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Heterotic effects for yield and yield-related attributes in F_1 population of bread wheat (*Triticum aestivum* L.)

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Abstract
The present study was carried out at the Experimental Farm (located at Kharora), Department of Agriculture, Mata Gujri College, Fatehgarh Sahib, Punjab, during Rabi season of 2022-23 and 2023-24. Experimental materials comprised of 15 F_1 resulting from line x tester mating design, 8 parents and one check grown in Randomized Block Design in three replications. The analysis of variance for the design of the experiment revealed significant differences among treatments (genotypes) for all the characters except harvest index. Cross combinations Lal Bahadur x WH 1105, Lal Bahadur x DBW 17, PBW 226 x DBW 17 and RAJ 2184 x PBW 550 showed significant and desirable heterosis for grain yield and most of the traits. GCA and SCA effects revealed that parent Lal Bahadur and cross combination PBW 226 x DBW 17 and RAJ 2184 x PBW 550 was good general combiner and good specific combinations respectively, as these showed significant effects for most of the traits.

Keywords: Heterosis, combining ability, line x tester mating design

Introduction

Bread wheat (*Triticum aestivum* L.), also known as common wheat, is a long day, annual, C3 and predominantly autogamous species belonging to the Triticeae tribe of the grass family (Poaceae). Wheat is the second most important cereal crop after rice both in terms of area and production. Due to its large acreage, excellent production, and significant role in the global food grain trade, it has been described as the "King of cereals" (Bhushan *et al*., 2013) [3]. The center of origin of wheat is believed to be South-western Asia. It made a major contribution to the "Green Revolution's" success and was crucial in moving our nation from a ship-to-mouth economy to one that is self-sufficient (Singh *et al*., 2020) [23]. Species of wheat are categorized into three groups based on the ploidy level *viz*., diploid, tetraploid and hexaploid wheat. Bread wheat is an allohexaploid species with three subgenomes, A, B, and D, having the genomic constitution AABBDD and chromosome number $2n = 6X = 42$.

Heterosis is the imperative approaches of developing high yielding cultivars. It is the superiority of F_1 hybrid in one or more characters over its parents. The use of heterosis in a self-pollinating crop such as wheat is mostly determined by the magnitude and direction of heterosis (Burdak *et al*., 2023) [4]. The magnitude of heterosis is useful in determining genetic diversity and serves as a guide in the selection of desirable parents. The superiority of hybrids, especially over better parent, is more advantageous for the commercial exploitation of heterosis and parental combinations that can produce the greatest number of transgressive segregants (Nagar *et al*., 2019) [16]. Combining ability analysis used to evaluate various lines for their genetic value and suitability as parents in a hybridization program. Additionally, it helps characterize the behaviors of genes that contribute to the inheritance of several complicated quantitative features, such as grain yield. The knowledge of general combining ability provides the guidance to the breeder for the identification of superior performing parents which will perform better than the rest of population that are utilized in a hybridization programme, whereas, measure of specific combining ability enables a breeder to select higher yielding crosses for exploitation of heterosis and non-additive portion of genetic variance (Roy *et al*., 2021) [21].

Materials and Methods

The present study was carried out at the Experimental Farm, Department of Agriculture, Mata Gujri College, Fatehgarh Sahib, Punjab. Experimental material consisted of five lines (Lal Bahadur, PBW 226, RAJ 2184, HD 2285 and UP 2338) and three testers (WH 1105, DBW 17 and PBW 550) crossed in line x tester mating fashion to develop 15 cross combinations. Variety DBW 303 used as a check variety. Experiment was conducted in randomized block design with three replications in two rows with spacing of 22.5 cm within rows and 5 cm within plants. The recommended agronomic practices were adopted to raise a good quality crop.

The observations were recorded on fifteen characters, namely, days to booting, days to heading, days to anthesis, days to physiological maturity, plant height (cm), peduncle length (cm), spike length (cm), number of productive tillers per plant, number of spikelets per spike, number of grains per spike, number of grains per plant, grain yield (g), biological yield (g), harvest index (%) and test weight (g). Statistical analysis was performed by utilizing the mean values of five plants in each plot of parents and F_1's in all the three replications. Data was analyzed by Window State Software, Hyderabad. The analysis of variance was carried out following the procedure of Randomized Block Design (RBD) analysis (Panse and Sukhatme, 1989) [17] for each of the genotypes. The total variance was partitioned into three sources of variance, *viz*. replication, treatment and error. The line x tester' analysis was carried out following method given by Kempthorne (1957) [8] and elaborated by Arunachalam (1974) [2].

Results and Discussion

Analysis of variance for the design of the experiment

The analysis of variance for 23 genotypes which includes eight parents (Lal Bahadur, PBW 226, RAJ 2184, HD 2285, UP 2338, WH 1105, DBW 17 and PBW 550) and their 15 crosses made in line x tester mating design were observed for fifteen yield attributes in experimental season 2022-24. Table 1 revealed that the source of variation showed positive significance for all the yield attributes. Similar finding was reported by Kumawat *et al*. (2023) [13].

Estimation of heterosis

Heterosis is considered as the superiority of the hybrids in comparisons to either of its parents. It is the allelic or non-allelic interaction of genes under the influence of specific environment. The magnitude of heterosis provides information on the extent of genetic diversity in parents of a cross and helps in choosing the parents for superior F_1's, so as to exploit hybrid vigour (Burdak *et al*., 2023) [4]. High heterosis crosses may be used to obtain transgressive segregants, which would increase yield and yield components (Dudhat *et al*., 2022) [5]**.** The characteristics including early flowering, early maturity, short stature and high yield desired in a wheat genotype. The heterotic effect in F_1 generation over better parent and standard check presented in Table 3 and 4.

Due to earliness in booting stages provides best results for earliness in heading stage, anthesis and maturity stage. Negative value for days to booting is desirable as it leads to early maturity. Significant and desirable heterosis over better parent ranged from -2.03 (Lal Bahadur x DBW 17 and HD 2285 x DBW 17) to -4.39 (RAJ 2184 x PBW 550). Cross combinations Lal Bahadur x WH 1105, Lal Bahadur x DBW 17, Lal Bahadur x PBW 550, PBW 226 x PBW 550, RAJ 2184 x WH 1105, RAJ 2184 x DBW 17, RAJ 2184 x PBW 550, HD 2285 x DBW 17 and UP 2338 x PBW 550 showed desirable heterosis. Five crosses showed significant negative heterosis over check variety ranged from -2.05 (RAJ 2184 x DBW 17) to -3.41 (RAJ 2184 x PBW 550) namely, Lal Bahadur x WH 1105, PBW 226 x PBW 550, RAJ 2184 x WH 1105, RAJ 2184 x DBW 17 and RAJ 2184 x PBW 550. Similar results for days to booting in agreement with Kaur *et al*. (2022) [7].

Heterosis in negative direction for days to heading was desirable because it resulted in early maturity. Heterosis over better parent revealed that four cross combination showed significant and desirable heterosis over better parent ranged from -2.26 (HD 2285 x DBW 17) to -3.24 (RAJ 2184 x PBW 550). These crosses were Lal Bahadur x WH 1105, RAJ 2184 x WH 1105, RAJ 2184 x PBW 550 and HD 2285 x DBW 17. All the cross combination showed significant and desirable standard heterosis ranged from -25.24 (Lal Bahadur x DBW 17) to -28.13 (RAJ 2184 x PBW 550). Similar result on importance of negative heterosis for days to heading has been reported by Lal *et al*. (2013) [13]; Patel *et al*. (2015) [18]; Burdak *et al*. (2023) [4] and Kumawat *et al*. (2023) [13].

The heterobeltiosis for days to anthesis ranged from -1.80 (UP 2338 x WH 1105) to -3.34 (RAJ 2184 x PBW 550) and exhibited by four crosses namely, Lal Bahadur x WH 1105, PBW 226 x PBW 550, RAJ 2184 x PBW 550 and UP 2338 x WH 1105. Similar results were given for days to anthesis by Murugan and Kannan (2017) [15] and Kaur *et al*. (2022) [7].

Six crosses exhibited significant negative heterobeltiosis for days to physiological maturity ranged from -1.92 (PBW 226 x DBW 17) to -2.70 (RAJ 2184 x PBW 550 and UP 2338 x WH 1105). Crosses which exhibited significant and desirable heterosis over better parent were Lal Bahadur x WH 1105, Lal Bahadur x DBW 17, PBW 226 x DBW 17, RAJ 2184 x WH 1105, RAJ 2184 x PBW 550, UP 2338 x WH 1105. Eight cross combinations showed significant negative heterosis over check ranged from -1.46 (UP 2338 x PBW 550) to -5.60 (Lal Bahadur x WH 1105) were Lal Bahadur x WH 1105, Lal Bahadur x PBW 550, PBW 226 x WH 1105, PBW 226 x PBW 550, RAJ 2184 x WH 1105, RAJ 2184 x PBW 550, UP 2338 x WH 1105, UP 2338 x PBW 550. Similar result on the importance of negative heterosis for days to physiological maturity has been reported by Patel *et al*. (2015) [18]; Raiyani *et al*. (2016) [19]; Joshi and Kumar (2020) [6]; Burdak *et al*. (2023) [4] and Kumawat *et al*. (2023) [13].

Short statured varieties showed the significance of negative heterosis for plant height. Range of heterosis over better parent for plant height was from -6.32 (UP 2338 x PBW 550) to -21.49 (PBW 226 x WH 1105). The highest and significant heterosis in negative direction was observed for the crosses namely, PBW 226 x WH 1105, PBW 226 x DBW 17, PBW 226 x PBW 550, RAJ 2184 x WH 1105, RAJ 2184 x DBW 17, HD 2285 x DBW 17 and UP 2338 x PBW 550. Range of heterosis over standard check varies from -6.97 (RAJ 2184 x WH 1105) to -19.88 (PBW 226 x WH 1105). The highest and significant heterosis in negative direction was observed for the crosses namely, PBW 226 x WH 1105, PBW 226 x PBW 550, RAJ 2184 x WH 1105, RAJ 2184 x DBW 17 and HD 2285 x WH 1105. The present result in agreement with Lal *et al*. (2013) [13]; Raj and Kandalkar (2013) [20]; Raiyani *et al*. (2016) [19] and Kumawat *et al*. (2023) [13Q].

The negative heterosis is desirable for peduncle length. The heterosis for this character ranged from -6.27 (UP 2338 x PBW 550) to -13.23 (PBW 226 x PBW 550). The highest negative significant heterosis was found in crosses *viz*. PBW 226 x PBW 550, RAJ 2184 x DBW 17, HD 2285 x PBW 550, UP 2338 x DBW 17 and UP 2338 x PBW 550. Standard heterosis ranged from -6.11 (RAJ 2184 x WH 1105) to -16.09 (PBW 226 x PBW 550). Lal Bahadur x PBW 550, PBW 226 x WH 1105, PBW 226 x DBW 17, PBW 226 x PBW 550, RAJ 2184 x WH 1105, RAJ 2184 x DBW 17, HD 2285 x WH 1105, HD 2285 x DBW 17, HD 2285 x PBW 550, UP 2338 x DBW 17 and UP 2338 x PBW 550. Similar results for peduncle length was given by Vanpriya *et al*. (2006) [26]; Raiyani *et al*. (2016) [19].

Three cross combinations exhibited significant positive heterobeltiosis for spike length namely, RAJ 2184 x PBW 550 (16.25), UP 2338 x WH 1105 (12.95) and Lal Bahadur x PBW 550 (12.07). Economic heterosis for spike length varies from 12.01 (PBW 226 X PBW 550) to 22.98 (UP 2338 x WH 1105). Lal Bahadur x WH 1105, Lal Bahadur x DBW 17, Lal Bahadur x PBW 550, PBW 226 x DBW 17, PBW 226 x PBW 550, RAJ 2184 x WH 1105, RAJ 2184 x PBW 550, HD 2285 x WH 1105, HD 2285 x DBW 17, HD 2285 x PBW 550, UP 2338 x WH 1105 and UP 2338 x DBW 17. Positive heterosis for spike length has been reported by Raj and Kandalkar (2013) [20]; Patel *et al*. (2015) [18]; Joshi and Kumar (2020) [6] and Burdak *et al*. (2023) [4].

More productive tillers resulted in higher yield. Crosses with positive and significant heterobeltiosis for number of productive tillers per plant were RAJ 2184 x PBW 550 (67.05) and HD 2285 x PBW 550 (48.55). Magnitude of economic heterosis ranged from 44.76 (PBW 226 x DBW 17) to 102.10 (RAJ 2184 x PBW 550). Crosses which possessed significant and positive standard heterosis were Lal Bahadur x WH 1105, Lal Bahadur x DBW 17, Lal Bahadur x PBW 550, PBW 226 x DBW 17, RAJ 2184 x PBW 550, HD 2285 x PBW 550 and UP 2338 x DBW 17. Similar findings has been reported by Vanpariya *et al.* (2006) [26]; Raiyani *et al*. (2016) [19] and Burdak *et al*. (2023) [4]

Higher number of spikelets per spike required for obtaining higher yield. For this character, only one cross UP 2338 x WH 1105 showed positive and significant heterosis over better parent with value of 6.89. All crosses showed significant positive heterosis over check variety ranged from 9.03 (UP 2338 x PBW 550) to 23.96 (RAJ 2184 x PBW 550 and UP 2338 x WH 1105). Significant positive heterosis for this character has also been reported by Kumar and Maloo (2011) [12]; Ahmad *et al*. (2016) [1] and Dudhat *et al*. (2022) [5].

Higher values of positive heterosis for number of grains per spike considered favourable as it lead to more number of grains per spike and thus more grain yield. The magnitude of heterobeltiosis for this trait ranged from 30.12 (RAJ 2184 x DBW 17) to 99.27 (Lal Bahadur x WH 1105). Crosses which showed desirable and significant heterobeltiosis were Lal Bahadur x WH 1105, Lal Bahadur x DBW 17, Lal Bahadur x PBW 550, PBW 226 x DBW 17, PBW 226 x PBW 550, RAJ 2184 x WH 1105, RAJ 2184 x DBW 17, RAJ 2184 x PBW 550, HD 2285 x WH 1105, HD 2285 x DBW 17, HD 2285 x PBW 550, UP 2338 x WH 1105, UP 2338 x DBW 17 and UP 2338 x PBW 550. On the other hand, all crosses showed significant positive heterosis over standard check variety ranged from 107.53 (PBW 226 x WH 1105) to 183.28 (PBW 226 x DBW 17). The present study in agreement with Kumar and Maloo (2011) [12]; Burdak *et al*. (2023) [4] and *et al*. (2023) [13].

Heterobeltiosis for number of grains per plant ranged 47.29 (HD 2285 x DBW 17) to 169.57 (Lal Bahadur x PBW 550). Crosses showing significant and desirable heterosis over better parent were Lal Bahadur x WH 1105, Lal Bahadur x DBW 17, Lal Bahadur x PBW 550, PBW 226 x DBW 17, PBW 226 x PBW 550, RAJ 2184 x WH 1105, RAJ 2184 x PBW 550, HD 2285 x WH 1105, HD 2285 x DBW 17, HD 2285 x PBW 550, UP 2338 x WH 1105 and UP 2338 x DBW 17. All crosses showed significant positive heterosis over check variety ranged from 127.25 (RAJ 2184 x DBW 17) to 421.46 (RAJ 2184 x PBW 550). The present study corresponds with the findings reported by Kaur *et al*. (2022) [7].

Heterosis over better parent for grain yield ranged from 36.36 (RAJ 2184 x PBW 550) to 67.69 (Lal Bahadur x WH 1105). Six crosses exhibited desirable and significant heterosis namely, Lal Bahadur x WH 1105, Lal Bahadur x DBW 17, PBW 226 x DBW 17, RAJ 2184 x PBW 550, HD 2285 x PBW 550 and UP 2338 x WH 1105. Four cross combinations showed significant positive heterosis over check ranged from 41.09 (RAJ 2184 x PBW 550) to 57.25 (Lal Bahadur x DBW 17). Lal Bahadur x WH 1105, Lal Bahadur x DBW 17, PBW 226 x DBW 17 and RAJ 2184 x PBW 550 showed positive and significant standard heterosis. The present study in agreement with Khokhar *et al*. (2019) [9] and Dudhat *et al*. (2022) [5]

Three cross combinations exhibited significant positive heterobeltiosis for biological yield ranged from 38.93 (PBW 226 x DBW 17) to 47.06 (Lal Bahadur x DBW 17) and same three crosses showed significant positive heterosis over check ranged from 34.58 (RAJ 2184 x PBW 550) to 49.25 (Lal Bahadur x DBW 17). Cross Lal Bahadur x DBW 17, PBW 226 x DBW 17, and RAJ 2184 x PBW 550 showed desirable and significant heterosis over better parent and standard check. Similar findings has been reported by Raj and Kandalkar (2013) [20]; Nagar *et al*. (2019) [16]; Kaur *et al.* (2022) [7] and Burdak *et al*. (2023) [4].

Three cross combinations exhibited significant positive heterobeltiosis for harvest index which were PBW 226 x WH 1105 (30.19), PBW 226 x PBW 550 (32.45) and Lal Bahadur x WH 1105 (46.88) and two cross combinations showed significant positive heterosis over check were PBW 226 x PBW 550 (30.98) and Lal Bahadur x WH 1105 (36.31). Similar results have been reported by Kaur *et al.* (2022) [7] and Burdak *et al*. (2023) [4].

The significant and desirable heterosis over better parent for test weight exhibited by one cross UP 2338 x PBW 550 (10.21) whereas the magnitude of standard heterosis ranged from 10.99 (UP 2338 x DBW 17) to 16.97 (RAJ 2184 x PBW 550) and the crosses which showed desirable standard heterosis were Lal Bahadur x WH 1105, Lal Bahadur x PBW 550, PBW 226 x DBW 17, RAJ 2184 x DBW 17, RAJ 2184 x PBW 550, HD 2285 x PBW 550, UP 2338 x WH 1105, UP 2338 x DBW 17 and UP 2338 x PBW 550. Similar results on heterosis for test weight has been reported by Joshi and Kumar (2020) [6]; Burdak *et al*. (2023) [4] and Kumawat *et al*. (2023) [13].

Combining ability analysis

The analysis of variance for combining ability for all the characters under study is presented in Table 3. The variance due to line x tester effect exhibited significant differences for all characters except days to booting and test weight. The variance due to line effect was significant only for days to booting. The variance due to testers was significant for only one-character days to physiological maturity.

General combining ability

The information regarding general combining ability effects of the parents is of prime importance because it helps in successful prediction of genetic potentiality which would give desirable individuals in subsequent segregating population. The GCA effect of parents for yield and its components are given in Table 4. In the present investigation, it was observed that none of the parents was found as good general combiner for all the 15 characters under study because the combining ability of the parents was not consistent for all the yield components. Similar finding was reported by Singh *et al*. (2012) [25]; Singh *et al.* (2013) [24], and Kumar *et al*. (2015) [10]. The magnitude and direction of combining ability effects provides the guidelines for the utilization of parents in any breeding programme.

Estimates of GCA effect revealed that Parent Lal Bahadur was found to be good general combiner for 5 characters namely, days to physiological maturity, number of productive tillers per plant, number of grains per plant, grain yield and biological yield. Parent PBW 226 was found to be good general combiner for 2 characters *viz*., plant height and peduncle length. Genotype RAJ 2184 was found as good combiner for 2 characters namely, days to booting and days to heading. Parent WH 1105 was found as good general combiner for 2 characters *viz*, days to physiological maturity and plant height. Genotype PBW 550 was found to be good general combiner for 3 characters days to anthesis, days to physiological maturity and number of productive tillers per plant. Similar results reported for PBW 550 by Kumar and Kerkhi (2015) [10].

A close examination of GCA effects revealed that parent Lal Bahadur was found as good general combiner for highest number of five characters followed by PBW 550 for three characters, PBW 226, RAJ 2184 and WH 1105 each for two characters.

Specific combining ability

Specific combining ability is important parameter for judging and selecting superior cross combinations, which might be exploited through heterosis breeding. The SCA effect of crosses for yield and its components are given in Table 5. The estimates of SCA effects revealed that none of the hybrids was consistently superior for all the traits. Similar result was showed by Kumar and Kerkhi (2015) [10].

Out of 15 crosses, one cross for days to heading; three for days to anthesis; three for days to physiological maturity; one each for plant height, peduncle length, spike length; two for productive tillers per plant and number of spikelets per spike, one for number of grains per spike, two each for number of grains per plant, grain yield, biological yield; one for harvest index and none of the crosses for days to booting and test weight exhibited significant sca effects in desirable directions.

Cross Lal Bahadur x WH 1105 exhibited significant sca effect in desirable direction for four traits namely, days to heading, days to anthesis, days to physiological maturity and harvest index; PBW 226 x WH 1105 for plant height; PBW 226 x DBW 17 for four characters *viz*., number of grains per spike, number of grains per plant, grain yield and biological yield; RAJ 2184 x DBW 17 for peduncle length; RAJ 2184 x PBW 550 for seven characters namely, days to anthesis, days to physiological maturity, number of productive tillers per plant, number of spikelets per spike, number of grains per plant, grain yield and biological yield; HD 2285 x DBW 17 for days to anthesis and days to physiological maturity; UP 2338 x WH 1105 for spike length and number of spikelets per spike; UP 2338 x DBW 17 for number of productive tillers per plant.

The cross combinations PBW 226 x DBW 17 and RAJ 2184 x PBW 550 exhibited significant specific combining ability effects in desirable direction for grain yield. Results revealed that the crosses which exhibited significant specific combining ability effects in desirable direction for grain yield per plant and also showed significant sca effects for some other yield contributing traits. Cross PBW 226 x DBW 17 exhibited the significant sca effects in desirable direction for four traits and cross RAJ 2184 x PBW 550 exhibited the significant sca effects in desirable direction for seven traits. Similar results on grain yield and its contributing traits were reported by Srivastava *et al*. (2012) [25], Kumar *et al*. (2015) [10] and Yadav *et al.* (2017) [27].

Table 1: Mean performance of the parental lines and F1 hybrids in yield-related traits.

Traits	Lines			Testers			Hybrids		
	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
Days to booting	92.0	98.67	97.13	54.67	98.67	97.11	94.33	97.67	96.29
Days to heading	96.33	103.0	101.60	99.33	103.33	101.00	99.67	103.67	101.80
Days to anthesis	102.67	111.0	108.93	102.67	109.67	106.56	106.0	111.68	109.49
Days to physiological maturity	131.67	136	134.00	123.67	138.67	131.89	129.33	139.0	134.64
Plant height (cm)	101.77	105.93	104.76	90.53	107.03	98.50	83.17	103.43	98.13
Peduncle length (cm)	37.17	39.87	38.13	36.73	39.07	37.78	33.90	40.03	37.40
Spike length (cm)	13.33	14.27	13.79	12.53	12.87	13.20	13.16	15.70	14.64
Number of productive tillers per plant	11.53	13.80	12.17	10.0	12.0	11.78	9.73	19.27	13.79
Number of spikelets per spike	22.27	22.87	22.41	19.20	23.33	21.04	20.93	23.80	22.62
Number of grains per spike	37.67	60.67	51.39	42.88	55.33	47.92	69.11	94.33	82.47
Number of grains per plant	515.87	6.99.47	618.48	428.31	664.80	567.05	722.53	1657.93	1145.81
Grain yield (g)	31.50	39.70	35.25	32.0	41.70	36.23	27.22	60.33	44.34
Biological yield	55.20	83.93	72.27	76.50	80.67	79.10	58.37	123.43	87.00
Harvest index	43.03	60.51	50.98	45.85	52.33	46.90	40.74	63.20	52.09
Test weight	40.56	41.89	41.20	38.83	41.43	39.91	37.27	45.00	42.51

Table 2: Estimates of standard heterosis of 15 crosses.

Crosses	Standard Heterosis													
	Days to booting	Days to heading	Days to anthesis	Days to physio-logical maturity	Plant height (cm)	Peduncle length (cm)	Spike length (cm)	Number of productive tillers per plant	Number of spikelets per spike	Number of grains per spike	Number of grains per plant	Grain yield (g)	Biological yield (g)	Harvest index (%)	Test weight (g)
Lal Bahadur x WH 1105	-3.38 **	-3.23 **	-2.41 **	-2.51 **	-4.06	4.70	9.85	20.77	-0.58	99.27 **	148.51 **	67.69 **	12.63	46.88 **	6.06
Lal Bahadur x DBW 17	-2.03 *	0.32	-0.30	-2.16 **	-3.36	3.64	1.41	7.73	1.43	57.95 **	95.00 **	44.68 **	47.06 **	-6.46	1.73
Lal Bahadur x PBW 550	-2.36 *	-0.97	-1.51	-0.25	-0.74	-4.52	12.07 *	21.26	1.17	90.59 **	169.57 **	25.21	14.69	1.72	4.01
PBW 226 x WH 1105	-0.68	0.65	0.60	-0.50	-21.49 **	1.63	-7.73	-14.18	-6.46 *	13.91	12.36	-22.61	-40.13 *	30.19 *	-10.44 *
PBW 226 x DBW 17	-1.35	-1.29	-0.60	-1.92 **	-8.00 *	-3.73	5.14	15.00	1.14	55.49 **	85.80 **	36.69 *	38.93 *	-4.4	3.44
PBW 226 x PBW 550	-2.72 **	0.00	-1.81 *	-0.50	-11.49 **	-13.23 **	0.23	7.51	-1.75	38.90 **	50.37 *	29.57	-9.24	32.45 *	-1.6
RAJ 2184 x WH 1105	-3.72 **	-2.59 *	-0.30	-2.21 **	-10.25 **	-2.98	9.00	-10.50	0.29	71.00 **	77.53 **	9.15	10.61	-0.1	-0.1
RAJ 2184 x DBW 17	-3.04 **	-1.29	1.82 *	0.24	-11.18 **	-9.21 **	-2.35	-18.89	-5.43	30.12 **	8.68	-33.97 *	-27.64	-7.5	3.64
RAJ 2184 x PBW 550	-4.39 **	-3.24 **	-3.34 **	-2.70 **	-5.86	2.39	16.25 **	67.05 **	4.08	58.74 **	167.13 **	36.36 *	41.96 *	-4.06	7.43
HD 2285 x WH 1105	2.82 **	3.02 **	8.44 **	3.80 **	-5.56	2.33	6.03	-12.53	0.50	49.21 **	51.50 *	2.22	9.26	-32.68 **	4.58
HD 2285 x DBW 17	-2.03 *	-2.26 *	-0.61	-0.48	-7.69 *	0.98	3.52	6.11	-4.29	36.99 **	47.29 *	-1.68	-12.23	-2.41	-1.18
HD 2285 x PBW 550	-1.36	1.66	1.24	2.00 **	-1.93	-8.19 **	9.09	48.55 **	3.44	45.63 **	106.48 **	37.62 *	20.48	-11.15	6.64
UP 2338 x WH 1105	-1.69	-0.97	-1.80 *	-2.70 **	-2.57	-1.76	12.95 *	-2.5	6.89 *	77.65 **	85.86 **	37.21 *	9.65	-11.81	6.17
UP 2338 x DBW 17	-1.01	-0.32	-0.6	-0.96	-4.48	-9.53 **	4.93	22.99	-0.86	43.61 **	84.73 **	6.39	15.12	-14.85	3.06
UP 2338 x PBW 550	-2.37 *	-1.62	-1.2	-0.74	-6.32 *	-6.27 *	-2.64	-18.18	-5.99 *	47.97 **	19.56	-1.81	-16.47	-4.54	10.21 *
SE ±	0.88	1.00	0.90	0.92	3.12	1.08	0.67	1.76	0.65	5.54	151.28	5.60	13.31	6.30	1.94
CD at 5%	1.80	2.04	1.85	1.89	6.38	2.21	1.37	3.61	1.33	11.34	309.88	11.48	27.26	12.91	3.97
CD at 1%	2.43	2.75	2.49	2.55	8.61	2.98	1.85	4.87	1.79	15.30	418.03	15.48	36.77	17.41	5.35

Table 3: Estimates of standard heterosis of 15 crosses.

Crosses	Standard Heterosis													
	Days to booting	Days to heading	Days to anthesis	Days to physio-logical maturity	Plant height (cm)	Peduncle length (cm)	Spike length (cm)	Number of productive tillers per plant	Number of spikelets per spike	Number of grains per spike	Number of grains per plant	Grain yield (g)	Biological yield (g)	Harvest index (%)	Test weight (g)
Lal Bahadur x WH 1105	-2.39 *	-27.88 **	0.62	-5.60 **	-4.37	-2.64	16.45 **	74.83 **	18.06 **	172.47 **	375.24 **	53.12 **	14.31	36.31 *	13.75 *
Lal Bahadur x DBW 17	-1.02	-25.24 **	2.80 **	-0.97	-0.35	-3.63	12.79 *	55.94 **	23.26 **	162.46 **	307.74 **	57.25 **	49.25 **	5.57	9.56
Lal Bahadur x PBW 550	-1.37	-26.20 **	1.55	-2.92 **	-1.06	-7.67 **	18.80 **	75.52 **	20.14 **	145.45 **	337.39 **	14.34	16.40	0.6	11.55 *
PBW 226 x WH 1105	-0.34	-25.72 **	3.73 **	-2.68 **	-19.88 **	-6.50 *	3.11	20.03	11.08 **	107.53 **	147.20 **	-29.06	-40.69 *	20.89	-3.11

PBW 226 x DBW 17	-0.34	-26.44 **	2.48 **	-0.73	-5.14	-10.56 **	17.49 **	44.76 *	22.92 **	183.28 **	308.75 **	48.57 **	37.65 *	7.89	11.90 *
PBW 226 x PBW 550	-2.39 *	-26.20 **	1.24	-2.68 **	-9.67 **	-16.09 **	12.01 *	30.07	16.67 **	153.05 **	230.81 **	18.77	-10.08	30.98 *	6.45
RAJ 2184 x WH 1105	-2.73 **	-27.64 **	1.86 *	-3.16 **	-6.97 *	-6.11 *	13.84 *	25.17	19.44 **	176.28 **	246.56 **	12.95	7.17	10.5	8.78
RAJ 2184 x DBW 17	-2.05 *	-26.44 **	4.04 **	1.46 *	-7.93 *	-12.13 **	8.62	2.10	14.93 **	116.22 **	127.25 *	-28.24	-29.42	4.4	12.85 *
RAJ 2184 x PBW 550	-3.41 **	-28.13 **	-1.24	-3.65 **	-2.41	-0.91	21.41 **	102.10 **	23.96 **	156.46 **	421.46 **	41.09 **	34.58 *	6.13	16.97 **
HD 2285 x WH 1105	-0.34	-26.20 **	3.73 **	-0.24	-7.41 *	-6.37 *	15.72 **	22.34	11.67 **	141.22 **	194.53 **	-7.19	5.87	-12.13	10.25
HD 2285 x DBW 17	-1.02	-27.16 **	1.55	0.73	-4.82	-6.19 *	15.14 **	33.57	16.32 **	127.63 **	207.98 **	6.86	-14.39	27.37	6.42
HD 2285 x PBW 550	-1.02	-26.44 **	1.24	-0.73	-3.85	-11.22 **	19.06 **	79.72 **	14.93 **	135.44 **	301.42 **	25.54	11.45	15.97	12.43 *
UP 2338 x WH 1105	-1.02	-26.44 **	1.55	-3.41 **	-1.41	-3.05	22.98 **	36.36	23.96 **	172.07 **	273.15 **	14.44	6.25	8.47	12.27 *
UP 2338 x DBW 17	0	-25.72 **	2.80 **	0.24	-1.51	-10.73 **	16.71 **	60.84 **	20.49 **	138.64 **	286.26 **	15.64	12.29	4.74	10.99 *
UP 2338 x PBW 550	-1.71	-26.92 **	2.17 *	-1.46 *	-5.2	-7.51 **	6.01	6.99	9.03 *	126.63 **	140.05 **	-10.43	-22.73	17.42	16.54 **
SE ±	0.88	1.00	0.90	0.92	3.12	1.08	0.67	1.76	0.65	5.54	151.28	5.60	13.31	6.30	1.94
CD at 5%	1.80	2.04	1.85	1.89	6.38	2.21	1.37	3.61	1.33	11.34	309.88	11.48	27.26	12.91	3.97
CD at 1%	2.43	2.75	2.49	2.55	8.61	2.98	1.85	4.87	1.79	15.30	418.03	15.48	36.77	17.41	5.35

Table 4: Estimation of general combining ability (GCA) effects for yield and its components in bread wheat (*Triticum aestivum* L.)

S. No.	Name of parent	Traits													
		Days to booting	**Days to heading**	**Days to anthesis**	**Days to phys. maturity**	**Plant height (cm)**	**Peduncle length (cm)**	**Spike length (cm)**	**No. of productive tillers/ plant**	**No. of spikeles/ spike**	**No. of grains/ spike**	**No. of grains/ plant**	**Grain yield (g)**	**Biological yield (g)**	**Harvest index (%)**	**Test weight (g)**
	LINES															
1	Lal Bahadur	-0.18	0.2	-0.38	-1.98 **	3.67 **	1.12 *	0.17	2.30 **	0.52	4.15	253.52 **	9.97 **	17.75 **	0.84	0.43
2	PBW 226	0.38	0.64	0.51	-0.42	-6.33 **	-1.47**	-0.49	-1.25	-0.17	0.1	-100.04	-1.08	-7.91	3.51	-2.09 *
3	RAJ 2184	-1.29**	-1.13 **	-0.49	-0.09	-0.32	0.42	-0.01	-0.15	0.32	0.66	14.96	-2.68	-0.9	-2.47	0.91
4	HD 2285	0.6	-0.02	0.18	2.24 **	0.11	-0.2	0.25	0.05	-0.67 *	-4.29	-81.84	-2.75	-3.49	-0.9	-0.31
5	UP 2338	0.49	0.31	0.18	0.24	2.86 *	0.13	0.07	-0.95	0.01	-0.62	-86.59	-3.46	-5.45	-0.99	1.06
	TESTERS															
6	WH 1105	0.04	-0.27	0.31	-1.78 **	-2.64 *	1.00**	-0.03	-0.85	-0.18	2.08	-41.49	-2.58	-5.47	0.22	-0.81
7	DBW 17	0.51	0.53	0.78*	2.56 **	1.57	-0.5	-0.07	-0.5	0.34	-0.67	-40.66	1.7	4.86	-1.09	-0.06
8	PBW 550	-0.56	-0.27	-1.09 **	-0.78 *	1.07	-0.51	0.1	1.35 *	-0.16	-1.42	82.15	0.88	0.6	0.87	0.88

*, ** significant at 5% and 1% level respectively

Table 5: Estimation of specific combining ability (SCA) effects for yield and its components in bread wheat (*Triticum aestivum* L.)

S. No.	Cross combination	**Traits**														
		Days to booting	**Days to heading**	**Days to anthesis**	**Days to phys. maturity**	**Plant height (cm)**	**Peduncle length (cm)**	**Spike length (cm)**	**No. of productive tillers/plant**	**No. of spikelets/spike**	**No. of grains / spike**	**No. of grains / plant**	**Grain yield (g)**	**Biological yield (g)**	**Harvest index (%)**	**Test weight (g)**
1	Lal Bahadur x WH 1105	-0.82	-1.73 *	-1.42 *	-1.56 *	0.11	-0.19	0.09	1.43	-0.28	2.03	153.15	7.01	-4.74	10.05 *	1.63
2	Lal Bahadur x DBW 17	0.04	1.13	0.44	0.44	0.06	0.91	-0.34	-0.72	0.19	1.45	-62.31	4.31	13.82	-2.89	-0.73
3	Lal Bahadur x PBW 550	0.78	0.6	0.98	1.11	-0.17	-0.71	0.26	-0.71	0.1	-3.47	-90.84	-11.33 **	-9.08	-7.16	-0.9
4	PBW 226 x WH 1105	0.62	0.82	1.02	0.89	-5.99 *	0.83	-0.96	-0.25	-0.93	-15.55 **	-218.34	-13.46 **	-24.56 *	0.23	-2.34
5	PBW 226 x DBW 17	0.16	-0.98	-0.78	-0.78	5.09 *	0.69	0.91	1.75	0.81	12.43 **	294.48 *	12.04 **	29.88 **	-4.49	2.69
6	PBW 226 x PBW 550	-0.78	0.16	-0.24	-0.11	0.9	-1.53	0.05	-1.5	0.12	3.11	-76.14	1.43	-5.32	4.26	-0.35
7	RAJ 2184 x WH 1105	-0.04	-0.07	0.02	-0.11	1.39	-0.89	-0.07	-0.86	0.18	6.78	-17.43	4.25	8	1.4	-0.76
8	RAJ 2184 x DBW 17	0.16	0.8	1.89 **	1.89 **	-3.82	-1.83 *	-0.7	-3.41 *	-1.21 *	-10.46 *	-397.58 **	-15.84 **	-32.60 **	-0.12	0.06
9	RAJ 2184 x PBW 550	-0.11	-0.73	-1.91 **	-1.78 *	2.42	2.72 **	0.77	4.27 **	1.03 *	3.68	415.01 **	11.59 **	24.60 *	-1.28	0.7
10	HD 2285 x WH 1105	0.4	0.82	1.36 *	1.56 *	0.51	-0.38	-0.08	-1.33	-0.32	0.07	-86.04	-3.4	9.51	-10.66 *	1.03
11	HD 2285 x DBW 17	-0.73	-1.31	-1.44 *	-1.44 *	-1.01	1.2	-0.12	-0.61	0.04	-1.71	-44.11	-2.29	-17.57	8.95	-1.2
12	HD 2285 x PBW 550	0.33	0.49	0.09	-0.11	0.5	-0.82	0.21	1.94	0.28	1.64	130.14	5.7	8.06	1.71	0.17
13	UP 2338 x WH 1105	-0.16	0.16	-0.98	-0.78	3.98	0.63	1.02 *	1.01	1.36 **	6.67	168.67	5.61	11.79	-1.02	0.43
14	UP 2338 x DBW 17	0.38	0.36	-0.11	-0.11	-0.33	-0.97	0.26	2.99 *	0.17	-1.71	209.51	1.78	6.46	-1.45	-0.81
15	UP 2338 x PBW 550	-0.22	-0.51	1.09	0.89	-3.66	0.34	-1.28 *	-4.00 **	-1.53 **	-4.96	-378.17 **	-7.39	-18.25	2.47	0.38

*, ** significant at 5% and 1% level respectively

Conclusion

Cross combinations namely, Lal Bahadur x WH 1105, Lal Bahadur x DBW 17, PBW 226 x DBW 17 and RAJ 2184 x PBW 550 showed significant and desirable heterosis for most of the traits. In combining ability analysis, parent Lal Bahadur and cross combination PBW 226 x DBW 17 and RAJ 2184 x PBW 550 was the good general combiner and good specific combinations respectively as these showed significant effects for yield and its component traits. These cross combinations may be exploited commercially for getting benefits of heterosis for grain yield and its other component traits in wheat.

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