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Estimation of heterosis for yield and some yield components in bread wheat

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Abstract
The heterosis study for grain yield and its attributes was carried out in bread wheat [*Triticum aestivum* L. em. Thell] through half diallel mating design in four environments. The pooled analysis revealed significant differences between the environments for all the characters, indicating that environments had significant effect on the expression of different characters. The variance due to parents and F_1 were also significant for all the characters studied demonstrating the presence of significant variability among the material used in the study and presence of average heterosis for all the characters. The magnitude of heterobeltiosis and standard heterosis altered for all the crosses and for all the characters studied. For the traits *viz.*, flag leaf area, 1000 grain weight, grain yield per plant and number of grains per spike quite a large number of crosses manifested positive significant heterosis over the checks. In contrast to these, least heterotic effects were observed for days to heading and harvest index. The hybrids HI 1544 x HD 2987, Raj 4037 x HD 2987, PBW 175 x HD 2987, HD 2932 x Raj 4079 and PBW 175 x Lok 1 exhibited the highest, significant and positive heterotic effect and mean performance for grain yield per plant and some of its important component traits. This could be exploited commercially for heterosis breeding in wheat.

Keywords: Heterosis, Genotypes, Grain yield, diallel, bread wheat

Introduction
Bread wheat (*Triticum aestivum* L. em. Thell) is an annual self-pollinated crop with chromosome number 2n = 6x = 42. Wheat is the staple food for over 27 per cent of global population in more than 40 countries. It is popularly known as 'Stuff of life or King of the cereals' because of the acreage occupied, high productivity and the prominent position it holds in the international food grain trade. The main wheat growing countries include China, India, USA, Russia, France, Canada, Turkey, Australia and Ukrain. In India, area and production of wheat during year 2014-15 was recorded 30.97 million ha and 88.94 million tonnes with an average productivity of 2872 kg ha^{-1} (DAC&FW, 2015). Wheat grain contains starch (60-68%), protein (6-21%), fat (1.5-2.0%), cellulose (2.0-2.5%), minerals (1.8%) and vitamins. The uniqueness of wheat in contrast to other cereals is that wheat contains gluten protein which enables leavened dough to rise by forming minute gas cells and this property enables bakers to produce light breads. In a self-pollinated crop like wheat, the utilization of heterosis depends mainly upon the direction and magnitude of heterosis. Wheat breeders dealing with various aspects of hybrid wheat found that the economic heterosis for grain yield, on a large plot basis, ranged from 6 percentages (Borghi *et al*. 1986) [3] to as high as 41 percentages (Yadav and Murty 1976) [16]. The study was conducted for identifying the best cross combination(s) that could be used for commercial production of hybrid wheat as well as isolation of pure lines among the progenies of heterotic F_1s for further amelioration of grain yield in wheat.

Materials and Methods
Experimental site and design
Experimental material consisted of 8 diverse genotypes (Table 1) selected on the basis of broad range of genetic diversity for major yield components, geographical origin, heat tolerance and their suitability for different yield traits, were crossed in half diallel fashion resulting in 28 F_1s at Research Farm, Rajasthan College of Agriculture, Udaipur (Rajasthan) during the year 2014-15. These eight parents and their 28 F_1s and 2 checks viz., HI 1563 and HD 2967 were grown in a randomized block design with three replications under early (E_1), normal (E_2), late (E_3) and very late (E_4) sown conditions. The environments were created by four different date of sowings (Table 2). Row-to-row and plant-to-plant distances were 30cm

and 10cm respectively in each environment. Recommended plant protection procedures were followed for raising the crop in all the environments.

Table 1: List of parent material of wheat used in experiment

S. No.	Name of cultivar	Pedigree
1.	HD 2932 (PUSA WHEAT 111)	KAUZ/STAR//HD 2643
2.	GW 366	DL 802-3/GW 232
3.	Raj 4037	DL 788-2/RAJ 3717
4.	PBW 175	HD 2160 /WG 1025
5.	HI 1544 (PURNA)	HINDI 62/BOBWHITE/ CPAN 2099
6.	Raj 4079	UP 2363/WH 595
7.	HD 2987 (PUSA BAHAR)	HI1011/HD2348//MENDOS//IWP72/DL 153-2
8.	LOK 1	S-308/S 331,

Table 2: Detail of the four environments created were as follows

Environment	Date of sowing
E_1 (Early sown)	October 27, 2015
E_2 (Normal sown)	November 17, 2015
E_3 (Late sown)	December 07, 2015
E_4 (Very late sown)	December 27, 2015

Recording of data

The observation were recorded on five randomly selected competitive plants from each plot in each replication in case of parents, F_1s and checks in all the four environments separately on eleven distinct morphological characters, except days to 50% flowering and days to maturity, where it was observed on complete plot basis. The data on days to heading, days to maturity, plant height, number of effective tillers per plant, spike length, number of grains per spike, flag leaf area, 1000 grain weight, biological yield per plant, grain yield per plant and harvest index were recorded for statistical analysis.

Statistical analysis

The mean value of the recorded observation was subjected to analysis of variance (ANOVA) using the standard procedures of Panse and Sukhatme (1985) [10]. Heterosis, heterobeltiosis and economic heterosis were calculated according to the method suggested by Shull (1909) [15], Fonseca and Patterson (1968) [5] and Meredith and Bridge (1972) [9], respectively. To calculate heterobeltiosis and economic heterosis parent with higher mean values was considered desirable for all the characters except days to heading, days to maturity and plant height where lower mean values were considered desirable. The economic heterosis was calculated over the check for a particular character.

Result and Discussion

The pooled analysis of variance over four environments (Table 3) revealed significant differences between the environments for all the characters, indicated that environments had significant effect on the expression of different characters. The mean squares due to parents and F_1 were also significant for all the characters, indicated that between parents and between hybrids difference was significant and average heterosis was there. Parents vs. hybrids comparison were significant for number of effective tillers per plant, spike length, 1000 grain weight, grain yield per plant and harvest index, indicated presence of overall heterosis for all these characters. Highly significant differences due to genotypes × environments were observed for all the characters number of effective tillers per plant and grain yield per plant, indicated influence of different environments on the expression of genotypes.

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. According to modern concept, heterosis is expression of joint effect of favorable genes, interaction between alleles, non-allelic interaction and mitocondrial genes brought together from the parents. In self-pollinated crop like wheat, where commercial hybrid seed production is not feasible due to lack of suitable mechanism to produce hybrid seed, exploitation of hybrid vigour is limited. Therefore, at present heterosis *per se* may not be of economic value in this crop. However, it indicates genetic potential of parental combination and if the heterosis is due to epistatic gene effects, particularly of additive x additive type or due to repulsion phase linked loci, exhibiting partial or complete dominance, it is possible to fix the alleles at interacting state to preserve the heterotic effects in the pure lines (Arunachalam *et al*. 1984) [2]. Means transgressive segregants are possible. The allopolyploid nature of wheat will also favour preservation of such hybrid vigour for a considerable number of generations.

The exploitation of heterosis in crop plants is one of the major breakthroughs in plant breeding. The degree of heterosis over mid parental value has comparatively restricted scope and is of more hypothetical interest than of real-world utility. Hence, the heterosis measured in terms of superiority over the better parent and over the standard check is more treasured, which decides whether an experimental hybrids is worth exploiting or not.

The magnitude of heterosis and number of cross combinations showing heterosis over better parent and standard hybrid for grain yield per plant and its related characters are present in Table 4. Grain yield per plant in wheat is the character of economic importance for which 7 hybrids over better parent and 6 hybrids over economic heterosis exhibited significant and positive heterosis. Several hybrids exhibited significant and desirable direction of heterobeltiosis, economic heterosis for various characters such as days to heading (1 and 2 hybrids); days to maturity (2 and 2 hybrids); plant height (2 and 3 hybrids); number of effective tillers per plant (4 and 5 hybrids); spike length (2 and 6 hybrids); number of grains per spike (5 and 7 hybrids); flag leaf area (4 and 7 hybrids); 1000 grain weight (10 and 9 hybrids); biological yield per plant (2 and 9 hybrids); harvest index (5 and 2 hybrids), respectively.

The hybrid, Raj 4037 x HD 2987 for days to heading, Raj 4037 x HD 2987 for days to maturity, PBW 175 x HI 1544 for plant height, Raj 4037 x Raj 4079 for number of effective tillers per plant, HI 1544 x Lok1 for Spike length, Raj 4037 x HD 2987 for number of grains per spike, Raj 4037 x PBW 175 for flag leaf area, GW 366 x HD 2987 for 1000 grain weight, HD 2932 x Raj 4079 for biological yield per plant, Raj 4037 x HD 2987 for grain yield per plant and GW 366 x Lok1 for harvest index showed significant and maximum heterosis over better parent.

Maximum heterosis over standard check were observed in Raj 4037 x HD 2987 for days to heading, PBW 175 x HI 1544 for days to maturity, Raj 4079 x Lok1 for plant height, PBW 175 x HD 2987 for number of effective tillers per plant, HI 1544 x Lok1 for Spike length, Raj 4037 x HD 2987 for number of grains per spike, Raj 4037 x PBW 175 for flag leaf area, GW 366 x HD 2987 for 1000 grain weight, HI 1544 x HD 2987 for biological yield per plant, HI 1544 x HD 2987 for grain yield per plant and GW 366 x Lok1 for harvest index. A comparison of high heterotic crosses with best performing crosses (Table 4) further revealed that for all the characters, the performance of crosses was not associated with heterotic response, *i.e.* the best perform and heterotic crosses were different. This indicated that selection of crosses for grain yield and its related traits on the basis of either *per se* performance or heterotic response would be equally important, but the former is more desirable.

The utility of hybrid breeding approach lies in identification of the most heterotic and useful combinations in order to make commercial cultivation of hybrid beneficial. For this a comparison of the first seven high yielding hybrids was made with their *per se* performance for grain yield, heterotic effects and heterotic effects for other components (Table 5). The high yielding hybrids were in general the most heterotic crosses which indicated close association between hybrid mean performance and manifestation of heterosis. The relative ranking of hybrids based on the mean performance. This suggested that selection of hybrids should be based on per se performance. Similar findings have been reported by Kumar *et al*. 2014 [7].

Table 3: Analysis of variance (mean squares) pooled over environments for different traits in bread wheat

S. No.	Characters	Source										
		Env	**Rep/Env**	**Genotype**	**Parents**	**F_1**	**P vs F_1**	**G x E**	**P x E**	**F_1 x E**	**P vs F_1 x E**	**Pool Error**
		[3]	**[8]**	**[35]**	**[7]**	**[27]**	**[1]**	**[105]**	**[21]**	**[81]**	**[3]**	**[280]**
1.	Days to heading	2576.63**	2.66	28.86**	14.75*	33.58**	0.23	5.93	3.00	6.65	6.96	6.48
2.	Days to maturity	7534.36**	27.34	49.33**	38.36*	53.04**	25.93	9.03	9.53	8.61	16.98	15.03
3.	Plant height (cm)	3282.95**	25.58	82.02**	113.14**	76.27**	19.75	5.96	5.61	5.95	8.76	15.89
4.	No. of effective tillers per plant	171.389**	0.37	16.67**	2.53**	20.82**	3.75*	1.33**	0.51	1.57**	0.74	0.72
5.	Spike length (cm)	106.736**	1.33	6.83**	7.07**	6.83**	5.31*	0.49	0.26	0.52	1.32	0.91
6.	No. of grains per spike	994.919**	9.39	133.43**	162.22**	130.07**	22.59	5.71	5.81	5.60	8.01	10.87
7.	Flag leaf area (cm^2)	1023.31**	55.14**	95.61**	153.70**	84.07**	0.57	6.57	9.53*	5.05	26.78**	5.74
8.	1000 grain weight (g)	998.049**	8.85**	57.42**	55.04**	57.14**	81.64**	1.93	0.88	2.25	0.60	2.67
9.	Biological yield per plant (g)	3921.13**	29.45	439.13**	331.62**	483.27**	0.01	11.66	5.31	13.65	2.16	17.04
10.	Grain yield per plant (g)	1149.07**	2.71	56.86**	34.43**	62.51**	61.25**	2.63**	2.22	2.71**	3.25	1.65
11.	Harvest index (%)	821.036**	62.22**	86.92**	111.39**	68.97**	400.49**	20.88	17.08	22.29	9.49	21.50

*, ** Significant at 5 and 1 per cent, respectively (Model I)

[ ] Degree of freedom

Table 4: Magnitude of heterobeltiosis (HB) and economic heterosis (EH) over environments for different traits in bread wheat

S. No.	Traits	Range of heterosis								Number of cross combinations showing heterosis	
		Heterosis (%)		**Heterobeltiosis (%)**			**Economic heterosis (%)**			**Heterobeltiosis**	**Economic heterosis**
		Min.	**Max.**	**Min.**	**Max.**	**Best cross with heterotic effect**	**Min.**	**Max.**	**Best cross with heterotic effect**		
1	Days to heading	4.78	-4.45	-0.12	-3.39	Raj 4037 x HD 2987	0.01	-3.73	Raj 4037 x HD 2987	1	2
2	Days to maturity	4.01	-4.17	-0.21	-3.38	Raj 4037 x HD 2987	-0.01	-2.58	PBW 175 x HI 1544	2	2
3	Plant height (cm)	3.68	-6.58	-0.22	-6.27	PBW 175 x HI 1544	-0.19	-7.01	Raj 4079 x Lok1	2	3
4	No. of effective tillers per plant	-46.11	20.58	0.64	16.96	Raj 4037 x Raj 4079	0.15	15.03	PBW 175 x HD 2987	4	5
5	Spike length (cm)	-14.04	15.91	1.32	12.54	HI 1544 x Lok1	0.49	22.22	HI 1544 x Lok1	2	6
6	No. of grains per spike	-15.72	27.29	1.64	11.23	Raj 4037 x HD 2987	0.87	10.83	Raj 4037 x HD 2987	5	7
7	Flag leaf area (cm^2)	-14.94	28.56	0.27	21.97	Raj 4037 x PBW 175	1.64	16.15	Raj 4037 x PBW 175	2	9
8	1000 grain weight (g)	-13.95	12.60	1.21	9.54	GW 366 x HD 2987	0.41	7.64	GW 366 x HD 2987	10	9
9	Biological yield per plant (g)	-42.19	42.14	1.41	29.60	HD 2932 x Raj 4079	0.27	40.74	HI 1544 x HD 2987	4	7
10	Grain yield per plant (g)	-39.15	50.74	0.30	32.91	Raj 4037 x HD 2987	2.57	35.88	HI 1544 x HD 2987	7	6
11	Harvest index (%)	-8.72	28.95	0.74	27.84	GW 366 x Lok1	1.33	18.88	GW 366 x Lok1	5	2

A comparative study of seven crosses for grain yield *per se* (Table 5) indicated that none of the cross combinations depicated desired heterobeltiosis and standard heterosis for all the characters studied. The cross combination HI 1544 x HD 2987 exhibited significant and desired heterosis over standard checks for grain yield per plant also showed significant and desirable economic heterosis for number of grains per spike and biological yield per plant. The hybrid Raj 4037 x HD 2987 expressed desirable economic heterosis days to heading, number of effective tillers per plant, number of grains per spike, 1000 grain weight and biological yield. PBW 175 x HD 2987 showed desirable positive economic hetrosis over check-1 and check-2 for number of effective tillers per plant and biological yield. These three superior hybrids may be exploited commercially for getting benefits of heterosis for grain yield and its component traits in wheat.

It is not necessary that high heterosis for all the yield components only will result in high heterosis for yield but increase in any one or two yield components may also result into high degree of heterosis for yield. The result of the present investigation clearly showed that considerable heterosis did occur for all the characters studied. Hence, it is obvious that increase in yield of F_1 hybrids is the result of increase in values of other yield contributing characters. Similar results were also reported by Afiah *et al.* 2000 [1]; Rasul *et al*. 2002 [3]; Ribadia *et al*. 2007 [14]; Kamluddin *et al*. 2011 [6]; Punia *et al.* 2011 [12]; Patil *et al*. 2011 [11] and Lal *et al*. 2013 [8].

Table 5: Promising hybrids identified on the basis of *per se* performance and economic heterosis over environments for grain yield per plant

S. No.	Hybrids	*Per se* performance of grain yield per plant (g)	Economic Heterosis (%)	Significant economic heterosis for other traits in desired direction
1.	HI 1544 x HD 2987	18.57	35.88**	GS, BY, GY
2.	Raj 4037 x HD 2987	17.69	29.48**	DH, ET, GS, TW, BY, GY
3.	PBW 175 x HD 2987	16.74	22.48**	ET, BY, GY
4.	HD 2932 x Raj 4079	16.37	19.79**	GS, FLA, BY, GY
5.	PBW 175 x Lok 1	15.69	14.78**	GY
6.	HI 1544 x Raj 4079	15.63	14.36**	PH, FLA, TW, BY, GY
7.	HI 1544 x Lok 1	15.16	10.96**	ET, SL, BY, GY

** Highly significant at 1 per cent level of significance

DH:	Days to heading	GS:	No. of grains per spike	TW:	1000 grain weight
PH:	Plant height	SL:	Spike length	GY:	Grain yield per plant
ET:	No. of effective tillers per plant	FLA:	Flag leaf area	BY:	Biological yield per plant

Conclusion

The degree and magnitude of heterosis over better parent and standard check varied from cross to cross for all the characters over the pooled basis. This indicated that all the characters distinctly differed for mean heterosis and its range in desirable direction. Considerable amount of high heterosis in certain crosses and low in other crosses revealed that nature of gene action varied with the genetic makeup of the parents involved in crosses. As such, nature and magnitude of heterosis helps in identifying superior cross combinations to obtain better transgressive segregants. Three superior hybrids may be exploited commercially for getting benefits of heterosis for grain yield and its component traits in wheat.

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