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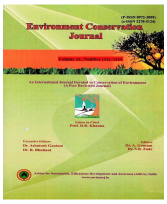

Study of heterosis for grain yield and its components in wheat (*Triticum aestivum* L. em. Thell.)

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ABSTRACT

The extent of wheat heterosis was determined by synthesizing 45 hybrids in a 10×10 diallel method, eliminating reciprocals, to determine how widespread it is. The 57 entries that made up the experimental material—10 parents, 45 crosses and 2 checks (HD 3086 and UP 2628), were assessed over the course of *rabi* 2018–19 using a Randomized Block Design (RBD) with three replications, and observations were made for 12 characters. For yield and its component traits, analyses of heterosis over mid parent, better parent and two standard checks were conducted. ANOVA exposed that there was a high significance existed among all the genotypes for all the characters studied. Yield and its contributing traits have been evaluated for their maximum heterotic range. One cross *i.e.,* CAL/NH//H567.71/3/SER1/4/CAL/NH//H567.71/5/2*KAU2/6/...×PBW 692 showed positive significance for relative heterosis, heterobeltiosis and standard heterosis over both checks for grain yield per plant. In terms of the number of productive tillers per plant and the number of grains per spike, UP 2901×QLD 73 was found to be a superior heterotic F_1. By displaying a negative significant standard heterosis over both checks, the cross between CAL/NH//H567.71/3/SER1/4/CAL/NH//H567.71/5/2*KAU2/6/...×UP 2901 demonstrated its earliness. The desired significant relative heterosis, heterobeltiosis and standard heterosis for spike length were present in HD 3234×UP 2762. The finest heterotic cross combinations for harvest index were determined to be CAL/NH//H567.71/3/SER1/4/CAL /NH//H567.71/5/2* KAU2/6/...×UP 2762 and VORB/SOKOLL×QLD 73. Higher heterotic crossings may be used to identify transgressive segregants that will increase bread wheat production and yield-contributing characteristics.

Introduction

Wheat (*Triticum aestivum* L. em. Thell.) is the main staple food consumed by billions of people worldwide having utmost importance to both the general welfare and national security of many nations. It is known as the "Stuff of life" or "King of cereals" due to the amount of land it takes up, its great productivity and its significant position in the global food grain trade. Due to rising processed food consumption brought on by global industrialisation and the westernization of cuisine, the demand for wheat is rising daily on a global scale. By 2050, the country's population growth would require more than 140 million tonnes of wheat grain, a 40% increase above current output levels (Singh *et al.,* 2019). Not only is a large increase in production necessary to fulfil the rising local food demand, but it is also necessary for export in order to earn foreign currency. This can be done via horizontal strategy, such as expanding the area under cultivation or a vertical approach, such as varietal or hybrid development, which is one of the most effective tools for increasing yield

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and productivity under various agroclimatic conditions. The cycle of stagnant wheat productivity around the world may be broken via heterosis breeding (Adhikari *et al.,* 2020). The key to increasing wheat production potential is heterosis manipulation. The study of heterosis aids in the early generational elimination of the less productive crossings and finds the parents that result in the best cross combinations with the highest expression of heterosis. The current research will help in assessing the extend of heterosis along with the selection of suitable parents for hybridization programme for the production of superior transgressive segregants with higher yield potential in various wheat crossings.

Material and Methods

Ten genetically diverse parents (CAL/NH//H567.71/3/SER1/4/CAL/NH//H567.71/ 5/2*KAU2/6/…, HD 3234, PBW 692, HUW 640, DBW 189, VORB/SOKOLL, UP 2762, UP 2901, QLD 73, QLD 65) were crossed in half diallel fashion and a total of 45 crosses were developed. The 10 parental lines along with 45 F_1's and two checks (HD 3086 and UP 2628) were evaluated in *rabi* 2018-19 in RBD with 3 replications at Norman E. Borlaug Crop Research Centre, Govind Ballabh Pant University of Agriculture and Technology, Pantnagar, India. The row to row spacing was 20cm with plant to plant spacing of 10cm and each entry per replication was planted in a single plot of 2 rows having 1m length. The recommended package of practices and cultural operations were followed (Dhar, 2014)The observations were recorded on 12 traits *viz.*, days to 75% heading, days to maturity, flag leaf area (cm^2), number of productive tillers per plant, plant height (cm), spike length (cm), number of spikelets per spike, number of grains per spike, 1000 grain weight (g), biological yield per plant (g), grain yield per plant(g) and harvest index (%). Five plants were selected randomly from each entry per replication for all the traits except days to 75% heading and days to maturity which were recorded on basis of whole plot observation (Roy *et al.,* 2021).

Statistical Analysis

ANOVA was performed by using the mean values for all the characters to test whether there exists a significant difference between the treatments or not (Sharma *et al*., 2018). The heterosis was calculated (in per cent) as increase or decrease in relation to average parent, mid parent and check parent. The formulae used are given below:

$$\textit{Relative}\ \textbf{Heterosis} = \left\{\frac{\overline{F_1} - \overline{MP}}{\overline{MP}}\right\} \times 100$$

$$\textit{Heterobeltiosis} = \left\{\frac{\overline{F_1} - \overline{BP}}{\overline{BP}}\right\} \times 100$$

$$\textit{Standard}\ \textbf{Heterosis} = \left\{\frac{\overline{F_1} - \overline{SP}}{\overline{SP}}\right\} \times 100$$

Where,

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

$\overline{MP}$ = Mid parental value

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

$\overline{SP}$ = Mean performance of standard variety

Results and Discussion

An additional chance to enhance and produce hybrids for yield traits together with adaptability for particular production environment is provided by the exploitation of hybrid vigor for yield and yield attributing traits. The extremely significant mean square estimates for every attribute under study show that there are substantial genetic variations between the genotypes. The results of the ANOVA (Table 1) showed that all characters except the number of spikelets per spike had significant mean sums of squares related to all genotypes. Additionally, all traits except spike length, days to maturity, and the number of spikelets per spike were significant for the mean squares owing to parents, while all traits were significant for the crosses except spike length. While flag leaf area, number of tillers per plant, plant height, spike length, number of grains per spike and biological yield per plant were significant due to mean squares related to parents v/s crosses. The degree of heterosis, which helps determine which parents to use to produce superior F_1 offspring, provides information on the genetic diversity of the parents involved in a cross. The commercial use of heterosis in plant breeding is thought to be an excellent application of genetics in agriculture. It is crucial for determining the course of upcoming breeding programs and for choosing promising cross combinations to obtain superior segregates in later generations in order to further increase wheat grain yield.

Table 1: Mean squares for twelve characters in wheat

SN	Characters	Replication [2]	Genotype [54]	Parent [9]	Crosses [44]	Parent v/s crosses [1]	Error [108]
1	Days to 75% heading	5.097**	6.035**	7.867**	5.796**	0.066	0.961
2	Days to maturity	7.255	6.404**	5.737	6.661**	1.094	2.971
3	Flag leaf area (cm^2)	26.823	43.530**	30.318**	44.154**	134.968**	11.370
4	Number of productive tillers per plant	28.291*	42.635**	12.089	37.164**	558.307**	7.909
5	Plant height (cm)	15.998	53.228**	51.992**	52.659**	89.391**	9.495
6	Spike length (cm)	3.796**	0.490*	0.609	0.423	2.350**	0.314
7	Number of spikelets per spike	4.967*	2.075	1.008	2.29 *	2.173	1.468
8	Number of grains per spike	61.642**	35.538**	52.893**	29.121**	161.700**	9.636
9	1000 grain weight (g)	3.066	44.151**	32.760**	47.371**	5.011	6.001
10	Biological yield per plant (g)	44.742	389.995**	537.884**	318.638**	2198.677**	51.704
11	Grain yield per plant (g)	5.097**	6.035**	7.867**	5.796**	0.066	0.961
12	Harvest index (%)	7.255	6.404**	5.737	6.661**	1.094	2.971

Commercial hybrid seed production is not feasible in self-pollinated crops such as wheat because of various limitations, including inadequate mechanisms to produce hybrid seed, absence of stable male sterile lines, high yielding and effective restorers, free pollen dispersal and high seed rate. Because of this, it is essential to examine heterotic combinations in terms of yield, its constituents, and quality features in the first filial generation (F_1). The superiority of hybrids, especially over better parent is more valuable for commercial exploitation of heterosis, according to Singh *et al.* (2004). They also identified the parental combinations that can produce the largest level of transgressive segregants. In the present investigation, for the majority of the characters, there was a significant range of heterosis, number of desirable hybrids and best hybrid (Table 2). The characteristics of wheat including early flowering, early maturity and small stature are desirable. Out of 45 crosses, during days to 75% heading, 2 crosses showed significant negative relative heterosis, 15 crosses showed significant negative heterobeltiosis and 13 and 26 crosses showed significant negative standard heterosis across CP1 and CP2 respectively. CAL/NH//H567.71/3/SER1/4/CAL/NH//H567.71/5 /2*KAU2/6/…×UP 2901 displayed the largest negative standard heterosis over the checks. Only VORB/SOKOLL×QLD 65 demonstrated negative significant relative heterosis and 3 crosses displayed significant negative heterobeltiosis for days to maturity among all crosses. The largest negative significant standard heterosis over the two checks was seen in CAL/NH//H567.71/3/SER1/4/CAL/NH//H567.71/5 /2*KAU2/6/...×UP 2901. According to the estimates of heterosis for plant height, a total of 7 and 10 crosses showed negative significant relative heterosis and heterobeltiosis, respectively. Also, significant negative standard heterosis was seen between the cross of HD 3234 and QLD 73 compared to both check parents. Short heighted varieties showing the significance of negative heterosis and heterobeltiosis for plant height due to increased lodging resistance and fertilizer responsiveness are preferred in plant breeding programmes as reported by Devi *et al.* (2013), Kumar and Kerkhi (2014), Kalhoro *et al.* (2015), and Madhukar *et al.* (2018) in their investigation for heterosis estimation in wheat and other related crops.The leaf and its associated characteristics are essential to the plant's survival under both ideal and insufficient moisture conditions. The expansion of the wheat flag leaf area is crucial for good yield production. Given that flag leaves play a major role in the synthesis of photosynthates, which are eventually translocated to grain, a number of wheat researchers came to the conclusion that positive heterosis for flag leaf area can ultimately result in increased grain output (Jatoi *et al.,* 2014). In the present investigation, 16 crosses showed positive relative heterosis significance and 9 crosses showed positive heterobeltiosis significance for flag leaf area. The highest positive significant heterosis over both mid and better parent was found in QLD 73×QLD 65. In UP 2762×UP 2901, the highest positive standard heterosis was found. This study's findings concur with those of Roy *et al.* (2021) and

Table 2: Heterosis range, number of desirable hybrids and best hybrid [over mid parent, better parent, CP1 (HD 3086) and CP2 (UP 2628)] for 12 traits in wheat

Trait	Heterosis hybrids	Heterosis range (%)	No. of desired hybrids	Best hybrids
Days to 75 % heading	MP	-2.21 to 2.77	2	CAL/NH//H567.71/3/SER1/4/CAL/NH//H567.71/5/2*KAU2/6/… × QLD 65
	BP	-3.58 to 1.45	15	HD 3234 × UP 2901
	CP1	-3.64 to 1.45	13	CAL/NH//H567.71/3/SER1/4/CAL/NH//H567.71/5/2*KAU2/6/… × UP 2901
	CP2	-5.36 to -0.36	26	CAL/NH//H567.71/3/SER1/4/CAL/NH//H567.71/5/2*KAU2/6/… × UP 2901
Days to maturity	MP	-2.26 to 3.27	1	VORB/SOKOLL × QLD 65
	BP	-3.47 to 2.50	3	VORB/SOKOLL × QLD 65
	CP1	-4.89 to 0.24	34	CAL/NH//H567.71/3/SER1/4/CAL/NH//H567.71/5/2*KAU2/6/… × UP 2901
	CP2	-5.12 to 0.00	36	CAL/NH//H567.71/3/SER1/4/CAL/NH//H567.71/5/2*KAU2/6/… × UP 2901
Flag leaf area (cm^2)	MP	-21.07 to 39.02	16	QLD 73 × QLD 65
	BP	-23.09 to 34.91	9	QLD 73 × QLD 65
	CP1	4.53 to 66.79	36	HUW 640 × QLD 65
	CP2	-5.68 to 57.90	25	UP 2762 × UP 2901
Number of productive tillers per plant	MP	-29.43 to 109.68	26	UP 2901 × QLD 73
	BP	-35.73 to 94.99	20	UP 2901 × QLD 73
	CP1	-52.96 to 9.77	1	HUW 640 × VORB/SOKOLL
	CP2	-53.13 to 9.38	1	HUW 640 × VORB/SOKOLL
Plant height (cm)	MP	-8.75 to 12.33	7	CAL/NH//H567.71/3/SER1/4/CAL/NH//H567.71/5/2*KAU2/6/…× VORB/SOKOLL
	BP	-12.33 to 8.17	10	HUW 640 × VORB/SOKOLL
	CP1	-6.23 to 13.81	2	HD 3234 × QLD 73
	CP2	-1.19 to 19.93	2	HD 3234 × QLD 73
Spike length (cm)	MP	-7.61 to 10.96	4	HD 3234 × UP 2762
	BP	-10.65 to 8.82	1	HD 3234 × UP 2762
	CP1	1.34 to 17.08	27	HD 3234 × UP 2762
	CP2	-7.76 to 6.56	21	HD 3234 × UP 2762
No. of spikelet/ spike	MP	-5.56 to 12.17	4	HUW 640 × VORB/SOKOLL
	BP	-7.28 to 11.49	2	HUW 640 × DBW 189
	CP1	4.21 to 22.90	25	HUW 640 × DBW 189
	CP2	-4.41 to 12.73	3	HUW 640 × DBW 189
Number of grains per spike	MP	-10.62 to 11.29	15	VORB/SOKOLL × QLD 65
	BP	-16.97 to 10.38	6	PBW 692 × VORB/SOKOLL
	CP1	-13.88 to 2.39	7	UP 2762 × QLD 73
	CP2	-13.88 to 2.39	7	UP 2762 × QLD 73
1000 grain weight (g)	MP	-16.42 to 18.29	8	CAL/NH//H567.71/3/SER1/4/CAL/NH//H567.71/5/2*KAU2/6/… × QLD 65
	BP	-21.28 to 10.79	3	CAL/NH//H567.71/3/SER1/4/CAL/NH//H567.71/5/2*KAU2/6/… × UP 2762
	CP1	-11.43 to 26.53	23	VORB/SOKOLL × QLD 73
	CP2	-20.22 to 13.97	7	VORB/SOKOLL × QLD 73
Biological yield per plant (g)	MP	-24.34 to 16.81	4	VORB/SOKOLL × QLD 65
	BP	-29.25 to 8.01	2	HD 3234 × PBW 692
	CP1	-12.45 to 35.42	12	CAL/NH//H567.71/3/SER1/4/CAL/NH//H567.71/5/2*KAU2/6/… × PBW 692
	CP2	-18.51 to 26.04	7	CAL/NH//H567.71/3/SER1/4/CAL/NH//H567.71/5/2*KAU2/6/… × PBW 692
Grain yield per plant (g)	MP	-21.35 to 19.47	13	CAL/NH//H567.71/3/SER1/4/CAL/NH//H567.71/5/2*KAU2/6/… × PBW 692
	BP	-26.22 to 14.86	5	CAL/NH//H567.71/3/SER1/4/CAL/NH//H567.71/5/2*KAU2/6/… × PBW 692
	CP1	-11.67 to 26.94	19	CAL/NH//H567.71/3/SER1/4/CAL/NH//H567.71/5/2*KAU2/6/… × PBW 692
	CP2	-12.51 to 25.73	17	CAL/NH//H567.71/3/SER1/4/CAL/NH//H567.71/5/2*KAU2/6/… × PBW 692
Harvest index (%)	MP	-12.68 to 35.76	14	CAL/NH//H567.71/3/SER1/4/CAL/NH//H567.71/5/2*KAU2/6/… × UP 2762
	BP	-15.18 to 34.73	5	CAL/NH//H567.71/3/SER1/4/CAL/NH//H567.71/5/2*KAU2/6/… × UP 2762
	CP1	-15.68 to 24.38	6	VORB/SOKOLL × QLD 73
	CP2	-15.43 to 24.74	8	VORB/SOKOLL × QLD 73

MP = average value of mid parent, BP = average value of better parent, CP1 = average value of check parent 1, CP2 = average value of check parent 2

Panwar *et al.* (2022) showing the importance of significant positive heterosis and heterobeltiosis for flag leaf area. In plant breeding, a variety with many productive tillers is preferred since they directly correlate with better grain yields per plant. The data also showed that a total of 26 and 20 crosses, respectively, showed positive significance over mid and better parent. High significant positive relative heterosis and heterobeltiosis were seen in UP 2901×QLD 73, whereas positive standard heterosis was present in HUW 640×VORB/SOKOLL. Garg *et al.* (2015), Ahmad *et al.* (2016) and Hei *et al.* (2016) also reported positive significant heterosis among their crosses revealing the role of high productive tillers directly correlate with better grain yields per plant. Increased spike length, spikelets per spike, grains per spike and 1000 grain weight are desired for the production of high yielding enhanced cultivars as these are significant yield contributing features.

Over the two assessments for spike length, HD 3234×UP 2762 showed the highest positive significant relative heterosis, heterobeltiosis and standard heterosis. Four crosses demonstrated significant positive relative heterosis, with HUW 640×VORB/SOKOLL showing the highest significant positive relative heterosis as per the estimates of heterosis for the number of spikelets per spike. Over the course of the examination, the highest positive significant heterobeltiosis and standard heterosis were found in HUW 640×DBW 189. From the estimates of heterosis for the number of grains per spike, it was further deduced that a total of 15 and 6 crosses, respectively, showed positive significant relative heterosis and heterobeltiosis. Positive estimations of standard heterosis were seen over both checks for UP 2762×QLD 73. Out of 45 crosses for 1000 grain weight, 8 and 3 crosses respectively recorded positive significance for relative heterosis and heterobeltiosis. Positive estimations of standard heterosis were seen over both inspections in VORB/SOKOLL×QLD 73. Additionally documented for the aforementioned traits are positive relative heterosis, heterobeltiosis, and standard heterosis by Baloch *et al.* (2016), Pesaraklu *et al.* (2016), and Choudhary *et al.* (2022).Grain yield is the trait of economic importance in wheat for which positive significant relative heterosis and heterobeltiosis were exhibited by 13 and 5 crosses respectively. CAL/NH//H567.71/3/SER1/4/ CAL/NH//H567.71/ 5/2*KAU2/6/…×PBW 692 performed well, demonstrating the highest positive significant relative heterosis, heterobeltiosis and standard heterosis for grain yield per plant. For biological yield per plant, this cross also showed the highest positive significant standard heterosis for both check parents.The recovery of excellent recombinants with high grain production per plant can therefore be advanced as also investigated by Singh *et al.* (2012), Ram and Shekhawat (2017), Rajput and Kandalkar (2018), and Roy *et al.* (2021)suggesting the importance of positive significance for biological and grain yield per plant. According to the analysis of estimates of heterosis for the harvest index, 14 and 5 crosses, respectively, showed positive significant relative heterosis and heterobeltiosis. The crosses between CAL/NH//H567.71/3/SER1/4/CAL/NH//H567.71/5 /2*KAU2/6/…×UP 2762 displayed the highest significant relative heterosis and heterobeltiosis while cross VORB/SOKOLL × QLD 73 showed highest positive significant standard heterosis. These hybrids can therefore be employed in breeding programs to produce plants with high harvest indices. Given that it denotes a large economic yield, a higher harvest index is a desired attribute. Dedaniya *et al.* (2018) and Panwar *et al.* (2022) have also reported significant positive heterosis for this trait.

Conclusion

Given that the parental genotypes exhibit substantial genetic diversity, there is a great deal of opportunity to use these genotypes in heterosis to improve grain yield and yield qualities. The level and extent of heterosis over the better parent, mid parent and standard check varied from cross to cross for each character. As a result, it was demonstrated that mean heterosis and its range in favoured direction varied significantly for each character. The considerable amount of high heterosis in certain crosses and low heterosis in other crosses indicates that the type of gene action varied depending on the genetic makeup of the parents involved in crossings. In order to identify the optimal cross combinations that would result in the best transgressive segregants, it would be helpful to know the type and level of heterosis. The cross between CAL/NH//H567.71/3/SER1/4/CAL/ NH//H567.71/5/2*KAU2/6/×PBW 692 shown positive significant relative heterosis, hetero beltiosis and standard heterosis in terms of grain yield per plant. In the future, breeding efforts may employ this hybrid to find excellent transgressive segregants from prior generations for grain yield enrichment.

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Conflict of interest

The authors declare that they have no conflict of interest.

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