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Evaluation of Heterotic Potential of Bread Wheat Hybrids under Very Late Sown Conditions

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ABSTRACT: The objective of the current study was to determine heterotic potential of various yield and other contributing traits in a 10 × 10 diallel set of different bread wheat genotypes. The experiment was conducted in randomized block design with three replications during *Rabi* 2021-22. Results of this research revealed that significant differences observed among the genotypes, parents and generation for all studied traits. Some crosses such as Raj 3765 × PBW 343, Raj 3077 × Raj 3765 and PBW 343 × WH 1021 showed maximum heterosis and PBW 343 × HD 2967, Raj 4079 × UP 2425 and PBW 343 × UP 2425 revealed maximum heterobeltiosis for grain yield and most of other contributing traits. These crosses recognized as desirable which may produce the maximum level of transgressive segregants and can be used for yield potential in bread wheat.

Keywords: Heterosis, diallel crossing, yield potential, bread wheat.

INTRODUCTION

Bread wheat (*Triticum aestivum* L. em. Thell.) is a most widely cultivated principle food crop among the cereals in world. It is an allopolyploid resulted from two distinct hybridization processes. The chromosomal doubling occurs after each hybridization, allowing for normal bivalent formation during meiosis and, ultimately, the production of viable plants (Dawlatzay *et al.*, 2022).

Heterosis has outstanding economic importance in agriculture. In terms of plant vegetative growth, adaptation, and productivity, heterosis is the F_1's superiority over both of its parents (Shull, 1908). Heterosis studies helps in evaluation of new strains for their parental utility, identify true heterotic crosses and removing poor crosses in early generations. It also provides valuable insight about the parents capacity for combining traits and their significance in breeding programs (Sharma *et al*. 1986; Borghi *et al*., 1988). The exploitation of heterosis in self-pollinating crops such as wheat has been limited due to difficulties in producing enough hybrid seed. Nowadays, it has satisfactorily cleared that self-fertilizing crops will exhibit heterosis to a degree close to that of cross-fertilizing crops (Larik *et al.*, 1995).

Therefore, the goal of current study was to estimate the degree of heterosis and heterobeltiosis among the hybrids of ten different bread wheat varieties that would be helpful for examining the performance and relationship between hybrids and their parents, as well as for choosing the best parents and crosses for a successful wheat breeding programme.

MATERIALS AND METHODS

Ten selected wheat genotypes were crossed in a diallel fashion excluding reciprocals. In *rabi* 2021-22 the experimental material consisting of ten parents along with their 45 F_1's and 45 F_2's progenies were planted in a randomized block design with three replications in very late sown conditions. The ten parents and 45 F_1's were grown by dibbling seeds in two rows each and the 45 F_2's in a plot of four rows each, in three replications. Each row was 3 m long with row to row spacing of 30 cm and plant to plant spacing of 10 cm was maintained. Non-experimental rows were planted all around the experimental plot to eliminate the border effects, if any. Recommended uniform agronomical package and practices were adopted to raise a good crop population in the field. Observations were recorded on grain yield per plant and other yield contributing traits such as days to 50% heading, days to maturity, plant height (cm), spike length(cm), fertile tillers per plant, flag leaf area (cm^2), 1000-grain weight (g), number of grains per spike, grain yield per spike (g), biomass per plant (g) and harvest index (%). Mean values over selected plants were used for statistical analysis. The analysis of varience was calculated from the method given by Panse and Sukhatme (1985). The heterosis over mid parent, heterosis over better parent (heterobeltiosis) and inbreeding dipression were calculated as the method suggested by Fonseca and Patterson (1968). The formulae were used for estimation of heterosis, heterobeltiosis and inbreeding dipression are given as following:

(a) Heterosis (Heterosis over mid parent)

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

(b) Heterobeltiosis (Heterosis over better parent)

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

(c) Inbreeding depression in per cent $= \frac{\overline{F1} - \overline{F2}}{\overline{F1}} \times 100$

Where,

$\overline{F1}$ and $\overline{F2}$ were the means over replications of a particular cross.

RESULTS AND DISCUSSION

The significant differences observed among the genotypes, parents and generation for all studied traits (Table 1), showing that characters displayed the presence of sufficient genetic diversity among the selected parents. Similarly, F_1 and F_2 generations also exhibited significant differences for all studied characters. Further analysis showed that the mean squares due to F_1 *vs* F_2 and parents *vs* generations were also found significant for all studied characters indicating existence of heterosis. Previous researchers also noted similar results such as Zare-Kohan and Heidari (2012); Singh *et al*. (2012).

In this current study, the heterosis varied from -14.49 to 12.23 for days to 50% heading, -11.41 to 8.96 for days to maturity, -16.77 to 10.85 for plant height, -29.05 to 31.76 for fertile tillers/plant, -30.42 to 35.07 for flag leaf area, -13.62 to 29.85 for spike length, -21.18 to 22.81 for number of grains/spike, -16.21 to 14.93 for 1000-grain weight, -18.02 to 30.75 for grain yield/spike, -16.21 to 14.93 for biomass/plant, -14.05 to 37.28 for grain yield/plant and -18.70 to 49.72 for harvest index. Whereas, heterobeltiosis ranged from -9.69 to 14.93 for days to 50% heading, -8.82 to 10.94 for days to maturity, -15.51 to 12.43 for plant height, -33.54 to 26.25 for fertile tillers/plant, -42.42 to 28.61 for flag leaf area, -14.33 to 15.76 for spike length, -24.66 to 12.18 for number of grains/spike, -17.46 to 12.24 for 1000-grain weight, -22.66 to 11.05 for grain yield/spike, -17.46 to 12.24 for biomass/plant, -17.73 to 22.93 for grain yield/plant and -22.42 to 29.57 for harvest index (Table 2). The results for different characters were in conformity with the findings of earlier researchers such as Akinci (2009); Kumar and Kerkhi (2014); Thomas *et al.* (2017); Kumar *et al.* (2018).

A number of hybrids showed heterotic effects in desirable direction for various studied traits. The average heterosis and heterobeltiosis was observed in 26 and 15 crosses for days to 50% heading; 26 and 20for days to maturity; 32 and 20 for plant height; 33 and 18 for fertile tillers/plant; 25 and 16 for flag leaf area; 25 and 15 for spike length; 21 and 17 for number of grains/spike; 26 and 16 for 1000-grain weight; 21 and 16 for grain yield/spike; 26 and 16 for biomass/plant;25 and 18 for grain yield/plant and 28 and 9 crosses respectively, for harvest index.

Selection of parents is the most crucial phase of any breeding programs with the objective to develop new genotypes with desirable characters. Therefore, the knowledge of heterosis assists in defining genetic diversity and selection of suitable parental combinations capable of producing the maximum level of transgressive segregants. According to Singh *et al.* (2004), heterosis over better parent (heterobeltiosis) can be more useful for identifying true heterotic cross combinations.

Earliness and dwarfness in wheat is advantageous and desirable hence, crosses with negative and significant heterosis and heterobeltiosis were considered superior for days to heading, days to maturity and plant height. While, positive significant magnitude of heterosis is desirable for grain yield and other contributing characters. In this study, the cross Raj 3765 × PBW 343 for days to 50% heading, number of grains/spike, 1000-grain weight and biomass/plant; Raj 3765 × HD 2967 days to maturity and grain yield/spike; PBW 343 × WH 1021 for plant height; PBW 343 × HD 2967 for fertile tillers/plant; Raj 4079 × WH 1021 for flag leaf area and spike length; and Raj 3765 × DBW 17 for harvest index exhibited maximum average heterosis. Whereas, the cross Raj 3765 × PBW 343 for days to 50% heading and number of grains/spike; Raj 3765 × HD 2967 days to maturity and flag leaf area; PBW 343 × UP 2425 for plant height, 1000-grain weight and biomass/plant; Raj 3765 × WH 1021 for fertile tillers/plant; Raj 3765 × HD 2967 for; Raj 4079 × PBW 343 for spike length and grain yield/spike and Raj 3765 × DBW 17 for harvest index exhibited maximum heterosis over better parent. These hybrids were considered to be most desirable crosses for various studied traits. Similar results also observed by Akbar *et al.* (2010); Upadhyay *et al.* (2020).

For grain yield/plant the crosses Raj 3765 × PBW 343, Raj 3077 × Raj 3765 and PBW 343 × WH 1021showed maximum and desirable heterosis while, the crosses PBW 343 × HD 2967, Raj 4079 × UP 2425 and PBW 343 × UP 2425 revealed maximum and desirable heterobeltiosis. These hybrids also exhibited heterosis and heterobeltiosis in desirable direction for most of the other yield attributing traits. The results of this study stayed the contentions of Grafius (1959) that there could be no distinctive gene system for grain yield *per se* as yield is end product of multiplicative interactions between its various contributing traits. As a result, heterobeltiosis for various yield-attributing traits may be the expression of heterobeltiosis for grain yield. Nevertheless, the crosses exhibiting heterotic expressions for grain yield were not heterotic for all other yield contributing characters traits (Table 3). As a result of considerable G × E interactions, it was also noted that expression of heterosis and heterobeltiosis was influenced by the environments for most of the characters. These results were in agreement with earlier reports of Singh *et al.* (2004); Gite *et al.* (2014); Kumar *et al.* (2017); Nagar *et al.* (2019).

Table 1: Analysis of variance showing mean squares for parents F_1's and F_2's for yield and its contributing traits.

Characters	Source of variation								
	Replication	Genotypes	Parents	Generation	F_1's	F_2's	F_1 *vs* F_2	Parents vs generation	Error
Df	**(2)**	**(99)**	**(9)**	**(89)**	**(44)**	**(44)**	**(1)**	**(1)**	**(198)**
Days to 50% heading	3.87	78.67**	23.51**	84.68**	77.37**	93.62**	12.89*	39.85**	2.99
Days to maturity	4.2	162.87**	29.47**	176.81**	115.84**	237.95**	169.61**	122.47**	4.52
Plant height	7.54	115.82**	86.28**	110.07**	94.79**	126.78**	47.3*	892.63**	11.69
Fertile tillers/plant	0.27	3.41**	1.74**	3.54**	3.14**	3.98**	1.13*	7.65**	0.2
Flag leaf area	0.43	131.19**	54.98**	139.87**	117.89**	163.47**	68.62**	45.05**	2.99
Spike length	0.13	2.01**	0.84**	2.1**	1.58**	2.66**	1*	4.24**	0.2
Number of grains/spike	4.1	82.66**	27.67**	88.92**	74.47**	104.86**	23.59**	20.2*	3.18
1000-grain weight	1.71	43.84**	14.29**	47.24**	41.62**	53.78**	7.01*	6.58*	1.55
Biomass/plant	1.71	43.84**	14.29**	47.24**	41.62**	53.78**	7.01*	6.58*	1.55
Grain yield/spike	0.004	0.12**	0.05**	0.13**	0.11**	0.15**	0.057*	0.06*	0.014
Grain yield/plant	0.02	22.36**	9.14**	23.16**	20.91**	25.84**	4.36*	70.22**	1.1
Harvest index	1.87	89.85**	43.31**	91.44**	84.38**	99.35**	54.49*	366.97**	8.53

Table 2: Estimation of heterosis (H), heterobeltiosis (HB) and inbreeding dipression (ID) for various characters in bread wheat hybrids.

Characters	Days to 50% heading			Days to maturity			Plant height			Fertile tillers/plant		
Crosses	**H**	**HB**	**ID**	**H**	**HB**	**ID**	**H**	**HB**	**ID**	**H**	**HB**	**ID**
Raj 3077 x Raj 4079	1.91	3.9**	-2.35*	6.01**	7.37**	-5.37**	10.85**	12.43**	1.84	29.73**	6.33	0.6
Raj 3077 x Raj 3765	9.05**	13.78**	1.35	7.4**	7.69**	-8.04**	5.33*	5.88*	-2.85	27.97**	4.38	1.8
Raj 3077 x PBW 343	-1.62	-0.47	3.3**	0.46	4.49**	-2.76**	-1.95	0.38	-3.55	11.69*	-0.77	1.55
Raj 3077 x PBW 590	12.23**	14.71**	15.81**	0	2.56*	-14.38**	-9.75**	-4.84	-7.72	-20.91**	-26.89**	-1.15
Raj 3077 x DBW 17	-3.26**	-2.35	-0.96	0.15	4.81**	-3.98**	-10.74**	-1.22	-8.24	22.18**	5.8	2.74
Raj 3077 x HD 2967	-2.38*	-0.97	-0.98	-5.59**	-2.56*	-12.5**	-2.76	-0.35	0.88	30.34**	4.82	1.15
Raj 3077 x HD 3059	-5.14**	-4.69**	0.99	-3.9**	-1.28	1.62	-6.17**	4.07	4.3	15.6**	7.69	1.59
Raj 3077 x WH 1021	5.88**	10.77**	0.93	-1.89*	-0.32	-8.04**	6.08**	6.66*	-1.52	9.52*	-8.61*	1.45
Raj 3077 x UP 2425	-4.35**	-1.49	1.01	-7.04**	-4.81**	-8.08**	3.41	6.8**	-1.9	19.25**	-3.66	3.8**
Raj 4079 x Raj 3765	-7.23**	-5.1**	1.08	-8.47**	-7.55**	2.07*	-10.24**	-8.48**	7.13	18.24**	17.5**	-0.53
Raj 4079 x PBW 343	-9.22**	-6.34**	1.04	-10.2**	-7.81**	6.78**	-13.75**	-12.95**	5.32	30.56**	18.99**	-0.53
Raj 4079 x PBW 590	3.67**	3.92**	6.13**	2.47**	3.75**	-6.33**	-2.26	1.56	-0.24	27.08**	11.39**	0.57
Raj 4079 x DBW 17	-1.90	0.98	0.48	-6.2**	-3.13**	-0.32	-10.11**	-2.04	2.04	-29.05**	-33.54**	0.95
Raj 4079 x HD 2967	-9.71**	-9.27**	2.15*	-9.2**	-7.5**	3.72**	-13.4**	-12.52**	6.07	22.84**	19.88**	-1.01
Raj 4079 x HD 3059	2.38*	4.88**	-2.33*	-3.54**	-2.19*	-2.56**	-0.17	9.03**	-1.2	25.82**	9.49*	7.51**
Raj 4079 x WH 1021	-7.5**	-5.13**	1.62	-7.79**	-7.5**	2.36**	-14.57**	-13.82**	3.33	20.39**	17.72**	-0.54
Raj 4079 x UP 2425	-5.91**	-4.98**	0.52	-7.88**	-6.88**	0.67	-15.83**	-14.31**	-0.27	19.25**	17.07**	-1.04
Raj 3765 x PBW 343	-14.49**	-9.69**	0.56	-9.63**	-6.27**	3.06**	-11.4**	-8.81**	1.14	27.59**	15.63**	-1.62
Raj 3765 x PBW 590	0.00	2.04	-10.5**	-0.57	1.7	-0.31	-0.89	5.08	-8.7	8.24*	-5.63	0.66

Raj 3765 x DBW 17	-4.12**	1.02	-8.59**	-5.3**	-1.17	-0.65	-13.9**	-4.17	-5.78	-18.79**	-24.38**	2.48
Raj 3765 x HD 2967	-9.18**	-6.63**	2.73*	-11.41**	-8.82**	0.35	-11.37**	-8.68**	-2.25	15.95**	13.86**	-0.53
Raj 3765 x HD 3059	-6.57**	-2.04	-3.13**	-1.66	0.74	7.28**	-8.1**	2.51	-2.82	9.03*	-5.62	5.96**
Raj 3765 x WH 1021	-6.91**	-6.67**	0.55	-7.18**	-5.95**	-0.34	-14.08**	-13.16**	1.63	29.9**	26.25**	-0.99
Raj 3765 x UP 2425	-6.3**	-5.1**	2.15*	-8.22**	-6.27**	-3.06**	-14.06**	-10.75**	-1.36	17.28**	15.85**	-0.53
PBW 343 x PBW 590	-2.37*	0.98	-0.49	-2.56**	-1.22	0.62	-9.25**	-6.59**	-6.37	-10.84*	-14.62**	6.31**
PBW 343 x DBW 17	3.45**	3.69**	-8**	2.65**	3.26**	-6.32**	-4.42*	3.14	-3.4	-5.97	-8.7	1.59
PBW 343 x HD 2967	-9.65**	-7.25**	1.56	-8.52**	-7.83**	2.29**	-13.03**	-12.95**	1.04	31.76**	17.47**	-4.62**
PBW 343 x HD 3059	3**	3.72**	-1.35	-0.3	0.91	-1.81*	-0.13	8.01**	6.06	-16.6**	-20.77**	9.71**
PBW 343 x WH 1021	-11.86**	-6.67**	0.55	-6.53**	-4.35**	2.6**	-16.77**	-15.26**	2.94	28.83**	19.87**	-4.42**
PBW 343 x UP 2425	-8.83**	-4.98**	2.09*	-7.23**	-5.81**	6.17**	-16.24**	-15.51**	-0.03	28.57**	15.24**	-1.06
PBW 590 x DBW 17	0.71	3.92**	-2.83**	-4.63**	-2.74*	-5.02**	-4.39*	0.11	-8.06	-5.06	-11.59*	12.3**
PBW 590 x HD 2967	1.22	1.96	0.48	-5.15**	-4.57**	0.96	-8.42**	-5.83*	14.8**	8.07*	-7.23	12.99**
PBW 590 x HD 3059	9.31**	12.25**	-0.44	1.07	1.22	-9.94**	-10.62**	-6.22**	6.92	10.17*	9.24	5.38**
PBW 590 x WH 1021	6.77**	9.23**	-0.47	7.08**	8.07**	3.16**	-0.36	4.47	1.45	7.41	-3.97	6.21**
PBW 590 x UP 2425	-3.21**	-2.49	-5.61**	-1.37	-1.22	-1.55	-6.28**	-4.37	1.56	-2.47	-15.85**	23.19**
DBW 17 x HD 2967	5.66**	8.21**	-5.36**	-2.23*	-0.9	-1.22	0.08	7.89**	7.18	-17.76**	-24.7**	3.2
DBW 17 x HD 3059	5.09**	5.58**	-0.44	8.96**	10.94**	-1.64*	-7.73**	-7.55**	6.6	6.67	-1.45	2.94
DBW 17 x WH 1021	-3.4**	2.05	-2.51*	2.26*	5.28**	-2.65**	-1.25	8.64**	7.35	13.49**	8.61*	12.2**
DBW 17 x UP 2425	-5.74**	-1.99	-6.09**	4.49**	6.73**	-0.86	-12.65**	-6.61**	10.57*	7.28*	-1.22	19.75**
HD 2967 x HD 3059	-1.9	0	-1.45	1.36	1.82	-1.19	-7.98**	-0.59	6.38	10.25**	-6.02	-5.13**
HD 2967 x WH 1021	-4.48**	-1.54	1.56	-3.36**	-1.86	5.38**	-16.53**	-14.93**	-0.42	24.92**	19.28**	-2.02
HD 2967 x UP 2425	-7.35**	-5.97**	1.06	-9.26**	-8.56**	-0.67	-13.84**	-13.18**	-7.91	23.64**	22.89**	-2.45*
HD 3059 x WH 1021	-7.32**	-2.56	-14.74**	4.15**	5.28**	1.77*	-10.09**	-0.87	10.05*	14.93**	1.99	9.09**
HD 3059 x UP 2425	11.06**	14.93**	4.76**	3.05**	3.36**	0.3	-10.03**	-3.59	20.69**	3.91	-10.98**	-5.48**
WH 1021 x UP 2425	-4.55**	-3.08*	-7.41**	-6.01**	-5.28**	-6.23**	-14.76**	-12.45**	-7.03	24.44**	19.51**	4.08**
S.E	**0.76**	**0.88**	**0.66**	**1.01**	**1.17**	**0.76**	**1.45**	**1.67**	**1.43**	**0.18**	**0.21**	**0.22**

Table 2 cont…

Characters	Flag leaf area			Spike length			Number of grains/spike			1000-grain weight		
Crosses	**H**	**HB**	**ID**	**H**	**HB**	**ID**	**H**	**HB**	**ID**	**H**	**HB**	**ID**
Raj 3077 x Raj 4079	26.53**	0.77	2.94	10.69**	1.58	0.78	-1.88	-7.01**	1.08	5.73**	1.95	0.4
Raj 3077 x Raj 3765	15.6**	-5.2	2.67	11.32**	4.56	-1.85*	-11**	-14.39**	5.78**	7.05**	0.03	1.14
Raj 3077 x PBW 343	2.14	-2.84	5.75	10.79**	7.73*	-2.72**	4.07	-1.4	1.49	4.06**	3.67**	1.87
Raj 3077 x PBW 590	-27.68**	-32.7**	3.37	9.02**	6.7	-2.88**	0	-2.49	4.7*	-8.79**	-8.89**	1.68
Raj 3077 x DBW 17	1.51	-1.58	5.71	-13.62**	-14.33**	13.69**	-3.42	-9.31**	12.87**	-4.41**	-9.25**	2.47
Raj 3077 x HD 2967	21.88**	1.22	1.9	7.56*	6.03	18.29**	-7.43**	-10.91**	3.81	6.33**	-0.41	1.5
Raj 3077 x HD 3059	-26.24**	-30.94**	13.44*	-1.19	-6.71	12.15**	-17.47**	-18.12**	13.84**	-11.06**	-15.29**	4.67**
Raj 3077 x WH 1021	6.39	-6.71*	11.32**	9.76**	5.4	2.46**	4.77*	2.65	1.82	-10.92**	-13.09**	0.47
Raj 3077 x UP 2425	-0.41	-14.39**	21.72**	-3.53	-3.55	5.73**	5.91**	5.69*	2.37	3.7**	2.37	-0.49
Raj 4079 x Raj 3765	15.77**	11.5**	-4.71	28.67**	11.55**	-2.27**	21.84**	11.33**	-8.79**	10.81**	7.25**	-1.08

Raj 4079 x PBW 343	29.58**	7.35**	-3.3	22.88**	15.76**	-0.77	12.2**	12.16**	-1.67	13.46**	9.01**	-2.31
Raj 4079 x PBW 590	-10.75**	-24.66**	16.46**	11.25**	0.11	4.48**	-1.37	-4.2	3.36	4.65**	1.02	-0.19
Raj 4079 x DBW 17	-29.41**	-42.42**	2.43	11.13**	2.75	5.19**	-3.16	-4.1	6.63**	-13.81**	-15.19**	2.02
Raj 4079 x HD 2967	18.2**	12.1**	-6.51*	23.29**	11.67**	-0.54	21**	10.6**	-0.21	9.56**	6.3**	-0.72
Raj 4079 x HD 3059	2.65	-13.81**	3.51	-0.33	-3.3	14.58**	2.11	-3.95	-0.6	0.68	-0.59	5.15**
Raj 4079 x WH 1021	35.07**	20.65**	-2.8	29.85**	14.85**	-1.58	18.8**	10.44**	-0.51	10.94**	9.62**	-1.96
Raj 4079 x UP 2425	29.86**	18.45**	-1.56	22.23**	12.19**	-0.6	18.17**	11.78**	-0.1	10.05**	7.47**	-1.38
Raj 3765 x PBW 343	33.24**	13.87**	-2	22.61**	12.19**	-1.59	22.81**	12.18**	-0.65	14.93**	7.03**	-2.26
Raj 3765 x PBW 590	-1.61	-14.25**	6.79	-8.48**	-12.24**	2.54*	-10.22**	-15.7**	5.41*	-5.92**	-12**	0.36
Raj 3765 x DBW 17	-30.42**	-41.5**	4.29	12.92**	5.25	3.48**	6.75**	-3.33	7.44**	-16.06**	-17.46**	2.98
Raj 3765 x HD 2967	30.68**	28.61**	-1.72	18.03**	12.39**	-5.03**	10.09**	10.05**	-0.64	7.14**	6.88**	-1.59
Raj 3765 x HD 3059	20.24**	4.22	18.43**	14.22**	1.68	2.78**	-1.16	-4.18*	6.62**	-5.08**	-6.98**	1.56
Raj 3765 x WH 1021	25.11**	15.67**	-0.96	13.95**	11.35**	-0.49	14.02**	11.9**	-1.53	12.49**	7.62**	-0.37
Raj 3765 x UP 2425	15.14**	8.81**	-8.35**	21.79**	14.37**	-1	10.56**	6.57**	-2.76	12.34**	6.27**	-0.73
PBW 343 x PBW 590	7.29*	4.84	32.71**	-1.45	-6.16	5.47**	1.98	-0.99	3.38	2.73*	2.24	-0.26
PBW 343 x DBW 17	7.79*	5.69	10.65*	5.7	3.61	2.6*	-1.9	-2.82	2.31	-4.91**	-10.04**	2.81
PBW 343 x HD 2967	25.4**	8.62**	-3.06	6.91*	2.52	-1.28	14.43**	4.57*	-2.22	13.03**	5.5**	-2.35
PBW 343 x HD 3059	-8.29*	-9.81*	8.47	-10.89**	-13.55**	0.9	-10.04**	-15.4**	2.82	-9.75**	-14.34**	1.78
PBW 343 x WH 1021	19.39**	9.55**	-5.53	18.36**	10.64**	-2.35**	20.13**	11.65**	-0.65	10.66**	7.56**	-4.46**
PBW 343 x UP 2425	21.66**	9.3**	-4.96	13.9**	10.78**	-1.32	16.18**	9.86**	-1.21	14.12**	12.24**	-2.16
PBW 590 x DBW 17	-1.32	-5.41	-0.45	-2.45	-5.29	16.13**	9.88**	5.71*	2.08	7.15**	1.83	6.09**
PBW 590 x HD 2967	-1.84	-13.25**	3.74	-3.18	-3.89	7.19**	-15.08**	-20.23**	2	4.05**	-2.45*	0.74
PBW 590 x HD 3059	-20.46**	-20.98**	13.25*	-2.25	-9.56**	-0.36	-1.75	-4.94*	1.39	-7.23**	-11.54**	4.43**
PBW 590 x WH 1021	-9.59**	-15.24**	6.61	-6.83*	-8.62*	17.1**	-21.18**	-24.66**	-0.11	-10.22**	-12.32**	1.66
PBW 590 x UP 2425	-13.94**	-21.04**	1.53	-7.17*	-9.18*	0.42	-20.42**	-22.56**	0.75	-3.33**	-4.47**	4.52**
DBW 17 x HD 2967	-24.22**	-35.44**	6.41	3.22	0.93	1.36	-3.2	-12.31**	1.5	-16.21**	-17.41**	1.5
DBW 17 x HD 3059	13.26**	9.25*	8.18*	1.54	-3.38	3.09**	-17.63**	-23.23**	3.97	-3.9**	-4.23**	3.76*
DBW 17 x WH 1021	17.58**	5.98	11.14**	-0.71	-5.4	0.11	14.56**	5.54*	2.36	5.12**	2.22	3.53*
DBW 17 x UP 2425	8.15**	-4.52	17.34**	-1.71	-2.48	-1.1	9.31**	2.44	-2.44	3.55**	-0.46	4.34**
HD 2967 x HD 3059	19.94**	5.4	23.27**	2.29	-4.71	2.19*	-2.47	-5.42*	0.57	0.8	-0.98	3.79**
HD 2967 x WH 1021	23.61**	16**	-0.17	13.09**	10.12**	-1.08	8.79**	6.81**	-0.58	11.11**	6.56**	-0.3
HD 2967 x UP 2425	14.01**	9.4**	-4.57	13.65**	12**	-3.03**	7.8**	3.95	-0.67	9.06**	3.4**	-0.8
HD 3059 x WH 1021	-13.66**	-19.54**	7.39	3.06	-6.33	-1.11	-0.37	-1.61	3.67	-8.3**	-10.52**	0.82
HD 3059 x UP 2425	-1.07	-9.77**	-1.49	5.29	-0.56	-9.36**	-1.81	-2.39	-3.97	-7.41**	-10.7**	-0.8
WH 1021 x UP 2425	14.12**	11.5**	1.94	14.87**	10.28**	0.33	10.77**	8.76**	2.51	9.44**	8.14**	0.05
S.E	**0.69**	**0.80**	**0.78**	**0.19**	**0.22**	**0.21**	**0.79**	**0.91**	**0.73**	**0.43**	**0.50**	**0.62**

Table 2 cont…

Characters	Biomass/plant			Grain yield/spike			Grain yield/plant			Harvest index		
Crosses	H	HB	ID	H	HB	ID	H	HB	ID	H	HB	ID
Raj 3077 x Raj 4079	5.73**	1.95	0.4	16.93**	5.67	1.07*	8.84*	0.58	-1.32	3.02	-1.44	-2.02
Raj 3077 x Raj 3765	7.05**	0.03	1.14	15.37**	-1.01	1.52**	36.83**	12.23**	-5.18**	29.24**	12.27**	-6.23
Raj 3077 x PBW 343	4.06**	3.67**	1.87	-5.21	-6.19	3.66**	0.8	0.33	0.91	-3.13	-3.23	-1.03
Raj 3077 x PBW 590	-8.79**	-8.89**	1.68	-15.51**	-20.25**	4.69**	-14.05**	-17.73**	-3.07	-5.81	-9.75*	-4.38
Raj 3077 x DBW 17	-4.41**	-9.25**	2.47	-7.69*	-11.82**	2.9**	-6.45	-10.82*	2.05	-2.08	-2.5	-0.36
Raj 3077 x HD 2967	6.33**	-0.41	1.5	9.52**	7.02	6.23**	7.49	7.11	-0.03	0.65	-5.42	-1.73
Raj 3077 x HD 3059	-11.06**	-15.29**	4.67**	10.23**	7.72*	4.89**	-2.02	-6.27	-2.35	10.2*	9.69	-7.27
Raj 3077 x WH 1021	-10.92**	-13.09**	0.47	0.18	-1.4	3.2**	13.84**	1.77	0.63	28.32**	17.33**	0.05
Raj 3077 x UP 2425	3.7**	2.37	-0.49	-5.14	-10.06**	2.1**	11.56**	5.48	1.65	8.04	3.44	2.51
Raj 4079 x Raj 3765	10.81**	7.25**	-1.08	16.11**	9.55**	-2.29**	32.95**	16.67**	9.68**	20.54**	8.91*	10.73*
Raj 4079 x PBW 343	13.46**	9.01**	-2.31	21.74**	11.05**	-4.59**	29.79**	19.43**	-3*	14.66**	9.6	-0.57
Raj 4079 x PBW 590	4.65**	1.02	-0.19	0.59	-3.97	4.72**	8.7*	4.77	-10.17**	4.51	4.34	-9.41
Raj 4079 x DBW 17	-13.81**	-15.19**	2.02	-18.02**	-22.66**	2.93**	0.73	-2.51	12.85**	16.49**	10.99*	10.83*
Raj 4079 x HD 2967	9.56**	6.3**	-0.72	24.8**	10.48**	-1.28*	25.18**	16.06**	-7.73**	13.92**	2.71	-6.95
Raj 4079 x HD 3059	0.68	-0.59	5.15**	-3.68	-14.73**	3.32**	-7.12	-10.43*	15.47**	-7.78	-12.15*	10.92
Raj 4079 x WH 1021	10.94**	9.62**	-1.96	24.01**	10.48**	-1.54**	24.68**	20.25**	11.13**	12.24**	7.02	12.85**
Raj 4079 x UP 2425	10.05**	7.47**	-1.38	14.16**	8.5**	-2.35**	25.42**	22.41**	-9.02**	13.97**	13.9**	-7.75
Raj 3765 x PBW 343	14.93**	7.03**	-2.26	24.24**	7.54**	-1.17*	37.28**	12.19**	-7.74**	20.69**	4.74	-5.49
Raj 3765 x PBW 590	-5.92**	-12**	0.36	-9.87**	-18.59**	1.23*	3.87	-11.69**	9.08**	11.21**	0.34	8.6
Raj 3765 x DBW 17	-16.06**	-17.46**	2.98	4.36	-6.78*	0.81	25.26**	6.88*	-4.74**	49.72**	29.57**	-7.88*
Raj 3765 x HD 2967	7.14**	6.88**	-1.59	30.75**	10.05**	-2.05**	33.97**	10.19**	-6.37**	25.17**	3.16	-4.68
Raj 3765 x HD 3059	-5.08**	-6.98**	1.56	20.3**	1.26	3.23**	6.86	-9.1**	4.86**	12.96**	-2.27	3.36
Raj 3765 x WH 1021	12.49**	7.62**	-0.37	30.27**	10.3**	-0.68	22.61**	11.13**	-4.29**	9.31*	3.28	-3.9
Raj 3765 x UP 2425	12.34**	6.27**	-0.73	21.23**	9.05**	-1.15*	29.96**	11.69**	-5.02**	16.44**	5.14	-4.45
PBW 343 x PBW 590	2.73*	2.24	-0.26	-2.61	-7.17*	0.67	14.81**	9.4	2.99	12**	7.22	3.38
PBW 343 x DBW 17	-4.91**	-10.04**	2.81	-7.62*	-10.86**	1.79*	-3.45	-8.38	-8.88**	1.49	1.15	-12.13*
PBW 343 x HD 2967	13.03**	5.5**	-2.35	13.32**	9.62*	-4.39**	23.95**	22.93**	-0.21	9.19	2.69	2.12

PBW 343 x HD 3059	-9.75**	-14.34**	1.78	5.15	1.72	3.38**	-2.57	-7.22	-9**	7.96	7.56	-11.05
PBW 343 x WH 1021	10.66**	7.56**	-4.46**	10.76**	7.9*	-5.1**	35.36**	20.51**	-1.77	22.6**	12**	2.49
PBW 343 x UP 2425	14.12**	12.24**	-2.16	14.94**	10.06**	-5.71**	29.11**	21.54**	-8.66**	13.3**	8.37	-6.29
PBW 590 x DBW 17	7.15**	1.83	6.09**	-4.42	-5.61	1.32*	-12.66**	-13.03**	-1.56	-18.7**	-22.42**	-7.99
PBW 590 x HD 2967	4.05**	-2.45*	0.74	-6.91*	-14.02**	0	16.51**	11.9*	0.9	11.17*	0.38	0.18
PBW 590 x HD 3059	-7.23**	-11.54**	4.43**	4.22	-3.74	0.97	-10.34*	-10.4*	-3.55	-3.59	-8.03	-8.32
PBW 590 x WH 1021	-10.22**	-12.32**	1.66	7.54*	0	4.67**	-7.09	-13.51**	3.35	3.64	-1.32	1.61
PBW 590 x UP 2425	-3.33**	-4.47**	4.52**	-12.36**	-12.77**	16.07**	-4.35	-5.57	4.17*	-1.03	-1.12	-0.51
DBW 17 x HD 2967	-16.21**	-17.41**	1.5	-10.09**	-15.97**	17.11**	-5.63	-9.73*	-16.24**	12.55*	6.19	-18.31**
DBW 17 x HD 3059	-3.9**	-4.23**	3.76*	-12.14**	-17.89**	17.12**	6.79	6.4	6.43**	11.17*	11.13*	2.79
DBW 17 x WH 1021	5.12**	2.22	3.53*	-0.17	-6.07	4.76**	-4.91	-11.13*	4.59*	-9.79*	-17.84**	1.04
DBW 17 x UP 2425	3.55**	-0.46	4.34**	0.79	0	24.53**	1.74	0.87	-0.17	-1.94	-6.51	-5.24
HD 2967 x HD 3059	0.8	-0.98	3.79**	0.74	0.74	22.99**	12.41**	7.9	-4.46*	11.56*	5.29	-8.75
HD 2967 x WH 1021	11.11**	6.56**	-0.3	9.49**	8.7*	-3**	32.69**	19**	-13.1**	18.86**	2.73	-13.22**
HD 2967 x UP 2425	9.06**	3.4**	-0.8	17.29**	8.81*	-0.87	24.05**	17.68**	-13.4**	13.82**	2.68	-11.9*
HD 3059 x WH 1021	-8.3**	-10.52**	0.82	-9.49**	-10.14*	-1.21	8.22*	0.79	-13.61**	17.72**	7.18	-14.52**
HD 3059 x UP 2425	-7.41**	-10.7**	-0.8	-6.44*	-13.21**	-2.9**	4.84	3.57	-8.17**	13.04**	7.74	-7.3
WH 1021 x UP 2425	9.44**	8.14**	0.05	17.85**	10.06**	18.57**	27.87**	20.48**	0.51	16.94**	11.44*	0.46
S.E	**0.43**	**0.50**	**0.62**	**0.03**	**0.04**	**0.07**	**0.48**	**0.55**	**0.38**	**1.32**	**1.52**	**1.08**

Table 3: Best crosses exhibiting maximum heterosis and heterobeltiosis for grain yield per plant along with desirable heterotic expression for other characters.

Particulars	Crosses possessing high heterosis and heterobeltiosis for grain yield per plant	Days to 50% heading	Days to maturity	Plant height	Productive tillers per plant	Flag leaf area	Spike length	Number of grains per spike	1000-grain weight	Biomass per plant	Grain yield per spike	Harvest index
Heterosis	Raj 3765 x PBW 343	+	+	+	+	+	+	+	+	+	+	+
	Raj 3077 x Raj 3765	-	-	-	+	+	+	-	+	+	+	+
	PBW 343 x WH 1021	+	+	+	+	+	+	+	+	+	+	+
Heterobeltiosis	PBW 343 x HD 2967	+	+	+	+	+	-	+	+	+	+	-
	Raj 4079 x UP 2425	+	+	+	+	+	+	+	+	+	+	+
	PBW 343 x UP 2425	+	+	+	+	+	+	+	+	+	+	-

In general, the heterosis or hybrid vigor decreases in F_2 generation as the dominance or dominance interaction effects diminish in this generation due to decreased heterozygosity, resulting into inbreeding depression. For grain yield and most of other contributing traits negative magnitudes of inbreeding depression is desirable except plant height, days to 50% heading and days to maturity. In this study, the heterotic crosses which revealed significant and maximum negative inbreeding depression for grain yield were DBW 17 × HD 2967, HD 3059 × WH 1021 and HD 2967 × UP 2425 displayed F_2 plants accomplished higher grain yield per plant as compared to F_1 hybrids. The significant and negative inbreeding depression for grain yield and other component characters reported by several earlier investigators such as Ved Prakash and Joshi (2003); Kumar *et al.* (2018).

CONCLUSIONS

The significant differences observed among the genotypes, parents and generation for all studied traits, revealed that characters displayed the presence of sufficient genetic diversity among the selected parents and these parents have worth to be evaluated for further wheat breeding programs. Highest inbreeding depression for grain yield were observed in DBW 17 × HD 2967, HD 3059 × WH 1021 and HD 2967 × UP 2425, indicating F_2 plants produced more grain yield as compared to F_1 hybrids of bread wheat. For grain yield/plant the promising crosses identified on the basis of heterosis and heterobeltiosis (heterosis over better parent) were PBW 343 × HD 2967, Raj 4079 × UP 2425, PBW 343 × UP 2425, Raj 3765 × PBW 343, Raj 3077 × Raj 3765 and PBW 343 × WH 1021. These crosses have been proposed to be advantageous for wheat genotypes improvement that can produce the maximum level of transgressive segregants and may be used in hybrid development of wheat for yield potential.

FUTURE SCOPE

The crosses identified in the present study may be considered as promising for tangible advancement of yield in wheat crop under very late environmental conditions. Therefore, progeny of these crosses may have potential for high grain yield and to provide transgressive segregants.

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