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Evaluation of F_1 Hybrid Performance and Heterosis in Bread Wheat [*Triticum aestivum* (L.) em. Thell]

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ABSTRACT

The present study was conducted in bread wheat (*Triticum aestivum* L. em. Thell.) to estimate heterosis for fifteen quantitative traits using a 10 × 10 half-diallel (excluding reciprocals), comprising 45 F_1s, 10 parents, and two standard checks, evaluated across three environments during Rabi 2020-21. Analysis of variance revealed significant genotypic differences for all traits, and pooled analysis (11 traits) confirmed significant environmental influence on heterosis expression. For grain yield per plant, heterosis over the better parent was expressed by 8, 8, 5, and 10 crosses in E1, E2, E3, and pooled analysis, respectively. MP1203 × DBW187 showed the highest heterosis in E1, E3, and pooled data, while Raj4238 × DBW187 was superior in E2. Economic heterosis over the standard check 'Sonalika' was recorded in 1, 8, 8, and 8 crosses, with Raj4238 × Raj3077 (E1), HD3086 × WR544 (E2, pooled), and HI1544 × Raj4079 (E3) exhibiting maximum values. For biological yield per plant, 18-21 crosses showed better parent heterosis, led by MP1203 × WR544, while 23-29 crosses surpassed the standard check, with HI1544 × WR544 and HD3086 × Raj4079 being most promising. Five crosses, HD3086 × WR544, Raj4238 × WR544, Raj4238 × Raj3077, HD3086 × Raj4079, and Raj4238 × Raj4079, consistently combined high yield and economic heterosis with desirable yield traits, indicating strong potential for commercial exploitation and wheat improvement programmes.

Keywords

Bread Wheat, Diallel, F_1 Hybrids, Heterobeltiosis, Relative Heterosis

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Introduction

Amid growing global food demand and increasing climate-related challenges, wheat stands as a vital staple crop, supplying the majority of calories, proteins, and essential micronutrients to populations worldwide (Pena *et al.,* 2017; Kumari *et al.,* 2025a, 2025b). Heterosis breeding is one of the strongest tools to achieve the targeted goal by taking a quantum jump in production and productivity under various agro-climatic conditions (Dudhat *et al.,* 2022). The exploitation of heterosis necessitates rigorous evaluation of germplasm to ascertain diverse donors with high nicking of genes, crossing aristocratic genotypes, and further recognition of highly heterotic F_1 crosses; subsequently, prudent segregants may be obtained from various combinations

(Kumari, 2022). In a self-pollinated crop like wheat, the scope of utilisation of heterosis depends mainly on the direction and magnitude of heterosis (Singh *et al.,* 2004). Estimation of heterosis over a better parent (heterobeltiosis) may be useful in identifying true heterotic cross combinations, but these cross combinations may be of enormous value if they exhibit superior performance to the standard variety or the best variety of the area (Raiyani *et al.,* 2016).

Heterotic effect is an increase or decrease in vigour and productivity of hybrids those juxtaposed to their parents, which is exhibited in F_1 and following generations (Birchler *et al.,* 2010). The commercial exploitation of heterosis in wheat has limited application because of the practical complications of hybrid seed production in adequate amounts (Kempe *et al.,* 2014; Easterly *et al.,* 2019).

The present study was, therefore, undertaken to estimate the magnitude of heterosis over the standard variety (economic heterosis) as well as better parent (heterobeltiosis) for yield and its component traits. These studies would be useful for hybrid development and to select potent transgressive segregants that can be further utilised for enhanced yield potential. The objective of this study was to determine the levels of heterobeltiosis and standard/ economic heterosis for different traits to identify desirable parents and develop high-yield wheat varieties for the use of hybrids in wheat breeding programs.

Materials and Methods

The experimental material comprised 10 parents, their 45 F_1s, and two check varieties, viz., Sonalika and HD 2967. The 45 F_1s were obtained by crossing 10 parental genotypes in a half diallel fashion (without reciprocals). All the 57 genotypes (10 parents + 45 crosses + 2 checks) were grown in a randomised block design with three replications in three different environments, i.e., Botany Farm of the Department of GPB, Rajasthan College of Agriculture, Udaipur (E1); Instructional Farm, CTAE, Udaipur (E2); and Krishi Vigyan Kendra, Badgaon, Udaipur (E3), during Rabi 2020-21 (Table 1). Each genotype was accommodated in one row plot of 3-metre length. Row-to-row and plant-to-plant distances were 22.5 cm and 10 cm, respectively. The experiment was conducted under irrigated conditions. Recommended crop production and protection practices were followed to raise a successful crop. Observations were recorded on ten randomly selected competitive plants from each genotype in each replication for fifteen traits, viz., days to 50% flowering, days to 75% maturity, plant height, number of effective tillers per plant, spike length, number of spikelets per plant, length of awns, number of grains per spike, flag leaf area, 1000-grain weight, biological yield per plant, grain yield per plant, harvest index, total protein content in grain, and total chlorophyll content, in all the three environments.

The mean values of parents and crosses were utilised to estimate heterosis over their respective better parent, mid-parent, and standard checks. The diallel cross analysis was carried out using Griffing's Model I (fixed effect) and Method II (parents and one set of F_1s without reciprocals), as proposed by Griffing (1956).

Estimation of heterosis

Heterobeltiosis and economic heterosis are expressed as per cent deviation toward the desirable direction over the better parent and standard check, respectively. Heterobeltiosis and economic heterosis were calculated according to the method suggested by Fonseca and Patterson (1968) and Meredith and Bridge (1972), respectively.

$$Heterobeltiosis = \frac{(\overline{F_1} - \overline{BP})}{\overline{BP}}$$

Where, BP = Better parent

$$Economic\ heterosis = \frac{(\overline{F_1} - \overline{BC})}{\overline{BC}}$$

Where, BC = Best check

To calculate heterobeltiosis and economic heterosis, parents with higher mean values were analysed as desirable for all the traits except days to 50% flowering, days to 75% maturity and plant height where a negative direction was considered desirable.

Results and Discussion

Analysis of variance in the individual environment expressed highly significant differences among genotypes for all 15 characters in all three environments. The effects due to mean parents were also significant in all environments except for length of awns in E1 and 1000-grain weight in E3. Mean squares due to crosses were also significant for all the characters.

Table.1 Details of the different environments

	Environments (E)		
	E_1	E_2	E_3
Site/location	Botany Farm, RCA, Udaipur	Instructional Farm, CTAE, Udaipur	Krishi Vigyan Kendra, Badgaon
Texture of soil	Clay loam	Sandy loam	Clay loam
Organic carbon (%)	0.55%	0.27%	0.58
Available phosphorus P_2O_5 (Kg/ha)	16.09	37.15	26.42
Potash K_2O (Kg/ha)	350.47	258.17	467.15

Table.2 Mean sum of squares for 11 characters over the environments in bread wheat [*Triticum aestivum* (L.) em. Thell].

S. No.	Characters	Source										Bartlett's test value
		Env	Rep/Env	Genotype	Parents	F_1	P v/s F_1	GxE	PxE	F_1xE	P v/s F_1xE	Pool Error	
1.	Days to 50% flowering	310.77**	4.19	105.34**	141.26**	86.05**	630.94**	10.39**	18.56**	8.79*	7.34	6.12	0.60
2.	Plant height	482.24**	31.75	206.62**	326.82**	185.33**	61.58	32.33**	47.62**	29.61**	14.25	17.62	4.61
3.	Spike length	19.09**	0.06	6.99**	9.16**	6.27**	19.15**	0.55**	0.31	0.60**	0.29	0.38	1.91
4.	No. of spikelets per plant	1545.56**	7.37	901.96**	450.61**	863.22**	6668.61**	84.12*	26.02	95.97**	85.25	60.69	1.94
5.	Length of awns	59.08**	0.52	7.62**	2.06**	8.66**	12.09**	0.73**	0.40	0.59**	9.57**	0.36	2.15
6.	No. of grains per spike	1004.96**	8.05	162.76**	149.19**	169.06**	7.92	10.06	7.02	10.20	31.24*	8.09	1.93
7.	Flag leaf area	418.58**	1.18	52.15**	51.87**	53.00**	17.33*	5.39*	1.64	6.26**	1.04	3.83	1.32
8.	1000- Grain weight	216.13**	5.73	29.40**	12.09**	33.60**	0.76	4.08*	1.50	4.68**	0.90	3.11	0.67
9.	Biological yield per plant	299.84**	2.28	294.21**	59.68**	343.39**	240.95**	5.64**	2.35	6.39**	2.16	3.87	1.18
10.	Grain yield per plant	292.10**	1.65	46.22**	26.08**	50.06**	58.63**	1.68**	2.45**	1.34**	9.48**	0.84	2.92
11.	Total protein content in grains	7.12**	0.28	2.12**	1.79**	2.20**	1.56**	0.36**	0.26	0.38**	0.35	0.20	0.34

*, ** Significant at P < 0.05 and P < 0.01, respectively (Model I).

Table.3 Extent of heterosis for grain yield per plant in bread wheat (*Triticum aestivum* L. em. Thell).

S.No	Cross	Heterobeltiosis				Economic Heterosis			
		E1	E2	E3	Pool	E1	E2	E3	Pool
1	HD3086 × Raj4238	-	-	-	-	-	-	1.96	-
2	HD3086 × Raj3077	-	-	-	-	-	-	-	-
3	HD3086 × Raj4037	-	-	-	-	-	-	-	-
4	HD3086 × HD3086	-	-	-	-	-	-	-	-
5	HD3086 × HI1544	-	-	-	-	-	-	-	-
6	HD3086 × Raj4079	1.48	-	-	-	6.00	19.21**	16.67**	14.07**
7	HD3086 × Raj3077	-	-	-	-	-	-	-	-
8	HD3086 × WR544	5.35	0.80	-	1.18	10.05	26.90**	19.55**	18.91**
9	HD3086 × DBW187	-	-	-	-	-	-	-	-
10	Raj4238 × Raj3077	5.57	8.86*	13.40*	9.36**	11.47*	18.10**	19.04**	16.29**
11	Raj4238 × Raj4037	-	15.30**	2.08	3.15	-	5.43	-	-
12	Raj4238 × HD3086	-	14.00*	11.82*	10.36**	-	2.63	2.81	-
13	Raj4238 × HI1544	-	-	-	-	-	-	-	-
14	Raj4238 × Raj4079	34.38**	20.94**	17.73**	23.44**	6.31	16.36**	18.57**	13.89**
15	Raj4238 × Raj3077	3.69	-	-	-	-	-	-	-
16	Raj4238 × WR544	33.77**	26.10**	8.75	22.85**	5.54	23.37**	20.67**	16.69**
17	Raj4238 × DBW187	25.01**	25.72**	20.69**	25.33**	-	4.26	3.39	2.14
18	Raj3077 × Raj4037	-	-	-	-	-	-	-	-
19	Raj3077 × HD3086	-	-	-	-	-	-	-	-
20	Raj3077 × HI1544	-	-	-	-	-	-	-	-
21	Raj3077 × Raj4079	-	-	-	-	-	-	-	-
22	Raj3077 × Raj3077	-	-	-	-	-	-	-	-
23	Raj3077 × WR544	-	-	-	-	-	-	-	-
24	Raj3077 × DBW187	-	-	-	-	-	-	-	-
25	Raj4037 × HD3086	-	-	-	-	-	-	-	-
26	Raj4037 × HI1544	-	-	-	-	-	-	-	-
27	Raj4037 × Raj4079	14.55*	4.01	4.01	10.24**	1.83	0.07	4.75	2.27
28	Raj4037 × Raj3077	-	-	-	-	-	-	-	-
29	Raj4037 × WR544	16.72**	5.96	-	8.26**	3.76	3.67	1.18	2.83
30	Raj4037 × DBW187	-	-	-	-	-	-	-	-
31	MP1203 × HI1544	2.32	-	-	-	-	-	-	-
32	MP1203 × Raj4079	-	-	-	-	-	-	-	-

33	MP1203 × Raj3077	-	-	-	-	-	-	-	-
34	MP1203 × WR544	11.62	-	-	-	-	-	-	-
35	MP1203 × DBW187	41.89**	23.95**	27.09**	30.17**	6.48	11.59*	16.85**	11.77**
36	HI1544 × Raj4079	6.91	8.24	6.06	7.06*	-	22.24**	23.13**	12.82**
37	HI1544 × Raj3077	7.41	-	-	-	-	-	1.00	-
38	HI1544 × WR544	19.45**	0.71	-	3.97	2.84	13.73**	11.85*	9.57**
39	HI1544 × DBW187	-	-	-	-	-	-	-	-
40	Raj4079 × Raj3077	6.97	5.91	-	3.88	-	4.84	0.60	-
41	Raj4079 × WR544	1.37	-	-	-	-	-	-	-
42	Raj4079 × DBW187	-	-	-	-	-	-	-	-
43	MP3288 × WR544	33.66**	10.40*	-	10.12**	1.69	9.29	2.83	4.59
44	MP3288 × DBW187	-	-	-	-	-	-	-	-
45	WR544 × DBW187	4.96	-	-	-	-	-	-	-

, * Significant at $P < 0.05$ and $P < 0.01$, respectively (Model I).

Table.4 Extent of heterosis for biological yield per plant in bread wheat (*Triticum aestivum* L. em. Thell).

SN	Cross	Heterobeltiosis				Economic Heterosis			
		E1	E2	E3	Pool	E1	E2	E3	Pool
1	HD3086 × Raj4238					7.43	10.55*	8.80	9.81**
2	HD3086 × Raj3077	6.07	8.43*	7.02	7.18**	24.25**	28.38**	28.73**	28.17**
3	HD3086 × Raj4037								
4	HD3086 × HD3086								
5	HD3086 × HI1544					4.55	6.71	6.88	6.92*
6	HD3086 × Raj4079	18.12**	21.12**	16.94**	18.71**	38.37**	43.40**	40.67**	41.96**
7	HD3086 × Raj3077								
8	HD3086 × WR544								
9	HD3086 × DBW187							0.21	
10	Raj4238 × Raj3077						1.40	1.57	0.85
11	Raj4238 × Raj4037	9.04*	8.28*	11.56**	9.64**	21.49**	26.43**	27.04**	26.03**
12	Raj4238 × HD3086						14.40**	7.86	7.22**
13	Raj4238 × HI1544								
14	Raj4238 × Raj4079					6.68	8.01	8.04	8.45**
15	Raj4238 × Raj3077					4.03	3.45	4.24	4.75
16	Raj4238 × WR544					6.80	8.51	9.39	9.12**
17	Raj4238 × DBW187					2.63	4.31	11.10*	6.92*
18	Raj3077 × Raj4037	15.51**	18.48**	16.98**	17.64**	21.20**	25.25**	25.66**	25.07**
19	Raj3077 × HD3086					1.02	1.51	1.96	2.32
20	Raj3077 × HI1544	5.60	4.03	3.27	4.27	14.09**	16.99**	17.03**	16.99**
21	Raj3077 × Raj4079								
22	Raj3077 × Raj3077	21.23**	27.41**	32.33**	27.07**	27.20**	34.68**	39.93**	35.10**
23	Raj3077 × WR544	28.46**	30.60**	29.85**	29.65**	34.78**	38.06**	37.31**	37.83**
24	Raj3077 × DBW187	13.72**	11.94**	2.90	11.65**	19.33**	18.33**	15.66**	18.70**
25	Raj4037 × HD3086								
26	Raj4037 × HI1544	17.63**	8.15	8.29	11.21**	27.08**	21.62**	22.72**	24.78**
27	Raj4037 × Raj4079	16.70**	16.16**	15.56**	16.11**	24.22**	24.71**	34.50**	28.91**
28	Raj4037 × Raj3077								
29	Raj4037 × WR544	31.41**	26.19**	13.60**	23.39**	30.62**	31.00**	22.03**	28.86**
30	Raj4037 × DBW187	29.11**	31.65**	23.21**	28.35**	28.34**	38.71**	38.50**	36.34**
31	MP1203 × HI1544	4.39				12.78**	8.57	11.81*	11.95**
32	MP1203 × Raj4079								

33	MP1203 × Raj3077	18.34**	16.61**	31.34**	22.12**	16.85**	21.10**	31.01**	24.07**
34	MP1203 × WR544	39.21**	35.69**	40.37**	38.72**	37.46**	40.92**	40.99**	40.94**
35	MP1203 × DBW187	12.34*	6.64	15.21**	11.72**	10.93*	12.36**	29.51**	18.67**
36	HI1544 × Raj4079	18.92**	12.32**	13.48**	15.88**	28.48**	26.31**	32.08**	30.02**
37	HI1544 × Raj3077	7.79	8.30*	9.22*	8.46**	16.46**	21.79**	23.76**	21.69**
38	HI1544 × WR544	34.09**	24.61**	27.18**	28.51**	44.86**	40.13**	44.12**	44.19**
39	HI1544 × DBW187								
40	Raj4079 × Raj3077	7.63	31.49**	3.55	13.90**	14.56**	41.16**	20.53**	26.45**
41	Raj4079 × WR544	28.66**	23.14**	8.09	19.48**	36.95**	32.20**	25.81**	32.64**
42	Raj4079 × DBW187								
43	MP3288 × WR544	24.46**	16.42**	15.21**	18.60**	21.00**	13.70**	15.71**	17.71**
44	MP3288 × DBW187								
45	WR544 × DBW187	27.47**	25.61**	5.07	18.72**	25.02**	32.35**	18.11**	26.11**

*, ** Significant at P < 0.05 and P < 0.01, respectively (Model I).

Table.5 Promising crosses identified in bread wheat (*Triticum aestivum* L. em. Thell) based on their per se performance and economic heterosis, along with component characters showing significant desirable heterosis across environments for grain yield per plant.

SN	Genotypes	*Per se* performance of grain yield	Economic heterosis	Significant heterosis for other traits in the desired direction[i]
1	HD3086 × WR544	17.02	18.91**	DF, SL, NSP, AL, 1000-GW, HI
2	Raj4238 × WR544	16.70	16.69**	DF, DM, NETP, NSP, 1000-GW, HI, TPC, TCC
3	Raj4238 × Raj3077	16.65	16.29**	FLA, HI
4	HD3086 × Raj4079	16.33	14.07**	DM, AL, NGS, 1000-GW, BYP, TCC
5	Raj4238 × Raj4079	16.30	13.89**	DF, NETP, SL, AL, FLA, HI

** Significant at P < 0.01 level of significance.

[i]DF = days to 50% flowering; DM = days to 75% maturity; NETP = number of effective tillers/plant; SL = spike length (cm); NSP = number of spikelets/plant; AL = length of awn (cm); NGS = number of grains/spike; FLA = flag leaf area; 1000-GW = 1000-grain weight (g); BYP = biological yield/plant (g); HI = harvest index (%); TPC = total protein content in grains (%); TCC = total chlorophyll content (mg/g).

Table.6 Total number of crosses showing significant heterobeltiosis, economic heterosis, and SCA effects on a pooled basis for 11 characters in bread wheat [*Triticum aestivum* (L.) em. Thell].

S. No.	Characters	Heterobeltiosis	Economic heterosis
1.	Days to 50% flowering	02[i]	29
2.	Plant height	08	06
3.	Spike length	-	01
4.	Number of spikelets per plant	19	-
5.	Length of awns	17	-
6.	Number of grains per spike	04	10
7.	Flag leaf area	07	01
8.	1000-grain weight	09	-
9.	Biological yield per plant	21	29
10.	Grain yield per plant	10	08
11.	Total protein content in grains	06	-

[i]Total number of crosses.

Mean square due to parents v/s crosses were also significant for all the characters in all the three environments except days to 75% maturity in E3, plant height in E1 and E3, number of grains per spike in E1 and E3, flag leaf area in E1, E2 and E3, 1000-grain weight in E1, E2 and E3, grain yield per plant in E1 and total protein content in grains in E1 (Supplementary Table 1). The Bartlett test indicated that error variance was homogenous for eleven characters in the experiment. Therefore, a pooled analysis was carried out for these characters only. The pooled analysis for these characters exhibited significant differences among all three environments for all the traits, indicating that environments had a significant effect on the expression of different characters. The mean squares due to parents and F_1 were also significant for all the characters, revealing that between-parents and between crosses differences were significant, and overall heterosis was present in the material (Table 2). These results are in accord with earlier findings reported by Swelam *et al.,* (2014), Ismail (2015), and Dhoot *et al.,* (2020).

Heterosis over better parents for grain yield was exhibited by 8, 8, 5 and 10 crosses in E_1, E_2, E_3 and on a pooled basis, respectively. Cross MP1203 x DBW187 exhibited maximum heterosis in E_1 (41.89), E_3 (27.09) and on a pooled basis (30.17), while Raj4238 x DBW187 showed maximum heterosis in E_2 (25.72) over the better parent. Hybrid vigour over standard check for grain yield per plant was exhibited by the total 1, 8, 8 and 8 crosses in E_1, E_2, E_3 and on a pooled basis, respectively. The maximum magnitude of hybrid vigour over standard check was exhibited in the cross Raj4238 x Raj3077 in E_1 (11.47), HD3086 x WR544 in E_2 (26.90) and on a pooled basis (18.91) and while cross HI1544 x Raj4079 in E_3 (23.13) (Table 3).

For biological yield per plant, hybrid vigour over better parent was observed in 18, 19, 15 and 21 crosses in E_1, E_2, E_3 and on a pooled basis, respectively. The cross MP1203 x WR544 exhibited a maximum degree of heterosis in E_1 (39.21), E_2 (35.69), E_3 (40.37) and on a pooled basis (38.72). Out of 45 crosses, 23, 24, 24 and 29 crosses expressed significant hybrid vigour over the standard check for biological yield per plant in E_1, E_2, E_3 and on a pooled basis, respectively. HI1544 x WR544 exhibited maximum heterosis in E_1 (44.86), E_3 (44.12) and on a pooled basis (44.19) while HD3086 x Raj4079 showed maximum heterosis in E_2 (43.40) over the standard check (Table 4). Similar findings were also reported by Desale and Mehta (2013), Mahpara *et al.,* (2015), Baloch *et al.,* (2016), Saren *et al.,* (2018), Kumar *et al.,* (2020) and Malav *et al.,* (2020).

Five cross combinations, HD3086 × WR544, Raj4238 × WR544, Raj4238 × Raj3077, HD3086 × Raj4079, and Raj4238 × Raj4079 were identified as promising based on high per se grain yield (16.30-17.02 g/plant) and significant positive economic heterosis (13.89-18.91%), along with desirable heterosis for one or more yield-contributing traits across environments (Table 5). These findings are also noticed by Devi *et al.,* (2013), Desale and Mehta (2013), and Dhoot *et al.,* (2020).

On a pooled basis across 11 characters, the highest number of crosses showing significant heterobeltiosis was recorded for biological yield per plant (21), followed by number of spikelets per plant (19) and length of awns (17). For economic heterosis, days to 50% flowering and biological yield per plant each had the maximum number of significant crosses (29), followed by number of grains per spike (10) and grain yield per plant (8) (Table 6). These findings are in agreement with Abdullah *et al.,* (2002), Rahul (2017), Rajput and Kandalkar (2018), and Kumar *et al.,* (2020).

In conclusion, the present study revealed ample variability among the parents, indicating a high potential for the exploitation of heterosis in bread wheat for grain yield improvement. The crosses HD3086 × WR544, Raj4238 × WR544, Raj4238 × Raj3077, HD3086 × Raj4079, and Raj4238 × Raj4079 were identified as the most promising heterotic combinations for grain yield, alongside other yield-contributing traits. These hybrids hold considerable potential for further evaluation and utilisation in hybrid breeding programmes aimed at accelerating genetic gains in grain yield.

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Author Contributions

Manisha Kumari: Conceived the original idea and designed the model the computational framework and wrote the manuscript; Hemlata Sharma: Formal analysis, writing review and editing; Abhay Dashora: Validation, methodology, writing—reviewing

Declarations

Ethical Approval Not applicable.

Consent to Participate Not applicable.

Consent to Publish Not applicable.

Conflict of Interest The authors declare no competing interests.

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