	-6.23**	15.24**	16.73**	-4.33**
HI 1588/ MP 4080	0.30	0.61	-8.29**	0.25	1.06	-0.35	0.37	0.55	-13.20**	8.61**	13.61**	-3.65**
HI 1588/ HD 2392	12.17**	14.84**	6.91**	-2.70**	-1.82**	-3.28**	13.19**	16.43**	3.27**	31.39**	35.40**	12.99**
HI 1588/ GW 273	-4.70**	2.53**	0.83	2.25**	3.18**	1.64*	1.28**	3.88**	-8.13**	-2.19*	4.59**	-9.08**
UP 2669/ MP 4080	0.86	3.39**	-3.04**	1.57*	1.57*	-0.65	4.00**	5.99**	-6.55**	3.44**	6.87**	-8.23**
UP 2669/ HD 2392	16.95**	17.46**	12.43**	-1.78**	-1.68**	-3.92**	15.28**	16.15**	5.17**	52.52**	55.20**	31.15**
UP 2669/ GW 273	8.62**	13.82**	14.92**	-0.56	-0.46	-2.73**	14.90**	15.44**	4.22**	31.96**	39.41**	22.67**
MP 4080/ HD 2392	6.96**	9.17**	1.93*	-1.63*	-1.53**	-3.78**	10.07**	13.01**	0.42	20.96**	22.84**	7.30**
MP 4080/ GW 273	9.66**	17.65**	16.02**	-1.73*	-1.63**	-3.87**	21.89**	24.79**	10.56**	45.94**	49.35**	35.65**
HD 2392/ GW 273	-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 GW 496)	No. of desired hybrids
1.	Days to 75% flowering	GW 418 x GW 273(-11.27)	PBW 612 x GW 273(-17.61)	GW 418 x Raj 4229 (-10.51)	26
2.	Days to maturity	GW 418 x GW 273(-6.86)	GW 418 x GW 273(-12.83)	GW 418 x Raj 4229 (-4.76)	16
3.	Plant height (cm)	HD 2392 x GW 273(-16.91)	HD 2392 x GW 273(22.31)	PBW 612 x Raj 4229(25.74)	24
4	Tillers per plant	HD 2392 x GW 273(125.64)	HD 2392 x GW 273(117.82)	HD 2392 x GW 273(37.50)	2
5.	Spike length (cm)	MP 4080 x GW 273(66.94)	MP 4080 x GW 273(57.31)	UP 2669 x GW 273(30.25)	21
6	Spikelet / spike	PBW 612 x GW 273(19.82)	PBW 612 x GW 273(16.14)	HD 2392 x GW 273(17.06)	22
7.	Test weight (g)	Raj 4229 x GW 273(26.09)	Raj 4229 x GW 273(14.11)	HI 1588 x UP 2669(34.76)	20
8	Yield per Plant (g)	HI 1588 x MP 4080(54.59)	HI 1588 x MP 4080(39.64)	UP 2669 x MP 4080(54.30)	16
9.	Protein content (%)	UP 2669 x HD 2392(17.46)	UP 2669 x HD 2392(16.95)	UP 2669 x GW 273(14.92)	6
10.	Starch content	HI 1588 x GW 273(3.18)	HI 1588 x GW 273(2.25)	HI 1588 x GW 273(1.64)	1
11.	Wet gluten	MP 4080 x GW 273(24.79)	MP 4080 x GW 273(21.89)	MP 4080 x GW 273(10.56)	4
12.	Zeleny value	UP 2669 x HD 2392(55.20)	UP 2669 x HD 2392(52.52)	MP 4080 x GW 273(35.65)	8

Acknowledgement

Authors acknowledge with thanks the Associate Research Scientist, Agricultural Research Station, S. D. Agricutural University, At-Ladol, Ta-Vijapur for providing necessary facilities to carry out the present investigation.

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