Hybrid vigour over environments for yield and its components in bread wheat

SR Pancholi[1], SN Sharma[1], Yogendra Sharma[2] and SR Maloo[3]

Abstract

Magnitudes of heterosis over mid-parent, better-parent and inbreeding depression were calculated in a 10 x 10 half diallel set of bread wheat (*Triticum aestivum* L. em. Thell.) for fourteen quantitative traits under three sowing conditions. Heterosis and heterobeltiosis for grain yield was mainly dependent upon biological yield per plant, grain weight per ear, 1000-grain weight and number of grains per ear. Sufficient degree of heterosis and heterobeltiosis was observed for all the characters. The crosses UP 2611 x PBW 533 in early sown, WH 786 x PBW 509, HD 2859 x PBW 509 and UP 2590 x HD 2859 in normal sown and WH 786 x JKW 8 and WH 786 x PBW 509 in late sown conditions, emerged as heterotic as well as heterobeltiotic crosses for yield per plant. The crosses HUW 567 x UP 2590 and Raj 4058 x UP 2590 showed significant negative inbreeding depression for grain yield per plant and indicated transgressive segregation pattern in F_2 generation. Bread wheat is a self-pollinated crop where exploitation of heterosis is better option but a suitable mechanism to produce hybrid seed at a commercial scale is not yet popular in India.

Key words: Bread wheat, heterosis, heterobeltiosis, gene effects, yield traits

Introduction

The study of heterosis and inbreeding depression provides a direct bearing effect on the breeding methodology to be employed for varietal improvement. Studies of heterosis also provide useful information about combining ability of the parents and their usefulness in breeding programs. However, the real commercial feasibility of hybrid bread wheat depends upon the heterotic advantage over the best commonly grown varieties. Wheat breeders dealing with various aspects of hybrid bread wheat found that the standard heterosis for grain yield on large plot basis ranges from 10 % to as high as 45 %. The present study has been carried out to estimate the heterosis (%) over mid parent (MP), better parent (BP), and inbreeding depression (ID) for grain yield and its components in a 10 x 10 half diallel set in bread wheat under three environments to identify parental lines that could be used for exploitation of hybrid vigour for commercial production as well as isolation of pure lines from segregating population of heterotic crosses for further amelioration of grain yield in bread wheat.

Materials and Methods

Ten genotypes of bread wheat (*Triticum aestivum* L. em. Thell.) namely viz; HP 1863, WH 786, UP 2611, HUW 567, Raj 4058, PBW 533, JKW 8, UP 2590, HD 2859 and PBW 509 were selected on the basis of a broad range of genetic diversity for major yield components from the germplasm maintained at Agricultural Research Station, Durgapura, Jaipur in AICW & BIP Project of ICAR, were crossed in all possible combinations excluding reciprocals. The 10 parents along with their 45 F_1's and 45 F_2's were grown in a randomized block design with three replications under early (E_1 - 1st November), normal (E_2 - 20th November) and late (E_3 - 20th December) sown conditions at Research Farm of Agricultural Research Station, Durgapura, Jaipur, Rajasthan. The parents and F_1s were grown in two rows while the F_2 s were grown in six rows of 3 m length with the spacing of 30 cm between rows and 10 cm between plants. Ten competitive plants in parents and F_1's and 30 plants in F_2 progenies were selected randomly for recording observations on fourteen characters namely viz; days to heading, days to maturity, plant height (cm), number of tillers per plant, flag leaf area (cm^2), peduncle length (cm), ear length (cm), number of spikelets per ear, number of grains per ear, grain weight per ear (g), 1000-grain weight (g), biological yield per plant (g), harvest index (%) and grain yield per plant (g) under each environment, separately.

The mean of each plot was used for statistical analysis. Analysis of variance for all the characters in each environment was done as suggested by Panse and Sukhatme (1967). The heterosis (H %), heterobeltiosis (HB %) and inbreeding depression (ID) were estimated as suggested by Matzinger *et al.* (1962) and Fonseca and Patterson (1968), respectively.

Results and Discussion

The analysis of variance revealed significant differences among parents, F_1s and F_2s for all the characters in all the environments, except for days to heading in parents in E_1, E_1 and E_3 environments in F_1s and mean squares for spikelets/ear were also non significant E_3 in F_2s. This indicated the presence of adequate amount of variation for all the characters. Mean squares due to parents vs F_1 were found significant for all the characters in all the environments, except for days to heading in E_2 and E_3; grain weight per ear in E_1 and E_3; days to maturity, flag leaf area and spikelets per ear in E_2 and E_3; peduncle length and number of grains per ear in E_2; number of tillers per plant, grain yield per plant and biological yield per plant in E_3 environment (Table 1), indicating the presence of heterosis. This is in conformity with the findings obtained by Ved Prakash and Joshi (2003) and Jag Shoran *et al.* (2005).

[1] All India Coordinated Wheat and Barley Improvement Project, S. K. Rajasthan Agricultural University, Agricultural Research Station, Durgapura, Jaipur- 302 018.
[2] Nusun Genetic Research Ltd., Infocity, Gandhinagar, Gujarat – 382 007.
[3] Dean, Rajasthan College of Agriculture, MPAU&T, Udaipur
Corresponding author: sharma.rau@gmail.com

Table 1. Analysis of variance showing mean squares in individual environment for parents, F_1s and F_2s for different characters of bread wheat under three sowing environments

S. No.	Characters	Env. / d.f.	Replications	Genotypes	Parents	F1s	F2s	Ps vs. F1s	Ps vs. F2s	Error
			2	99	9	44	44	1	1	198
1.	Days to heading	E1	3.463	26.530**	33.352	24.745	24.115**	102.966**	29.337	13.632
		E2	8.013	40.195**	71.689**	33.447**	40.303**	0.135	76.800*	12.677
		E3	23.170	28.610**	28.385*	20.540	25.494**	0.034	504.300**	9.944
2.	Days to maturity	E1	1.963	30.261**	34.478**	24.447**	33.664**	64.889**	102.252**	5.744
		E2	8.043	51.018**	84.448**	45.094**	50.432**	0.946	77.195**	4.101
		E3	2.710	32.003**	51.333**	35.218**	25.794**	0.436	20.582*	3.165
3.	Plant height (cm)	E1	28.162	116.939**	70.107**	97.150**	148.348**	11.586	144.102**	16.194
		E2	39.834	184.508**	259.181**	155.823**	197.744**	68.850*	369.884**	16.774
		E3	29.242	141.067**	69.564**	62.311**	209.918**	240.811**	741.822**	14.817
4.	No. of tillers/ plant	E1	0.548	3.114**	1.659**	3.723**	2.587**	13.267**	6.552**	0.389
		E2	1.157	2.547**	0.787	2.711**	2.372**	14.651**	13.240**	0.515
		E3	1.301	1.517**	1.044	1.655**	0.908**	1.945	27.973**	0.520
5.	Flag leaf area (cm2)	E1	12.299	95.954**	82.135**	54.462**	118.967**	32.692*	890.130**	4.508
		E2	10.499	96.368**	89.906**	38.951**	83.253**	21.484	2875.652**	4.140
		E3	18.072	26.467**	27.425**	16.946**	31.684**	4.141	192.282**	9.301
6.	Peduncle length (cm)	E1	4.325	23.877**	33.116**	15.200**	30.954**	34.284**	6.533	2.593
		E2	5.908	24.696**	31.573**	12.391**	35.053**	0.063	69.008**	2.329
		E3	4.641	57.086**	166.933**	41.060**	43.890**	247.462**	55.651**	1.691
7.	Ear length (cm)	E1	0.478	2.705**	1.862**	2.002**	3.234**	6.182**	8.321**	0.352
		E2	0.188	3.474**	1.859**	2.323**	4.911**	2.881**	3.333**	0.337
		E3	0.862	2.458**	1.568**	1.182**	3.888**	3.740**	0.817	0.416
8.	No. of spikelets/ ear	E1	1.390	8.912**	11.574**	8.856**	6.706**	81.835**	35.570**	2.208
		E2	0.270	13.221**	11.630**	9.924**	16.158**	1.945	44.004**	1.509
		E3	3.360	6.230**	7.778**	6.578**	2.795	7.375	133.704**	2.276
9.	No. of grains/ear	E1	9.053	76.162**	146.948**	71.883**	59.221**	448.389**	32.033	8.703
		E2	21.243	120.535**	120.681**	93.358**	137.373**	0.034	628.681**	9.193
		E3	14.440	65.468**	68.578**	59.206**	33.206**	49.648*	1763.333**	7.002
10.	1000-grain weight (g)	E1	3.243	54.340**	84.913**	42.535**	53.736**	125.081**	343.243**	4.699
		E2	14.370	55.469**	67.901**	51.523**	52.059**	61.765**	318.016**	6.208
		E3	14.916	59.906**	52.472**	48.200**	35.322**	108.475**	1781.386**	5.242
11.	Grain weight/ear (g)	E1	0.035	0.256**	0.263**	0.242**	0.278**	0.016	0.119	0.045
		E2	0.016	0.264**	0.143**	0.257**	0.262**	0.642**	1.919**	0.037
		E3	0.072	0.173**	0.105**	0.110**	0.120**	0.080	5.902**	0.032
12.	Biological yield/ plant (g)	E1	65.869	133.548**	115.724**	118.058**	135.576**	1019.745**	87.753	25.815
		E2	64.090	160.945**	73.478**	140.348**	155.146**	2017.086**	823.491**	28.267
		E3	13.294	80.920**	89.636**	69.576**	42.221**	30.851	2208.832**	9.575
13.	Harvest index (%)	E1	9.435	19.097**	20.088**	18.264**	15.775**	9.435	158.828**	3.564
		E2	12.721	16.945**	18.679**	16.802**	14.350**	27.329*	71.330**	4.303
		E3	9.677	16.853**	18.981**	16.379**	15.133**	29.580*	47.872**	4.801
14.	Grain yield/plant (g)	E1	15.355	22.400**	16.196**	20.788**	22.049**	159.983**	76.949**	5.604
		E2	14.509	24.940**	14.375**	22.353**	22.026**	274.895**	227.902**	5.783
		E3	0.314	12.395**	12.171**	9.583**	6.306**	0.810	390.374**	1.501

* and ** Significant at 5 and 1 per cent level of significance, respectively.

The superiority of hybrids particularly over better parent (heterobeltiosis) is more important and useful in determining the feasibility of commercial exploitation of heterosis and also indicating the parental combinations capable of producing the highest level of transgressive segregants. In this study as the parents are highly adapted varieties/ strains, heterosis over mid parent and better parent have high practical significance. In the present investigations both heterosis and heterobeltiosis have been worked out. The results of present study for grain yield revealed that the heterosis ranged from –22.45% (HP 1863 x UP 2611) to 58.15% (UP 2611 x PBW 533) in early sown, -18.41% (HUW 567 x UP 2590) to 77.21% (UP 2590 x HD 2859) in normal sown and –35.75% (HP 1863 x UP 2611) to 46.69% (WH 786 x PBW 509) in late sown environment. Twenty four crosses in E_1, twenty eight in E_2 and seventeen in E_3 exhibited significant heterosis, out of which twenty two in E_1, twenty seven in E_2 and seven in E_3 exhibited significant positive heterosis. The crosses UP 2611 x PBW 533, HP 1863 x HUW 567, UP 2590 x PBW 509 and HP 1863 x Raj 4058 in E_1; UP 2590 x HD 2859, HD 2859 x PBW 509, WH 786 x PBW 509 and PBW 533 x PBW 509 in E_2 and WH 786 x PBW 509, WH 786 x JKW 8 and HP 1863 x Raj 4058 in E_3 showed high desirable heterosis. A comparison across the environments indicated that the crosses *viz*; HP 1863 x Raj 4058, UP 2611 x UP 2590 and PBW 533 x HD 2859 showed desirable heterosis in all the environments.

Similarly, heterobeltiosis for grain yield ranged from –31.13% (HP 1863 x UP 2611) to 47.15% (UP 2611 x PBW 533) early sown, -23.60% (HUW 567 x JKW 8) to 62.08% (WH 786 x PBW 509) in normal and –39.25% (UP 2611 x Raj 4058) to 44.56% (WH 786 x JKW 8) in late sown condition. Results further exhibited that twenty four crosses in E_1, twenty each in E_2 and E_3 exhibited significant heterobeltiosis, out of which seventeen each in E_1 and E_2 and three in E_3 exhibited significant positive heterobeltiosis for grain yield per plant. The crosses UP 2611 x PBW 533, UP 2611 x HUW 567 and HP 1863 x PBW 533 in E_1; WH 786 x PBW 509, HD 2859 x PBW 509, UP 2590 x HD 2859, PBW 533 x PBW 509 and WH 786 x PBW 533 in E_2 and WH 786 x JKW 8, WH 786 x PBW 509 and HP 1863 x Raj 4058 in E_3 showed high desirable heterobeltiosis. A comparison across the environments indicated that the crosses UP 2611 x UP 2590, PBW 533 x JKW 8 and UP 2590 x PBW 509 showed nearly consistent heterobeltiosis in all the environments except in E_3. The cross UP 2611 x UP 2590 was found to be heterotic in all the environments while heterobeltiotic in E_1 and E_2 only (Table 2). Similar results were reported by Joshi *et al.* (2003), Vedprakash and Joshi (2003), Sharma *et al.* (2004) and Singh *et al.* (2004).

Table 2. Desirable cross combinations of bread wheat showing significant levels of heterosis (H), heterobeltiosis (HB) and inbreeding depression (ID) for grain yield under three sowing environments

E_1				E_2				E_3			
Cross	H	HB	ID	Cross	H	HB	ID	Cross	H	HB	ID
$P_1 \times P_4$	51.67**	32.06**	33.98**	$P_1 \times P_4$	22.48**	21.73*	36.84**	$P_1 \times P_5$	35.79**	24.84**	65.89**
$P_1 \times P_5$	44.71**	13.79	27.78**	$P_1 \times P_5$	41.94**	35.22**	48.12**	$P_2 \times P_7$	45.73**	44.56**	30.04**
$P_1 \times P_6$	40.29**	33.39**	16.98**	$P_1 \times P_8$	39.68**	33.80**	20.03**	$P_2 \times P_{10}$	46.69**	37.49**	28.62**
$P_1 \times P_7$	43.82**	30.57**	-15.80**	$P_2 \times P_3$	43.46**	36.93**	-4.73	$P_3 \times P_8$	23.24*	7.43	49.08**
$P_1 \times P_8$	37.42**	28.98**	7.85	$P_2 \times P_6$	43.28**	40.41**	17.26**	$P_5 \times P_7$	29.25**	14.59	45.31**
$P_2 \times P_3$	18.67*	15.59	-41.60**	$P_2 \times P_9$	25.47*	21.31	-29.39**	$P_6 \times P_8$	24.48*	7.99	44.71**
$P_2 \times P_7$	23.63**	23.40*	13.08**	$P_2 \times P_{10}$	64.14**	62.08**	23.28**	$P_6 \times P_9$	30.34**	9.00	39.98**
$P_3 \times P_4$	42.78**	39.58**	28.28**	$P_3 \times P_7$	38.60**	33.77**	21.23**	S.E.±	0.94	1.09	0.43
$P_3 \times P_6$	58.15**	47.15**	36.83**	$P_3 \times P_8$	35.60**	29.15**	20.05**				
$P_3 \times P_7$	30.24**	27.09**	-0.49	$P_3 \times P_{10}$	41.63**	36.83**	23.95**				
$P_3 \times P_8$	32.41**	24.79*	21.80**	$P_4 \times P_{10}$	39.70**	24.48*	36.92**				
$P_4 \times P_6$	39.78**	27.37**	18.96**	$P_5 \times P_6$	30.68**	11.75	13.30**				
$P_4 \times P_7$	28.13**	22.30*	12.00**	$P_6 \times P_7$	27.73*	26.62*	-1.46				
$P_4 \times P_9$	31.70**	29.95**	7.84*	$P_6 \times P_{10}$	51.65**	50.49**	0.36				
$P_4 \times P_{10}$	25.34**	22.71*	24.24**	$P_7 \times P_9$	37.94**	31.89*	11.87*				
$P_6 \times P_9$	34.64**	28.23**	-8.35*	$P_7 \times P_{10}$	38.40**	38.26**	12.26*				
$P_8 \times P_9$	34.43**	22.52*	26.19**	$P_8 \times P_9$	77.21**	56.66**	43.37**				
$P_8 \times P_{10}$	46.62**	32.70**	41.76**	$P_8 \times P_{10}$	39.13**	28.25**	25.33**				
$P_9 \times P_{10}$	30.88**	29.86**	15.19**	$P_9 \times P_{10}$	67.07**	59.58**	31.13**				
S.E.±	1.21	1.4	0.73	S.E.±	1.37	1.58	0.85				

P_1= HP 1863, P_2= WH 786, P_3= UP 2611, P_4= HUW 567, P_5= Raj 4058, P_6= PBW 533, P_7= JKW 8, P_8= UP 2590, P_9= HD 2859 and P_{10}= PBW 509.

* and ** Significant at 5 and 1 per cent level of significance, respectively.

Heterosis over mid parent and better parent has been estimated in order to explore the possibility for production of the hybrids. The expression of heterosis and heterobeltiosis, in general, was variable for different traits under all the environments. The heterotic expression was fairly high and desirable for peduncle length (127.57% in E_3), biological yield per plant (80.79% in E_2), grain yield per plant (77.21% in E_2), grain weight per ear (61.15% in E_3), number of tillers per plant (52.54% in E_3) and 1000-grain weight (48% in E_3). Similarly, magnitude of heterobeltiosis was fairly high and desirable for peduncle length (106.71% in E_3), biological yield per plant (68.81% in E_3), grain yield per plant (62.08% in E_2), number of tillers per plant (44.50% in E_3), grain weight per ear (42.74% in E_3) and 1000-grain weight (42.14% in E_3). The results are in agreement with those of others obtained in varying environments for different characters (Dubey *et al.* 2001; Salgotra *et al.* 2002 and Joshi *et al.* 2003).

The heterotic expression normally declines in F_2s generation as the dominance or dominance interaction effects dissipate in this generation due to reduced heterozygosity, thereby resulting into inbreeding depression. Significant inbreeding depression in present investigation was observed for different characters in all the three environments with some exceptions where significant negative inbreeding depression was exhibited *i.e.* a significant increase in F_2 over F_1 [Table 3]. For e.g., HP 1863 x UP 2611 and PBW 533 x UP 2590 for number of tillers per plant; HP 1863 x UP 2590 and PBW 533 x HD 2859 for flag leaf area; HUW 567 x PBW 533 and WH 786 x HD 2859 for peduncle length; UP 2611 x PBW 533 for ear length and number grains per ear; WH 786 x HD 2859, HUW 567 x UP 2590 and Raj 4058 x HD 2859 for 1000-grain weight; HUW 567 x UP 2590 and Raj 4058 x UP 2590 for grain yield per plant; HUW 567 x UP 2590 for biological yield per plant; Raj 4058 x PBW 509 and PBW 533 x PBW 509 for harvest index; WH 786 x HD 2859, HUW 567 x UP 2590, WH 786 x UP 2611 and Raj 4058 x HD 2859 for grain weight per ear in almost all the environments whereas, WH 786 x UP 2611 in E_1, UP 2611 x PBW 533 in E_2 and HP 1863 x UP 2611 in E_3 for number of spikelets per ear. Similar results were also obtained by Joshi *et al.* (2003), Singh (2003), Vedprakash and Joshi (2003), Sharma *et al.* (2004) and Singh *et al.* (2004).

Table 3. Crosses possessing high heterosis and heterobeltiosis for grain yield/plant with desirable (+) heterotic expression for other characters in different environments

Particulars	Environments	Crosses	Magnitude of SCA effect for grain yield/plant	*Per se* performance for grain yield/plant	Magnitude of heterosis or heterobeltiosis in %	Days to heading	Days to maturity	Plant height	Number of tillers/plant	Flag leaf area	Peduncle length	Ear length	Number of spikelets/ear	Number of grains/ear	1000-grain weight	Biological yield/plant	Harvest index	Grain weight/ear
Heterosis		UP 2611 x PBW 533	5.27**	21.37	58.15	-	-	-	-	-	-	-	+	+	-	+	-	+
	E_1	HP 1863 x HUW 567	3.31**	20.07	51.67	-	-	-	+	+	+	-	-	-	+	+	-	+
		UP 2590 x PBW 509	4.48**	21.05	46.62	-	-	-	+	+	+	-	-	-	+	+	-	+
		UP 2590 x HD 2859	6.74**	23.77	77.21	-	-	-	-	-	-	-	-	+	-	+	-	+
	E_2	HD 2859 x PBW 509	2.68*	19.46	67.07	-	-	-	-	-	-	-	+	-	+	+	-	+
		WH 786 x PBW 509	3.69**	20.75	64.14	-	-	-	+	+	+	-	+	+	+	+	-	+
		WH 786 x PBW 509	2.73**	12.79	46.69	-	+	-	-	-	-	-	-	+	+	+	-	+
	E_3	WH 786 x JKW 8	2.33**	11.95	45.73	+	+	-	-	-	+	-	-	-	+	+	-	-
		HP 1863 x Raj 4058	4.40**	15.92	35.79	-	-	-	+	-	-	+	+	+	-	+	-	-
Heterobeltiosis		UP 2611 x PBW 533	5.27**	21.37	47.15	-	-	-	-	-	-	-	-	+	-	+	-	+
	E_1	UP 2611 x HUW 567	3.78**	21.22	39.58	-	-	-	-	-	-	-	-	-	-	+	+	-
		HP 1863 x PBW 533	1.25	16.67	33.39	-	+	-	-	-	-	-	-	+	-	+	-	-
		WH 786 x PBW 509	3.69**	20.75	62.08	-	-	-	-	-	-	-	-	-	+	+	-	+
	E_2	HD 2859 x PBW 509	2.68**	20.43	59.58	-	-	-	-	-	-	-	-	-	+	+	-	-
		UP 2590 x HD 2859	6.74**	23.77	56.66	-	-	-	+	-	-	+	-	-	-	+	-	+
		WH 786 x JKW 8	2.33**	11.95	44.56	+	+	-	-	-	+	-	-	-	+	+	-	-
	E_3	WH 786 x PBW 509	2.73**	12.79	37.49	-	-	-	-	-	-	-	-	-	+	+	-	+
		HP 1863 x Raj 4058	4.40**	15.92	24.84	-	-	-	+	-	-	+	-	+	-	+	-	-

* and ** Significant at 5 and 1 per cent level of significance, respectively.

Negative inbreeding depression is desirable for grain yield per plant. Thirty two crosses in E_1, thirty one in E_2 and thirty eight in E_3 exhibited significant inbreeding depression, among these four in E_1 and three in E_2 tilted towards negative direction of magnitude (Table 2), which was considered desirable combination for grain yield. Better homeostatic power due to segregational variation in F_2 or favoured dispersion in this generation could make some of crosses in F_2s superior to F_1s for different characters under study. The presence of such enhanced vigour in F_2 can be attributed to additive gene action. Such crosses are expected to throw transgressive segregants, which may be profitably handled through pedigree method of breeding. Absence of inbreeding depression or negative inbreeding depression is valuable in conventional breeding programme for tangible advancement of the bread wheat. The crosses HP 1863 x UP 2611, WH 786 x UP 2611 and Raj 4058 x UP 2590 in E_1; HUW 567 x UP 2590, UP 2611 x HD 2859 and HUW 567 x JKW 8 in E_2 and Raj 4058 x HD 2859, UP 2611 x PBW 509 and WH 786 x PBW 533 in E_3 showed high desirable inbreeding depression. A comparison across the environments indicated that the cross HUW 567 x UP 2590 showed desirable inbreeding depression in all the environments.

Several theories have been put forward to explain the genetic basis of heterosis in crop plants but the dominant linked gene hypothesis (Jones, 1917) has found favourable in self pollinated crops to explain the phenomenon. Both additive and non-additive gene effects have been suggested to explain heterosis. If heterosis is due to epistatic gene action, particularly of additive x additive type or due to repulsion phase linked loci, exhibiting partial or complete dominance, it should be possible to fix the alleles at interacting loci to preserve the heterotic effects in the pure lines. In addition, the heterotic hybrid can also produce desirable transgressive segregants in their advance generations (Arunachalam *et al.* 1984). Under such situation, it will be useful to observe the genetic effects in crosses involving them, which may throw desirable recombinants in later generations. However, dispersion of alleles, as one of the major causes of heterosis, cannot be ruled out as enough evidence now supports dispersion of complementary genes as the major cause of heterosis (Singh and Singh, 1984).

A comparative study of heterotic crosses revealed that the crosses involving the parents PBW 533, HUW 567 and HP 1863 in E_1; WH 786 and PBW 509 in E_2; WH 786, HP 1863 and PBW 509 in E_3 and HP 1863 in most of the environments were found to be heterotic for a number of traits over the environments. The crosses UP 2611x PBW 533 in E_1; WH 786 x PBW 509, HD 2859 x PBW 509 and UP 2590 x HD 2859 in E_2 and WH 786 x JKW 8 and WH 786 x PBW 509 in E_3 emerged as good heterotic as well as heterobeltiotic crosses for grain yield per plant (Table 3). Three crosses *viz.*, HP 1863 x Raj 4058, UP 2611 x UP 2590 and PBW 533 x HD 2859 showed desirable heterosis in all the environments while UP 2590 x PBW 509, PBW 533 x JKW 8, UP 2611 x UP 2590 and HP 1863 x UP 2590 showed nearly consistent heterobeltiosis in E_1 and E_2 for grain yield per plant. The crosses showing heterotic expression for grain yield per plant were not heterotic for all the characters. Furthermore, heterotic expression declined for most of the traits under late sown condition with some exceptions, which are in agreement with Sharma and Tandon (1993). It was also noted that the expression of heterosis and heterobeltiosis was influenced by the environments for almost all the characters.

Heterosis for grain yield per plant was mainly contributed by biological yield per plant, grain weight per ear, 1000-grain weight, number of tillers per plant, peduncle length, number of spikelets per ear and number of grains per ear in all the three environments and by flag leaf area in E1 and E2 and by ear length in E2 and E3 in addition to the characters. Heterobeltiosis for grain yield per plant was mainly contributed by biological yield per plant, number of grains per ear and grain weight per ear in E1 and by biological yield per plant, grain weight per ear, 1000- grain weight, number of tillers per plant and ear length in E2 and E3 in addition to number of grains per ear in E3 (Table 3). The results are in agreement with the results of Dubey et al. (2001), Salgotra et al. (2002) and Joshi et al. (2003).

In general, mechanism for the expression of heterosis and heterobeltiosis for grain yield was mainly dependent upon biological yield per plant, grain weight per ear, 1000-grain weight and number of grains per ear. On the basis of heterosis, heterobeltiosis, SCA effects and *per se* performance the crosses UP 2611 x PBW 533 in E_1, UP 2590 x HD 2859 in E_2 and HP 1863 x Raj 4058 in E_3 emerged as good crosses for grain yield per plant (Table 3). Grafius (1959) suggested that there could be no separate gene system for yield *per se* as yield is an end product of multiplicative interaction between its various components. Thus, heterosis for yield could be determined by finding the effect of heterosis for individual yield components or alternatively by multiplicative effect of partial dominance of component characters.

The expression of heterosis and heterobeltiosis was highly variable for different traits in different environments. The crosses UP 2611 x PBW 533 in E1; WH 786 x PBW 509, HD 2859 x PBW 509 and UP 2590 x HD 2859 in E2 and WH 786 x JKW 8 and WH 786 x PBW 509 in E3 had significant heterosis and heterobeltiosis for grain yield per plant. Therefore, progeny of these crosses may have potential for high grain yield and the progeny of heterotic crosses of E3 may have resistance to high temperature along with high grain yield. Furthermore, the degree of heterosis is important in deciding the direction of future breeding programmes. The negative inbreeding depression may result from the advantage of population buffering, which may occur in F2 generation due to the segregation of genes or sometimes because of formation of superior gene combinations, such a situation is valuable in conventional breeding programme.

Reference

1. Arunachalam V, Bandhyopadhyay A, Nigam SN and Gibbons RW (1984). Heterosis in relation to genetic divergence and combining ability in groundnut (*Arachis hypogaea* L.). *Euphytica* **33**: 33-39.
2. Dubey LK, Sastry EVD and Sinha K (2001). Heterosis for yield and yield components in wheat (*Triticum aestivum* L.) under saline and normal environments. *Annals of Arid Zone* **40**: 57-60.
3. Fonseca S and Patterson FL (1968). Hybrid vigour in seven parent diallel crosses in common winter wheat (*Triticum aestivum* L.). *Crop Science* **8**: 85-88.
4. Grafius JE (1959). Heterosis in barley. *Agronomy Journal* **51**: 551-554.
5. Jag Shoran, Kant L and Singh RP (2005). Improving spring wheat by combining winter wheat gene pool. *Indian Journal of Genetics* **65**: 241- 244.
6. Jones DF (1917). Dominance of linked factors as a means of accounting for heterosis. *Genetics* **2**: 446-47.
7. Joshi SK, Sharma SN, Singhania DL and Sain RS (2003). Hybrid vigour over environments in a ten parent diallel crosses in common wheat. *SABRAO Journal of Breeding* **35**: 81-91.
8. Matzinger DF, Mannand TJ and Cockerham CC (1962). Diallel cross in *Nicotiana tabacum. Crop Science* **2**: 238-286.
9. Panse VC and Sukhatme PV (1967). Statistical methods for agricultural workers. Pub. by ICAR, New Delhi.
10. Salgotra RK, Thakur KS, Sethi GS and Sharma JK (2002). Heterosis in winter x spring wheat crosses. *Indian Journal of Genetics* **62**: 104-106.
11. Sharma RK. and Tandon JP (1993). Heterosis in relation to heat stress in wheat. *In:* Heterosis breeding in crop plants- theory and applications. pp. 58-59.
12. Sharma SN, Mann MS and Sain RS (2004). Heterosis in durum wheat (*Triticum turgidum var. durum*). *SABRAO Journal of Breeding* **36**: 127-130.
13. Singh H, Sharma SN, Sain RS and Sastry EVD (2004). Heterosis studies for yield and its components in bread wheat under normal and late sowing conditions. *SABRAO Journal of Breeding* **36**: 1-11.
14. Singh RC (2003). Role of heterosis and inbreading depression in the inheritance of grain yield and its components in wheat (*Triticum aestivum* L.). *Annals of Agricultural and Biological Research* **8**: 25-28.
15. Singh RK and Singh M (1984). Concepts of heterosis and exploitation of hybrid vigour in pulse crops. In: Proc. Natl. Seminar on Pulse Research and Development, 21 May, 1984. Jabalpur.
16. Ved Prakash and Joshi P (2003). Genetics of metric traits in spring wheat under normal and late sown environments. *Crop Improvement* **30**: 177-187.