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Heterosis studies using Diallel analysis in bread wheat (*Triticum aestivum* L.)

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Abstract
The present study was carried out for the estimation of heterosis and heterobeltosis in bread wheat during the year 2017-18. A diallel set of 9 x 9 was prepared by crossing nine genotypes in all possible combinations excluding reciprocals. Parents and their F_1 generations were planted in RBD (randomized block design) with three replications. The observations were recorded on five randomly selected plants in parents and F_1s for thirteen traits. Analysis of variances showed that significant variation is present among all the genotypes for all studied traits. The mean sums of squares due to parents as well as crosses were found highly significant for all thirteen traits, indicating the existence of substantial variation for all the traits among the genotypes as well as crosses. No any cross combination was found that exhibit significant heterosis for all the traits in the present investigation. Cross combinations namely, HD3059 × Raj3765, HD2967 ×WH1184, HD2967 × Raj3765, HD3059 × WH1184 and HD3059 × WH283 were found most promising for the grain yield per plant by showing high *per se* performance and heterosis over better parent. These crosses could be extensively used for developing superior segregates and better pure lines for different breeding programmes.

Keywords: Heterosis, heterobeltosis, diallel, crosses and traits

1. Introduction

Wheat (*Triticum aestivum* L *em* Thell.) is the principal food crop of most areas of world and occupies prominent position in India after rice. In India, it is grown on an area of 29.72 m hectare with total production 98.61 m tonnes and productivity 33.18 q/ha (Anonymous, 2017-18). Yield is a polygenic trait that is controlled by many components. Continuous varietal adoption and their improvement lead the wheat productivity to reach a new level. Non uniformity of increment in wheat productivity all over the country indicates that there are the opportunities for enhancing its production in future. Yield plateau is the major consequence after the green revolution. Therefore, the plant breeding tools have a great importance in changing the present situation. For the plant breeders selection of suitable parents with improved genetic potential for developing better verities is the major task. The most important technique for breaking yield barrier is hybridization. The identification of superior parents is the important pre-requisites for beginning an efficient and effective breeding programme.

Heterotic effect is increase or decrease in vigour and productivity of hybrids those compared to their parents which is expressed in F_1's and following generations. The heterosis studies are useful for the evaluation of newly developed lines for their parental usefulness. The commercial exploitation of heterosis in wheat has limited application because of practical difficulties of hybrid seed production in sufficient quantity. High heterotic hybrids may offer better probability for identification of desirable pure lines in advanced generations as compared to hybrids with low heterosis (Sharif *et al*., 2001) [21]. Heterosis studies may produce desirable segregants by identifying superior cross combination. Yield barriers may be overcome by heterosis breeding. Transgressive segregants for yield and component traits are obtained by exploiting the crosses having high heterosis. In wheat this phenomenon could be commercially exploited which could increase yield per acre. Heterosis study helps in the elimination of less productive crosses in the early generations. Keeping in view all the above facts, the present investigation was planned to estimate heterosis and heterobeltosis for grain yield and its related traits and to identify the superior crosses with their parents.

2. Material Methods

First time Freeman (1919) [10] recorded heterosis in wheat. Later on for many characters including yield and its components, it was detected by Bitzer *et al*. (1967) [5]. Nine diverse wheat genotypes namely WH1105, HD2967, HD3086, HD3059, Raj3765 WH1124, WH283, WH711, WH1184 were selected as parents on the basis of their origin, adaptability, diversity, yield potential, drought and heat tolerance traits. Crosses were attempted during *Rabi*, 2016-17 in a diallel fashion (excluding reciprocals). Further the F_{1s} were grown during *Rabi* season of 2017-18 under timely sown irrigated conditions at the wheat research area of Department of Genetics and Plant Breeding, CCS Haryana Agricultural University, Hisar, so as to obtain F_2 generation.

The investigation was conducted to evaluate the 36 F_1s and their nine parents for quantitative traits and yield components in field. Each entry was evaluated in single row of 2.5 meter length. Row to row and plant to plant distance was kept at 20 cm and 10 cm, respectively.

Five randomly competitive plants from each replication in parents and F_1s were selected and the observations were recorded for the traits *viz*, days to heading, days to maturity, plant height, number of productive tillers per plant, spike length, grain weight per spike, main spike weight, peduncle length, number of grains per spike, 100 grain weight, biological yield per plant, grain yield per plant, harvest index. The diallel cross analysis was carried out by the method as described by Mather and Jinks (1982) [18].

In the present study heterosis expressed as percent increase (+) or decrease (-) of F_1 mean over mid parent mean (MP) and better parent mean (BP) is referred as relative heterosis and heterobeltiosis respectively (Fonseca and Patterson, 1968) [9]. It is calculated as: $\frac{F_1-MP}{MP}$ over mid parent and $\frac{F_1-BP}{BP}$ heterosis over better parent. F_1= Mean performance of F_1 hybrid; MP = Mean performance of mid-parent and BP = Mean performance of better parent. Negative direction was considered for days to heading, days to maturity and plant height and positive direction was considered for other traits.

3. Result and Discussion

The ANOVA table 1 showing that significant variation is present among all the genotypes for all studied traits. The mean sums of squares due to parents as well as crosses were found highly significant for all thirteen traits, indicating the existence of substantial variation for all the traits among the genotypes as well as crosses. But the mean sum of squares due to parent v/s crosses were found significant for all the traits except for number of productive tillers per plant, peduncle length, gain yield per plant, biological yield per plant and harvest Index.

In the present investigation no any cross combination was found that exhibit significant heterosis for all the traits. However, cross HD2967 x WH1184 had significant heterosis over better parent for number of productive tillers per plant, days to heading, grain yield per plant and harvest index. While, crosses HD2967 x Raj3765, WH1105 x HD3059 and HD3059 x Raj3765 showed significant and positive heterosis over better parent for grain yield per plant and harvest index. Hei *et al*. (2016) [14], Kumar *et al*. (2017) [17] and Singh *et al.* (2018) [24] reported positive and significant heterosis for grain yield along with other traits. In the present study better parent heterosis for grain yield per plant ranged from -42.12 to 42.05 per cent for grain yield per plant. However magnitude and direction of heterosis varied from trait to trait and cross to cross. The presence of high heterosis for grain yield and its contributing traits is not only for developing hybrids but also helps to produce transgressive segregants for developing of superior homozygous lines.

Crosses HD3059 x WH283 (-8.99%) followed by WH283 × WH711 (-8.33%) and HD2967 x WH1184 (-6.14%) exhibited highest significant negative heterosis over better-parents indicating these were better cross combinations for early flowering. Similarly for days to maturity significant and negative heterosis displayed over better-parent by only two crosses namely, WH1105 x HD2967 (-4.16%) and WH283 x WH711(-4.00%) which is ranged from -4.16 (WH1105 × HD2967) to 4.40 (WH1105 × Raj3765). The reduced height was favoured over increase in grain yield. Significant negative heterosis over better parent for reduced height was shown by the crosses namely; WH711 X WH1184 (-12.15%) followed by WH1124 x WH711 (-9.46%), WH1124 x WH1184 (-7.90%), WH283 x WH1184 (-6.63%) and HD3086 x WH1184 (-5.90%). The range of heterobeltosis was found from -12.15% (WH711 X WH1184) to 10.48% (HD2967 X HD3086). Prakash *et al*. (2006) [20], Jaiswal *et al*. (2010) [7, 15], Hei *et al*. (2016) [14], Kumar *et al*. (2017) [17] and Singh *et al.* (2018) [24] were also found similar findings for plant height, days to maturity and days to heading in bread wheat.

The cross combinations, namely; HD2967 x WH283 (33.10%), HD2967 x WH1184 (31.86%) and WH1105 x WH711 (25.65%) were exhibiting significant positive heterosis over better parent for number of productive tillers per plant. It was ranged from -30% (WH1105 X WH1124) to 33.10% (HD2967 x WH283). Sharma and Tondon (1998) [23], Jaiswal *et al*. (2010) [7, 15] and Hei *et al*. (2016) [14] also found heterobeltiosis for number of productive tillers per plant in wheat.

The crosses viz., WH1105 x WH711, HD2967 x WH283, HD283 x WH711, HD3059 x WH283, HD3086 x WH711 and WH283 x WH711 showing significant positive heterosis over better parent for spike lenght. The range of heterosis over better parent for spike length was from -8.14% (HD2967 x WH1184) to 16.11% (WH283 x WH711). Only five crosses were showing positive and significant heterosis for grain weight per main spike over better parent. The heterobeltotic crosses were Raj3765 x WH283, Raj3765 x WH711, Raj3765 x WH1184, WH711 x WH1184 and WH283 x WH711. Heterobeltiosis for grain weight per main spike ranged from -31.89% (WH1105 x WH283) to 27.85 % (Raj3765 x WH711). Similar findings were reported by Jaiswal *et al*. (2010) [17, 15], Bilgin *et al*. (2011) [4] and Gite *et al* (2014) [12].

Number of grains per spike is one of the most important yield related trait in wheat. Heterosis over better parent for number of grain per spike was ranged from – 21.43% (HD2967 x WH283) to 26.52% (Raj3765 x WH283) (Table 3). Only five crosses showing significant positive heterosis over better parent. Maximum heterosis over better parent was recorded by the cross Raj3765 x WH283 (26.52%). Similar findings were also noticed by Akhter *et al*. (2003) [1], Xinnian *et al*. (2007) [25], Krystkowiak *et al*. (2009) [16], Jaiswal.*et al*. (2010), Bilgin *et al*. (2011) [4], Hei *et al*. (2016) [14] and Nawara *et al* (2016) [19].

From the Table 3 it was depicted that heterosis over better parent for peduncle length ranged from -17.17% (WH283 x WH711) to 4.74% (HD3086 x Raj3765). Heterosis over better parent for the trait 100 grain weight was ranged from -13.04% (WH1105 × WH283) to 21.04% (HD2967 x WH283). Out of 36 only nine crosses displayed significant positive heterosis over better parent. Maximum heterosis over better parent for the trait 100 grain weight was found in cross HD2967 × WH283 (21.04%) followed by HD3086 × WH711 (16.98%) (Table 3).

Only seven crosses namely, HD2967 x Raj 3765(35.77%), WH1105 x HD3059 (29.57%), HD2967 x WH711 (27.95%), HD2967 x WH1184 (29.66%), HD3059 x Raj 3765 (42.05%), HD3059 x WH283 (24.28%) and HD3059 x WH1184 (18.63%) showed significant positive heterosis over better parent for grain yield per plant. It was ranged from -42.119 (WH1105 x HD3086) to 42.05(HD3059 x Raj 3765) (Table 3). Our results are in accord with the earlier findings reported by Elsayed and Moshref (2005) [6], Hassan *et al*. (2006) [13], Xinnian *et al*. (2007) [25], Gami *et al*. (2010), Jaiswal *et al*. (2010) [7, 15], Bilgin *et al*. (2011) [4], Hei *et al*. (2016) [14] and Singh *et al*. (2018) [24].

Heterosis for biological yield per plant ranged from -36.30% (WH1105 x HD3086) to 19.44% (Raj3765 x WH1124) over better parent (Table 3). Only two crosses namely, HD3059 x WH1124 and Raj3765 x WH1124 out of 36 crosses, showed significant and positive heterosis over better parent with 18.94 and 19.44 per cent respectively (Table 3). Heterosis over better parent for harvest index ranged from -32.25% (WH 1124 x WH 283) to 40.19% (HD2967 x Raj3765). Only three crosses depicted significant positive heterosis over better parent. Maximum heterosis was shown by the cross HD2967 x Raj3765 (40.19%) followed by cross HD2967 x WH1184 (39.24 %) and HD3059 x Raj3765 (29.08%) (Table 3). Similar findings were reported by Hassan *et al*. (2006) [13], Xinnian *et al*. (2007) [25], Gami *et al*. (2010) [11], Jaiswal *et al*. (2010) [7, 15], Bilgin *et al*. (2011) [4], Hei *et al*. (2016) [14] and Singh *et al*. (2018) [24].

Consequently, the results exhibited significant negative as well as positive heterosis over better parent in number of crosses for several studied traits. From the study it revealed that the parents showing high heterotic effects were genetically diverse. From sufficient amount of heterosis in several crosses and low in other crosses revealed that nature of gene action varied with genetic constitution of their parents (Sharma, 2001) [21].

The top five heterotic crosses namely, HD3059 × Raj3765, HD2967 ×WH1184, HD2967 × Raj3765, HD3059 × WH1184 and HD3059 × WH283 were revealed from the tabel for high *per se* performance for grain yield and heterosis over better parent involving genetically diverse parents, confirming the predictable results as articulated by Falconar.(1981) [8]. As yield is last product of multiple interactions among several components because there is no any separate gene system for yield *per se*.

Table 1: Analysis of variance (ANOVA) for thirteen traits in nine bread wheat genotypes

Source	d.f.	Days to heading	Days to maturity	Plant height (cm)	No of productive tillers per plant	Spike length (cm)	Main spike weight (g)	Grain weight per main spike(g)	No of grains per spike	Peduncle length (cm)	100 grain weight (g)	Grain yield per plant (g)	Biological yield per plant (g)	Harvest Index (%)
Replicates	2	4.11	4.27	32.91	11.47**	0.01	0.29**	0.29**	7.92	13.74**	0.11	59.26**	97.14	107.45**
Genotypes	44	25.35**	24.69**	75.62**	13.90**	1.61**	0.28**	0.28**	136.54**	18.52**	0.35**	93.39**	358.42**	131.65**
Parents	8	41.31**	30.66**	172.69**	7.15**	1.69**	0.36**	0.36**	224.33**	33.54**	0.13**	34.31**	542.84**	42.92*
Crosses	35	22.19**	18.84**	52.45**	15.83**	1.20**	0.22**	0.22**	105.05**	15.49**	0.37**	109.29**	322.16**	153.49**
Parent Vs. Crosses	1	8.56	181.42**	109.90**	0.13	15.11**	1.73**	1.73**	536.0**	4.48	1.51**	9.7	152.13	76.99
Error	88	2.93	7.03	14.41	1.94	0.55	0.06	0.06	12.65	2.47	0.04	8.1	52.96	20.92

*, ** Significant at P=0.05 and 0.01, respectively.

Table 2: Extent of hetrosis (%) over better parent for days to heading, days to maturity,. plant height and number.of productive tillers.per plant, Spike length and Main spike weight in wheat

Crosses	Days to heading	Days to maturity (cm)	Plant height (cm)	Number of productive tillers per plant	Spike length (cm)	Main spike weight (g)
	Heterosis (%)	Heterosis (%)	Heterosis (%)	Heterosis (%)	Heterosis (%)	Heterosis (%)
WH1105 × HD2967	-6.14**	-4.16 **	1.89	-19.07 *	0.77	3.97
WH1105 × HD3086	0.30	0.68	0.65	-20.73 **	8.33	5.00
WH1105 × HD3059	-4.64 **	1.35	2.09	2.73	7.14	4.81
WH1105 × Raj3765	2.45	4.40**	4.71	-7.10	6.38	21.41*
WH1105 × WH1124	-3.90**	3.01*	-5.82	-30.00**	5.27	13.18
WH1105 × WH283	-0.30	1.39	1.24	-5.92	5.46	3.22
WH1105 × WH711	3.67**	0.22	-3.40	25.65**	14.17**	19.37*
WH1105 × WH1184	-2.35	4.33**	-4.19	-32.30**	-1.67	9.59
HD2967 × HD3086	-5.26 **	-1.97	10.48**	-15.83*	-3.26	-4.42
HD2967 × HD3059	-0.87	0.88	2.55	-0.48	0	-5.67
HD2967 × Raj3765	-0.88	-1.1	3.27	-19.29*	8.55	-4.33
HD2967 × WH1124	0.88	1.32	0.38	0.95	0.51	10.17
HD2967 × WH283	-2.34	-0.44	2.94	33.10**	15.38**	3.42
HD2967 × WH711	-4.09 **	1.54	-3.04	6.86	2.36	5.83
HD2967 × WH1184	-6.14 **	-1.32	-4.78	31.86**	-8.14	5.67
HD3086 × HD3059	-4.64**	1.57	3.95	5.56	9.89 *	10.0
HD3086 × Raj3765	0.30	4.11**	-3.3	-16.00 *	1.02	-13.08
HD3086 × WH1124	0.60	1.83	-0.95	-8.67	2.70	0.17
HD3086 × WH283	-3.57 **	2.97*	1.83	-5.56	11.99*	4.67

Crosses			Days to Heading	Days to Maturity	Plant Height (cm)	Number of productive tillers per lant	Spike length (cm)	Main spike Weight (g)
			Heterosis (%)	Heterosis (%)	Heterosis (%)	Heterosis (%)	Heterosis (%)	Heterosis (%)
HD3086	×	WH711	-0.9	-0.44	-3.08	5.78	13.61**	5.08
HD3086	×	WH1184	-2.93 *	0.91	-5.90 *	-25.22 **	-4.42	0.42
HD3059	×	Raj3765	-1.74	-1.13	3.59	15.3	2.04	-5.33
HD3059	×	WH1124	-2.61 *	-0.23	1.27	-13.6	0.26	-6.25
HD3059	×	WH283	-8.99 **	-0.23	1.05	-0.79	9.19	-5
HD3059	×	WH711	-2.90 *	2	-5.68	-20.03*	5.56	-6.67
HD3059	×	WH1184	-5.51 **	2.48	-4.83	0.88	-4.65	2.33
Raj3765	×	WH1124	0.9	3.94*	-5.32	-14.08	-3.59	0.88
Raj3765	×	WH283	-0.89	2.08	2.65	-12.63	8.21	23.89*
Raj3765	×	WH711	4.05**	0	-6.06	-20.16 *	8.46	16.77
Raj3765	×	WH1184	-4.11 **	0.68	-5.07	-17.70 *	5.35	1.43
WH1124	×	WH283	-5.95 **	0.93	0.43	-18.10*	0.13	26.56**
WH1124	×	WH7 11	-0.3	-1.56	-9.46 **	5.24	-0.77	16.02
WH1124	×	WH1184	-4.40**	2.05	-7.90 **	-12.68	-6.12	4.71
WH283	×	WH711	-8.33 **	-4.00 **	1.02	-12.31	16.11**	22.29*
WH283	×	WH1184	-4.40 **	0.68	-6.63 *	-20.58**	4.42	9.67
WH711	×	WH1184	0	0.22	-12.15**	-16.37*	-4.12	2.02
C.D. at 5%			3.19037	4.93939	7.06879	2.59674	1.37594	0.68194
C.D. at 1%			3.68392	5.70352	8.16233	2.99845	1.5888	0.78743

Table 3: Extent of hetrosis (%) over better parent for Grain weight per main spike, Number of grains per spike, Peduncle length, and 100 grain weight, grain yield per plant, biological yield per plant and harvest index in wheat

Crosses			Grain weight per main spike(g)	Number of grains per spike	Peduncle Length(cm)	100 grain Weight(g)	Grain yield/plant(g)	Biological yield/plant(g)	Harvest Index(%)
			Heterosis (%)	Heterosis (%)	Heterosis (%	Heterosis (%)	Heterosis (%)	Heterosis (%)	Heterosis (%)
WH1105	×	HD2967	-8.44	0.95	0.72	0.66	-29.12 **	-14.76	-16.56
WH1105	×	HD3086	-9.22	-5.71	1.84	4.57	-42.11 **	-36.30 **	-7.88
WH1105	×	HD3059	-9.67	-0.48	-3.42	-5.33	29.57**	13.34	-4.35
WH1105	×	Raj3765	5.89	3.81	2.34	-1.84	-29.86 **	-21.77 **	-13.13
WH1105	×	WH1124	-14.44 *	-7.14	-11.50**	-10.50*	-24.13**	-3.29	-25.59**
WH1105	×	WH283	-31.89**	-19.05 **	-3.9	-13.04 **	-4.69	-17.28 **	-0.71
WH1105	×	WH711	-13.11	-8.57*	-7.39 *	-9.05 *	10.87	-7.76	20.43
WH1105	×	WH1184	3.22	2.86	3.36	2.96	-25.28**	-25.62 **	1.36
HD2967	×	HD3086	-12.89	-19.52**	1.75	2.08	-16.36 *	-13.37 *	-9.71
HD2967	×	HD3059	-8.78	-8.1	-1.9	-1.17	2.24	-7.66	-1.34
HD2967	×	Raj3765	-10.33	-12.38 **	2.54	3.54	35.77**	-18.92 *	40.19 **
HD2967	×	WH1124	-7	-10.00 *	-5.21	11.25**	-14.58	-14.01	-11.66
HD2967	×	WH283	-12.89	-21.43 **	-12.96**	21.04**	13.14	-13.97 *	8.19
HD2967	×	WH711	7.44	4.76	-3.41	3.89	27.95**	11.53	14.95
HD2967	×	WH1184	10.11	6.67	4.95	1.04	29.66 **	-14.23 *	39.24**
HD3086	×	HD3059	2.89	11.17*	-6.67	8	-1.92	-24.60 **	7.19
HD3086	×	Raj3765	-4.44	6.01	4.74	6.07	3.85	-8.8	16.36
HD3086	×	WH1124	5.22	16.94**	-5.54	4.92	-11.44	-30.19 **	5.79
HD3086	×	WH283	-0.89	4.37	-3.38	16.01**	-1.84	-5.51	1.82
HD3086	×	WH711	-12.67	-2.19	-4.15	16.98**	12.87	-7.98	18.85
HD3086	×	WH1184	-2.33	15.71**	-0.53	-0.24	-25.94 **	-35.21 **	13.35
HD3059	×	Raj3765	-15.00*	-8.59	2.18	1.84	42.05**	-4.15	29.08**
HD3059	×	WH1124	-4.44	5.56	-8.17 *	3.92	4.26	18.94*	-13.25
HD3059	×	WH283	-10.89	-7.07	-15.35**	3.22	24.28**	-8.46	-4.08
HD3059	×	WH711	-1.67	-9.09 *	-5.89	5.83	-32.34 **	-29.68 **	-16
HD3059	×	WH1184	-0.44	2.53	-3	9.92*	18.63*	5.62	-3.58
Raj3765	×	WH1124	-10.41	-3.45	-8.17 *	4.75	1.16	19.44*	-23.57*
Raj3765	×	WH283	27.17**	26.42**	0.5	11.47**	8.85	-17.28 **	20.54
Raj3765	×	WH711	27.85**	8.18	-2.88	2.47	-29.76 **	-25.80 **	-4.84
Raj3765	×	WH1184	19.12*	4.71	5.96	14.56**	-17.96 *	-6.26	-12.57
WH1124	×	WH283	-15.56*	-1.72	-0.37	14.52**	-17.95*	-12.87	-32.25**
WH1124	×	WH7 11	-15.44 *	9.2	-16.50 **	0.45	-7.05	10.96	-24.92**
WH1124	×	WH1184	0.22	5.24	-5.5	6.4	-26.22**	-18.79 **	-22.08*
WH283	×	WH711	26.90**	13.19 *	-17.17 **	-7.55	-32.63 **	-32.97**	-14.41
WH283	×	WH1184	6.07	2.09	-3.92	0.24	-21.95**	-12.31	-13.55
WH711	×	WH1184	24.03**	6.81	-8.66 *	14.64**	-31.04**	-19.92 **	-13.94

C.D. at 5%		0.45	6.62	2.93	0.39	5.3	13.55	8.52
C.D. at 1%		0.52	7.64	3.38	0.45	6.12	15.64	9.83

4. Conclusion

Keeping in view of the above findings, it may be concluded that all the crosses exhibited heterosis in one or more traits. The magnitude of heterotic effects was high for number of productive tillers per plant and grain yield per plant and moderate for number of grains per spike, grain weight per spike, 100-grain weight and biological yield per plant. Cross combinations namely, HD3059 × Raj3765, HD2967 ×WH1184, HD2967 × Raj3765, HD3059 × WH1184 and HD3059 × WH283 were found most promising for the grain yield per plant by showing high *per se* performance and heterosis over better parent. These crosses could be extensively used for developing superior segregants and better pure lines for different breeding programmes.

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